A Novel Handover Protocol to Prevent Hidden Node Problem in Satellite Assisted Cognitive Radio Networks

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***Abstract*—The rapid growth in wireless technologies has intensified the demand for the radio spectrum. On the other hand, the research studies reveal that the spectrum utilization is unevenly distributed, which leads to the conclusion that there is a problem with the spectrum management and allocation rather than the scarcity of the spectrum itself. This inefficiency in spectrum usage in addition to the escalating demand for the radio spectrum fostered the research studies that focus on new communication paradigms referred to as Dynamic Spectrum Access (DSA) and cognitive radio networks, which are based on opportunistically utilizing the radio spectrum. IEEE 802.22 is the first standard for cognitive radio networks, in which, however, network entry and initialization, as well as the hidden incumbent problem have not yet completely been addressed. On the other hand, mobility is also an unexplored issue in cognitive radio networks. In this paper, we propose a novel protocol that combats the hidden incumbent problem during network entry, initialization and handover, while at the same time taking the mobility pattern of the cognitive devices into consideration. Our proposed scheme is based on a satellite assisted cognitive radio architecture. Our model outperforms the current IEEE 802.22 scheme and other work in the literature in terms of connection setup delay[1].**

I. Introduction

According to Federal Communications Commission (FCC), spectrum is sparsely utilized in some frequency bands, whereas it is overcrowded in other frequency bands [1]. The proliferation of wireless technologies and services exacerbates the inefficient spectrum usage and necessitates new methods to overcome its uneven utilization. Contrary to the existing wireless networks, which are based on fixed spectrum assignment policy, Dynamic Spectrum Access (DSA) methods that enable the devices to opportunistically access the spectrum have been proposed [2]. This method is put into practice by means of cognitive radio [3], which can be defined as a fully reconfigurable and computationally intelligent wireless blackbox that can sense its environment and automatically change its communication parameters in response to the network and user demands.

A cognitive radio network consists of primary and secondary users. The former is a licensed user and hence has exclusive rights to access the radio spectrum, whereas the latter is an unlicensed user that can opportunistically access the free spectrum bands, provided that it vacates them as soon as a primary user appears. Cognitive radio networks pose many research challenges, some of which are the hidden incumbent and network entry and initialization problems in IEEE 802.22 operation. Furthermore, mobility is also an unexplored issue in cognitive radio networks. Recently, an interesting architecture that suggests a LEO-satellite assisted cognitive radio architecture has been proposed [4]. In this paper, we propose a protocol that addresses the hidden incumbent, network entry and initialization problems as well as the mobility and handover issues in this satellite integrated cognitive network. The research results show that this architecture is quite beneficial in combatting the yet unresolved problems in cognitive radio networks.

The rest of the paper is organized as follows: Section 2 gives background information about IEEE 802.22 standard and the satellite assisted cognitive radio architecture, whereas Section 3 consists of our proposed protocol. The performance of the proposed mechanism is analyzed using the OPNET Modeler simulation tool. Initial simulation results are presented in Section IV. Finally, Section V concludes the paper.

II. Background

A. IEEE 802.22 Overview

IEEE 802.22 standard is the first standard for cognitive radio [5]. This IEEE Working Group focuses on developing a PHY and MAC air interface for unlicensed operation in the TV broadcast bands on a non-interfering basis. Unlike 802.16, 802.22 operation is mostly targeted at rural and remote areas and its coverage range is considerably larger. Furthermore, 802.16 does not include incumbent protection techniques. The system specifies an air interface where a base station (BS) manages its own cell, which contains many Customer Premise Equipments (CPE's). One of the primary tasks of the BS is to perform a unique feature called "*distributed sensing*", which guarantees proper incumbent protection. The PHY part consists of OFDMA modulation for both downstream and upstream, in combination with channel bonding techniques. Besides, the MAC layer encompasses a totally new set of functionalities, like network entry and initialization, spectrum

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interference measurements, spectrum management, and self-coexistence [6].

When there is a dependency on a centralized BS, network entry is a straightforward process in existing MAC protocols. Nevertheless, this is not the case for DSA networks, since there is no predetermined channel that a CPE may use to look for a BS. The current IEEE 802.22 standard addresses this problem by having a CPE scan all frequency channels when it starts up and then sending their occupancy information; i.e., whether incumbents have been detected or not, in the form of a spectrum occupancy map to the BS. Consequently, in the vacant channels, the CPE scans for Superframe Control Header (SCH) transmissions from a BS. Similarly, the BS periodically broadcasts an OFDMA frame with SCH in an unused frequency channel. If the CPE can identify the SCH, it then tunes to that frequency and transmits the CPE identifier in the uplink direction, which makes the BS aware of the CPE's existence.

The above described operation of IEEE 802.22 is incapable of preventing the hidden incumbent problem, which arises when there is a node near the CPE but outside the sensing region of the BS, operating in the same frequency as the broadcasting frequency of the BS. As the BS continues its transmission, it might interfere with the CPE, which cannot inform the BS of the existence of the licensed incumbent due to the interference. Moreover, the CPE is not allowed choose any other channel to connect to the BS, unless the BS provides the permission. Furthermore, the CPE may even become unable to decode the broadcasting frequency of the BS because of the interference. In this case, the CPE might think that there is no BS transmitting at that time and might switch off, and the BS might also think that there is no CPE alive and stop broadcasting after some time, which results in low spectrum utilization. To alleviate this problem, some enhancements like having the BS broadcast multiple frequencies instead of a single one have been proposed [7].

B. Satellite Assisted Cognitive Radio Overview

The satellite assisted cognitive radio network proposed in [4] consists of a LEO satellite and Smart Base Stations (SBS), as well as primary and secondary users. Figure 1 illustrates the architecture. SBS's have a direct duplex communication link with the satellite and they are capable of opportunistically using the spectrum. In this architecture, the satellite is the central controller; i.e., it is in charge of the spectrum allocation and management. SBS's gather status information in the form of a Environment Status Report (ESR) and send this information to the satellite. ESR's consist of Secondary User Report (SUR)'s, which contain interference values sensed at each frequency by the corresponding secondary user. The LEO satellite does the spectrum allocation based on the ESR values by maximizing an objective function, such as the total throughput.

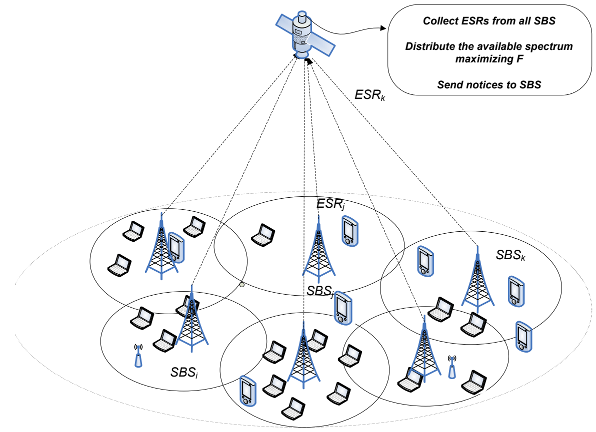

Fig. 1. Satellite assisted cognitive radio network architecture

III. The Proposed Handover Scheme

A. The Basic Steps

Consider the Mobile Node (MN) illustrated in Figure 2, which is still in the coverage region of SBS_1, but has started receiving signals from SBS_2 above a certain threshold. First of all, MN does spectrum sensing in all frequency channels and determines the interference values sensed at each frequency. Secondly, it sends a Handover Preparation Request (HO_PREQ) message to SBS_1, which contains these sensed interference values and the ID of the SBS_2. Consequently, SBS_1 conveys this message to the satellite. Since satellite is the spectrum allocator, it possesses the knowledge about the spectrum allocation in each SBS. This knowledge is represented in the form of a spectrum occupancy map for each SBS. Therefore, the satellite knows about the frequencies that are free in the coverage region of SBS_2. Having learned about the frequencies for which the sensed interference is low in the vicinity of the MN, the satellite basically determines the intersection of these two frequency sets. It then chooses one of these frequencies as the candidate frequency for the initialization of MN when it completes the handover process and connects to SBS_2. The satellite marks this candidate frequency as *"reserved"* in the spectrum occupancy map for SBS_2, and as *"to be released"* in the spectrum occupancy map for SBS_1. This way, any possibility of the assignment of this frequency to another node until the handover of this MN is completed is eliminated. There are actually 4 mark values for the frequencies in the spectrum occupancy maps: *"free"*, *"occupied"*, *"reserved"*, and *"to be released"*. The satellite sends this candidate frequency value to the MN in the form of a Handover Preparation Response (HO_PRESP) message via SBS_1. This way, the possibility of a hidden incumbent problem is eliminated, since the candidate frequency is chosen among the ones for which the currently sensed interference value by the MN is low. This implies that a node near the MN cannot interfere with the MN during its initial connection establishment with SBS_2, as it is guaranteed by this protocol that the initial connection establishment frequency is different.

Right after the handover process is completed, the satellite marks this frequency as *"free"* in the spectrum occupancy map of SBS_1 and as *"occupied"* in the spectrum occupancy map of SBS_2. If the handover process is not completed until some timeout value, then this reserved frequency is reverted back to *"free"* in the related spectrum occupancy map.

Another proposed approach in this architecture is the behavior of this protocol when no frequency was found by the satellite in the intersection of the two free frequency sets. As described in [7], utility graph coloring with proportional fair utility is implemented by the satellite in the spectrum allocation. In this case, satellite selects a relay node in the coverage region of SBS_2. This relay node is chosen as the one nearest to the MN among the ones that operate on multiple frequencies. One of its frequencies is used by the MN as a relay to implement its initial communication with SBS_2. This frequency is chosen so that it is not one of those frequencies that the MN currently senses any interference. In this case, the satellite specifies this frequency in the HO_PRESP message as the relay frequency. This way, a temporary multi-hop augmented structure is formed in the cellular architecture to aid the network entry and initialization process of the MN's. On the other hand, when an inter-satellite handover occurs, then the spectrum occupancy map for the related SBS is sent to the new satellite via Inter-Satellite Links (ISL's). Moreover, if the MN is unable to do its initialization right after the handover has happened, then the MN implements a contention based connection setup, just as in IEEE 802.22. Another point to be mentioned is that in this protocol, unlike in [7], we selected only one frequency. The reason is that if multiple frequencies were chosen, then all of them would have to be marked as *"reserved"* in the spectrum occupancy map, which would prevent them being used by other mobile nodes during the handover of this MN.

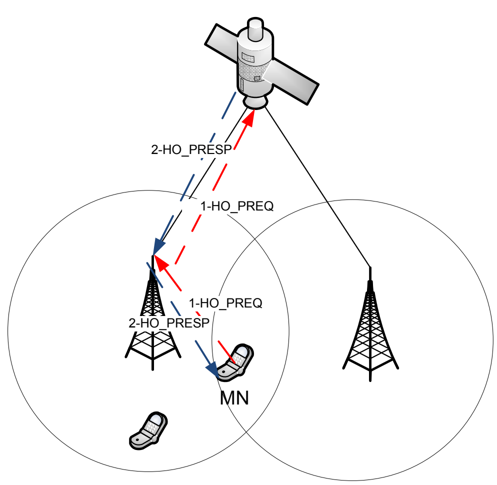

Fig. 2. Network entry and handover in cognitive satellite network

ID	ID_{SAT}	ID_{CELL}	EET	t_F *(S)*	HO_PREQ coord.
0	192.122.1.37	2	08:43:54	0842	(250, 330, 140)
0	192.122.1.38	3	08:53:06	1032	(345, 456, 344)
0	192.122.1.39	1	09:13:02	0304	(567, 600, 180)
0	....	....	....	....	....
1	192.122.1.157	4	20:26:01	0892	(100, 800, 760)
1	192.122.1.158	3	20:46:31	1892	(130, 670, 761)
1	....	....	....	....	....

Fig. 3. A typical SUMP table

B. Mobility Aspect

An important point in the above mentioned protocol is to determine the appropriate time to send the HO_PREQ message. If the MN sends this message as soon as it receives any signal from SBS_2, this behavior may lead to unnecessary signaling traffic or unnecessary reservation of a candidate frequency, since the actual handover may never take place. However, if it sends it too late, then the signaling may not be completed so that a candidate frequency is not ready when the handover is complete.

In [8], the authors propose a mobility pattern scheme for satellite networks, which takes the mobility of both the users and the satellite into consideration. They propose the usage of a central server, referred to as Billboard Manager (BM), where the satellite user mobility patterns (SUMP) are kept. In our work, we modify this mobility pattern scheme as shown in Figure 3 such that it also encompasses information about the geographical coordinates at which the HO_PREQ message should be sent in a particular SUMP.

In [9], authors formulate a handoff interference scheme for cellular networks, which specifies the additional noise created by the handoff process. They define the *"handoff margin"* as the maximum value of the mean handoff interference experienced at a given trajectory, and the *"Maximum Interference Point (MIP)"* as the point along the trajectory at which the handoff margin is achieved. In our scheme, the cognitive devices send their sensed handoff interference at certain intervals during the handover process to the BM, which then takes a weighted moving average of these handoff interference values for the related mobility pattern. Consequently, the BM takes a certain percentage, such as %20, of the MIP value and determines the coordinates at which this specific percentage is achieved. Consequently, it writes this value to the "HO_PREQ coord." column in the mobility pattern. As the reported handoff interference values continually arrive at the BM, the MIP value changes, and the BM reflects this change in the mobility pattern table accordingly.

IV. Simulation Results

The simulations were performed in OPNET (Optimum Network Performance) Modeler 14.0 [10]. The results were obtained for three different schemes; i.e., the conventional IEEE 802.22 operation [5], the enhanced 802.22 scheme that consists of multiple broadcasting [7], and our proposed scheme.

The number of nodes in the simulations vary between 2 and 10. The nodes perform handover, network entry and initialization as they continually move towards the coverage area of SBS_2. The network entry times of the nodes are uniformly distributed between 1 and 4. Furthermore, the multiple broadcasting scheme performs the broadcasting operation with 3 channels. The average values were taken over 200 runs of the simulations for all the three schemes.

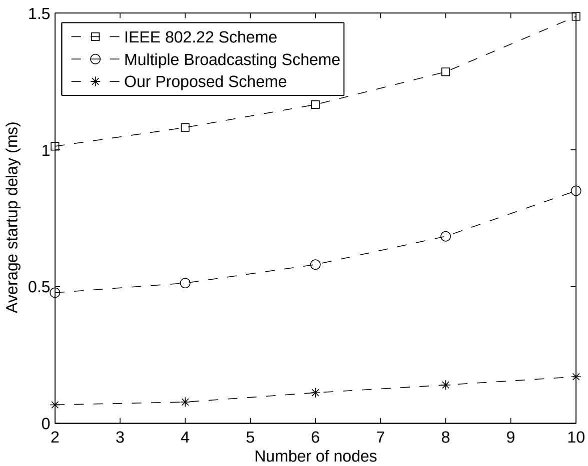

Fig. 4. Connection setup delay for the three schemes

As illustrated in Figure 4, our proposed scheme has less connection setup delay (delay between switching on and start of data transmission) than the multiple broadcasting scheme, which in turn has less connection setup delay than the conventional IEEE 802.22 scheme. Furthermore, the connection setup delay increases as the number of nodes increases due to the increased possibility of contention as well as hidden incumbent situation. Moreover, the performance advantage provided by our proposed scheme increases as the number of nodes increases, since in this case the possibility of a hidden incumbent situation increases and our scheme has the ability to tackle this situation, whereas the other two schemes fail to do so.

V. Conclusion

Satellites possess a wide knowledge about the users and the network in their service region due to their wide footprint. Hence, the use of satellites in a cognitive radio setting is quite beneficial in addressing the yet unresolved problems in cognitive radio networks. In this paper, we have proposed a novel handover protocol that avoids the hidden node problem, while taking the mobility pattern of both the users and the satellite into consideration. Our proposed scheme conduces better performance than the current IEEE 802.22 approach as well as other work in the literature in terms of less connection setup delay.

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