Cognitive Beacon Channel via GSM and UMTS

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Abstract— **This paper proposes the utilization of GSM logical channels (RACH, AGCH and TCH) and UMTS signaling (MIB and SIBs) of the Broadcast Channel to transmit a Cognitive Beacon Channel (CBC). The CBC will help to improve spectrum awareness by conveying signalization to mobile users in a multi-Radio Access Technology (RAT) environment (e.g. 3GPP, Wi-Fi, WiMAX and future cognitive radio systems). Taking advantage of this spectrum knowledge, the purpose of the CBC is to transmit the necessary information to allow Dynamic Spectrum Access (DSA) using a centralized architecture. The principal motivation of this proposition is to obtain benefit from existing 3GPP technologies proved to be efficient and accepted. Simulation results show that our proposals, using logical channels of GSM and UMTS outperform, respectively, the On-demand and the Broadcast CPC implementations of the E2R II project.**

Keywords- Cognitive Beacon Channel (CBC); GSM; UMTS; Cognitive Radio Systems; Multi- Radio Access Technology; Dynamic Spectrum Access (DSA).

I. INTRODUCTION

Dynamic Spectrum Access (DSA) represents a possible solution to solve the low efficiency in spectrum utilization [1] by allowing spectrum sharing. Nevertheless, in order to achieve efficient DSA, knowledge about spectrum occupation is vital.

In [2], different scenarios for DSA have been foreseen. These scenarios differ in the network architecture (i.e. distributed or centralized) and in the network orientation (i.e. Ad-hoc or cellular). In distributed Ad-hoc networks, to obtain the necessary parameters for spectrum access, a mobile station (MS) has to scan the entire spectrum looking for occupancy information. However, the scanning process may require a lot of time and can greatly impact the battery consumption in mobile devices [3]. In addition to the aforementioned, marketing research confirms that enhancing the battery life time, is the most desirable improvement in next generation mobile devices [4].

To overcome the above problems, the use of a Cognitive Pilot Channel (CPC) has been proposed as an assistant, for mobile stations (MSs), to select an appropriate network according to user's requirements (e.g. radio access technology (RAT), frequency channel, secondary use of the spectrum, etc). This proposal has been studied in the E2R II project and several papers have been published in this context [5]-[11].

There are other approaches with the same objective: to achieve network coordination for spectrum access using a specific channel only to convey control information to MSs. In [12], a Common Spectrum Coordination Channel (CSCC) has been proposed. In this approach, MSs use two half-duplex transceivers (TRx), one for control information exchange over the CSCC and the other is used for data transmission. MSs that want to use the spectrum or that are already transmitting; announce their radio parameters and spectrum usage information by broadcasting in the CSCC. The spectrum access is based on etiquette policies. Different spectrum access algorithms could be selected depending on network service conditions, for example: priority based methods, FCFS (First-Come-First-Served) or dynamic pricing auction [13].

In [14], another proposition using a dedicated channel for control information exchange is presented. The Resource Awareness Channel (RAC) uses a universally available frequency band to convey information about spectrum utilization of active MSs. As in [12], in this approach, active users periodically transmit on the RAC to inform other MSs about their spectrum occupation (i.e. the resources being used on their transmissions). The RAC is a random access channel; therefore, all users who want to transmit on the RAC first listen to the channel before initiating transmissions, following the multiple access method named Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). If the channel is busy, users postpone transmissions using a binary exponential back off. The purpose of this proposition is also to assist the MSs to modify their transmission parameters in an intelligent fashion, being aware of spectrum conditions to avoid interference between users.

In this paper, we propose the utilization of three logical channels (RACH, AGCH and TCH) of GSM and UMTS signaling (MIB and SIBs) of the Broadcast Channel to transmit a Cognitive Beacon Channel (CBC). Using the CBC, the network can provide to MSs the essential information to allow DSA. Simultaneously, we can take advantage of existing 3GPP technologies to convey signalization in a multi-Radio Access Technology environment.

The rest of the paper is organized as follows. Section II reviews some issues concerning the CPC approach in the E2R II project. Section III presents our proposition. In section IV, we compare our proposed CBC implementation, using logical channels of GSM and UMTS signaling, with the CPC implementation performed in the E2R II project. Finally, in section V, we present our conclusions.

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II. CPC ISSUES

A. Regulatory Issues

Spectrum bands are assigned via regulatory bodies. The regulators negotiate with operators the amount and the utilization conditions of the spectrum bands to be assigned [6].

Nevertheless, the approbation of a worldwide standardization and implementation of the CPC will require some modifications on the Radio Regulation (RR) of the International Telecommunications Union (ITU). These modifications also require an appropriate decision taken by a World Radio Conference (WRC) [7].

With regard to this worldwide CPC, in 2007 was approved to add to the next WRC's agenda (conference to be held in 2011), a proposal of *"the possible need for a worldwide cognitive pilot channel"*. This proposition was supported by important groups such as the European Conference of Postal and Telecommunications Administrations (CEPT) and several operators and manufactures such as Motorola, Nokia, Alcatel Lucent, Telefonica and Telecom Italia [7].

B. Secondary Use and DSA via the CPC

The rules in secondary use of the frequency spectrum specify that licensed users, known as primary users, have the rights to transmit and to receive without interference from other users in certain spectrum bands. When these bands are free from the presence of primary users, they can be used by secondary users. However, as soon as a primary user starts activity in its channel, the secondary user has to leave that channel to avoid interference [15].

If a worldwide standardization and implementation of a CPC is approved, it will represent an important tool for MSs to obtain knowledge about spectrum occupation. The possibility to transport this spectrum knowledge, via the CPC, can also be useful for spectrum owners (e.g. operators) to indicate the existence of spectrum holes on licensed radio bands. These spectrum holes represent spectrum portions assigned to primary users that are temporarily unutilized [16].

In the specific case of secondary use of the spectrum, the CPC can facilitate the DSA process to operators. Using the information conveyed by the CPC, spectrum owners can control the access to their spectrum by signaling authorized spectrum bands that can be used by secondary users. Moreover, this control for spectrum access, using the CPC, can also be applied to solve one of the principal problems of DSA in a cognitive radio context: to avoid interference from secondary to primary users without spectrum sensing by MSs. In addition, DSA and the secondary use of the spectrum can be beneficial to operators if renting procedures are carried out [8].

C. CPC Implementations Proposed in the E2R II Project

In [5], three different types of CPC implementations were proposed: the Out-band, the In-band and the Combined CPC. To implement the CPC in either case, the area covered by the CPC is divided into a certain number of meshes.

The Out-band implementation is characterized by the utilization of a new frequency channel (universal if possible) to transport the CPC. The drawbacks of this approach are the need for a universally available frequency band and the need for a new infrastructure to transmit the CPC.

In the In-band approach, the CPC requires neither a new universal frequency band nor a new infrastructure because the CPC transmission is made using a frequency channel (physical or logical) of an already existing RAT. The principal disadvantages of this proposal are the need to scan the totality of the spectrum to find the RAT used to transmit the CPC and that MSs must support the utilization of this RAT.

The third approach is a combination of the Out-band and the In-band CPC. The Combined CPC uses the Out-band approach only to transmit the location (RAT, frequency and operator) of the In-band CPC. The purpose of this process is to help the MSs to easily find where the CPC is transmitted (the main inconvenience of the In-band approach). After locating the CPC, using the Out-band approach, the In-band CPC conveys the detailed information about the spectrum utilization of the mesh where the MS is located. The drawbacks of this approach are the need for a universally available frequency to transmit the Out-band CPC and that MSs must support the RAT used to transmit the In-band CPC. However, the process of scanning the whole spectrum after switching on is avoided.

D. CPC Capturing Procedure at the Terminal Side

The CPC operational procedure at the terminal side is described as follows [8]. Initially, during a phase named "start-up", MSs are switched on and determine their location using a positioning system (e.g. a GPS). Afterwards, MSs detect the CPC and determine their mesh. As mentioned in [5], the detection of the CPC will depend on the implementation used for its transmission (i.e. Out-band, In-band or Combined CPC). After the CPC detection, the MSs decode the information (e.g. available RATs) of the mesh where they are located. Once the MSs have selected a specific network, they leave the "start-up" phase and enter in the "on-going" phase. This phase is carried out to periodically determine the variations in the radio environment (e.g. network reconfigurations, network load, etc).

E. CPC Delivery Strategies Proposed in the E2R II Project

Two different strategies to deliver the CPC were analyzed in [5]: the Broadcast and the On-demand CPC. The Broadcast CPC uses a unique channel named Downlink Broadcast CPC (DBCPC). This channel is periodically transmitted by the network to convey the information corresponding to different meshes in the area covered by the CPC. In this strategy, when the MSs have detected the CPC they just have to wait for the information corresponding to their mesh.

In the On-demand CPC, MSs do not have to wait to obtain the information of their corresponding mesh because the CPC information is transmitted when requested by the MSs. This approach requires the use of three logical channels. The first one, named Random Access CPC (RACPC), is an uplink slotted channel used by the MSs to send the requests to retrieve the CPC information. The second one, named Acquisition

Indicator CPC (AICPC), is a downlink channel used by the network to indicate that the requests sent by the MSs have been successfully received. The third one, named Downlink On-Demand CPC (DODCPC), is the channel used by the network to transmit the information of the mesh where the MS is located.

III. PROPOSED IMPLEMENTATION

We propose the utilization of GSM logical channels and UMTS signaling to transmit the CBC to mobile users.

In the case of the GSM standard, instead of the utilization of sparing bits from the BCCH as suggested in [9], we use the Random Access Channel (RACH), the Access Grant Channel (AGCH) and the Traffic Channel (TCH). We assume that the RACH is slightly modified to send the requests to retrieve the CBC information. Using the AGCH the network confirms the reception of the requests and the TCH is used to convey the information of the required mesh. The blocks used to transport the TCH have a maximum limit of 260 bits and the TCH has a block recurrence of 20 ms [17].

In the case of UMTS, we use a Master Information Block (MIB) and the System Information Blocks (SIBs) of the logical Broadcast Channel (BCH) to transmit the CBC information. The MIB conveys all the scheduling information needed to find the SIBs in the BCH. The MIB contains the number of segments, the System Frame Number (SFN) of the first segment and the SFN offset of the remaining segments for each of the SIBs [18]. The blocks used to transport the SIBs have a maximum limit of 246 bits and the UMTS Terrestrial Radio Access Network (UTRAN) transmits the SIBs every 20 ms and the MIBs every 80 ms [19].

Our proposal, using GSM and UMTS channels to transport the CBC, corresponds to an "In-band Transmission" in [5]. This is because GSM and UMTS are existing technologies; therefore, the CBC transmission will require neither new infrastructure nor new frequency channels.

The purpose of the information conveyed by the CBC, in the bands of GSM and UMTS, is the same as the CPC in [10]: to provide assistance to MSs in the DSA process and in reconfiguration procedures in heterogeneous networks.

IV. PERFORMANCE EVALUATION

In this section we compare our proposed CBC implementation, using logical channels of GSM and UMTS, with the CPC implementation in the E2R II project.

The Broadcast CPC and the On-demand CPC analyzed in [5] were compared with our proposals; using three channels of GSM for the On-demand case and the logical BCH (containing the MIB and the SIBs) of UMTS for the Broadcast case.

As in [5], for the On-demand approaches (E2R II and GSM), the requests to retrieve the CBC information are sent following a random access phase using simple S-ALOHA model. Each MS generates around of 1 request per hour to access the CBC. After successfully receive the requests, the system is modeled as a M/D/1 queue with arrival rate λ. The total delay estimated by simulations in the On-demand methods is the sum of two delays, the uplink access phase and the time to send the information of the mesh where the MS is located.

In the case of the On demand CBC approach, using GSM logical channels (RACH, AGCH and TCH), the simulation parameters that change in relation to the implementation proposed in the E2R II project were: the net bit rate (R_b) = 13 kb/s and the block recurrence (T_s) = 20 ms of the traffic channel of the GSM standard [17].

In the Broadcast approaches (E2R II and UMTS), after switching on, MSs determine their location and their mesh during the start-up phase. After this phase MSs, in the Broadcast implementation in the E2R II project, are always synchronized with the DBCPC and when mobile users need to obtain the complete information of their mesh, they just have to wait. In our proposition using UMTS, we assume that MSs only decode the BCH when the information of their corresponding mesh is transmitted. To achieve this, MSs first decode the MIB to exactly locate the SIB or SIBs where the information of their mesh is conveyed. For comparison purposes, the delay estimated by simulations in the Broadcast methods (E2R II and UMTS), is the average time that MSs need to decode the cognitive channel (CBC or CPC) to get the information of the mesh were they are located.

For the simulation of the Broadcast CBC using UMTS signaling (MIB and SIBs), the parameters that change in relation to the implementation proposed in the E2R II project were: the net bit rate (R_b) = 12.3 kb/s, the Transmission Time Interval (TTI) of the SIBs (T_s) = 20 ms, the $MIB_{Periodicity}$ = 80 ms, the $MIB_{Duration}$ = 20 ms [19] and the time (D_B) that MSs need to decode the CBC to obtain the relevant information of their mesh:

$$D_B = MIB_{Periodicity} + MIB_{Duration} + T_{m,B} \quad (1)$$

Where $T_{m,B}$ is the total transmission time of one mesh in broadcast [5].

It is worth mentioning that as in [5], the bit rate used for simulations in all systems (Broadcast and On-demand approaches in the E2R II project and our proposed GSM and UMTS) is equal to the net bit rate of information bits (i.e. without including synchronization or redundancy bits).

A. Simulation Results: Broadcast and On-demand CPC of E2R II, GSM and UMTS Proposals

In Figure 1 and Figure 2, the total delay as a function of the total user density for a fixed number of meshes (*Nm*) was analyzed.

Figure 1 shows the performance of Broadcast and On-demand CPC of the E2R II project and our UMTS and GSM proposals. The transmitter range of the cognitive channel (CPC or CBC) was set to 1 km, the number of meshes was equal to 1 and the corresponding mesh area was around 1700m × 1700m.

In Figure 1, we notice that contrary to the On-demand proposals, the delay of the Broadcast approaches is insensitive to the user density. The delay to receive the information is longer in the On-demand E2R II approach than in the GSM proposal and the difference, in terms of time decoding the cognitive channel, between the Broadcast implementation in the E2R II project and our UMTS proposal is equal to 185 ms.

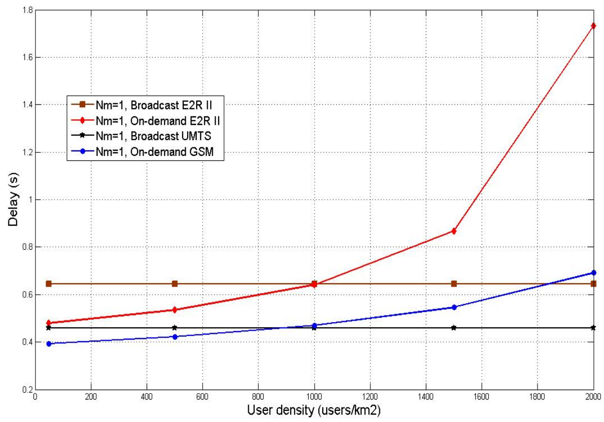

Figure 1. Total delay as a function of the user density with the number of meshes (*Nm*) equal to 1.

In Figure 2, the number of meshes was increased to 30. The cognitive channel range was 1 km; in consequence, the corresponding mesh area was around 320m × 320m.

As we can see in Figure 2, with the increase in the number of meshes, the time that MSs need to decode the cognitive channel in the Broadcast approach of the E2R II project becomes longer (i.e. users have to listen the DBCPC for a long time until they retrieve the information of their mesh) [5]. However, in the case of UMTS, this phenomenon does not occur because mobile users only have to decode their corresponding SIB or SIBs instead of decoding all the DBCPC.

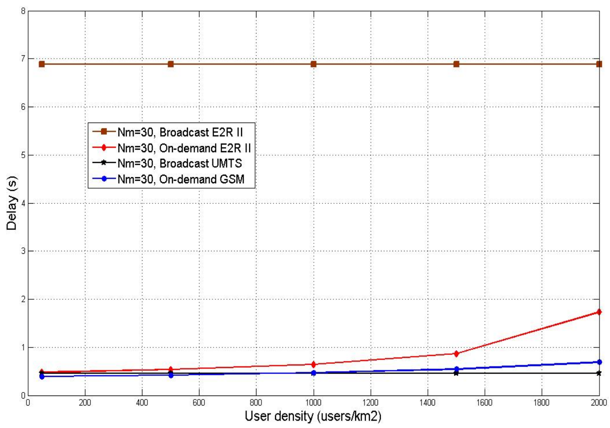

Figure 2. Total delay as a function of the user density with the number of meshes (*Nm*) equal to 30.

In Figure 1 and Figure 2, we observe that when the number of meshes is increased, the performance in terms of delay to retrieve the CPC or CBC information using the On-demand approaches (E2R II and GSM), is not affected.

In Figure 3, the total delay as a function of the transmitter range of the cognitive channel was compared. The user density was set to 2000 users/km^2 and the mesh size was fixed to 100m x 100m. Therefore, with the increase of the transmitter range, the number of meshes covered by the cognitive channel (CPC or CBC) and the total amount of requests also increase.

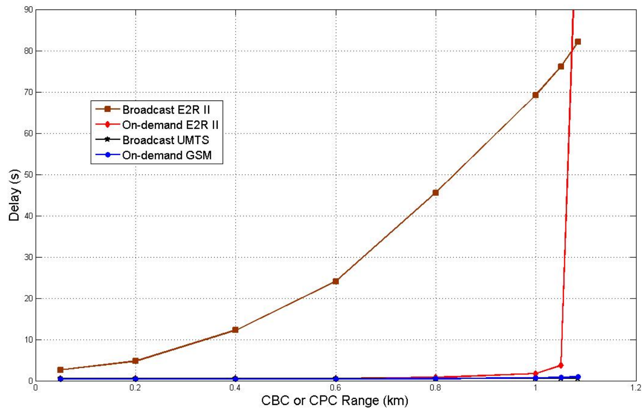

Figure 3. Total delay as a function of the of the cognitive channel range for a mesh size of 100mx100m.

As we observed previously in Figure 1 and Figure 2, the On-demand proposals are sensitive to the user density and as noted in [5], there is a fixed limit in terms of load (request per second) given by the M/D/1 queue system of the On-demand approach in the E2R II project. This is the cause of instability when the CPC range exceeds the barrier of 1.05 km in Figure 3. In the case of GSM, this instability does not occur at the same range because the bit rates (*Rb*) and the block recurrences (*Ts*) are different in both implementations. In Figure 3, we observe again that our propositions using GSM and UMTS obtain the shortest delay.

Finally, the last comparison to show the performance of the E2R II implementations and our propositions is plotted in Figure 4. This figure analyzes the required downlink bit rate as a function of the transmitter range of the cognitive channel. The delay maximum in retrieving the cognitive channel was set to 5 seconds and the same parameters of mesh size and user density considered in Figure 3 were used to plot Figure 4.

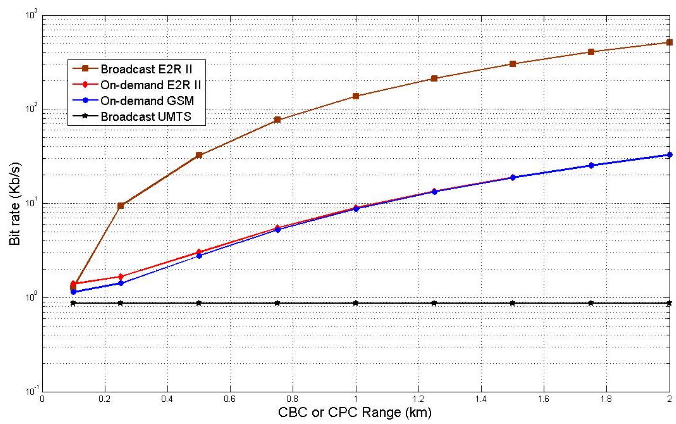

Figure 4. Required net bit rate to ensure a maximum delay of 5s as a function of the of the cognitive channel range for a mesh size of 100m×100m.

As we can see in Figure 4, the required bit rate using UMTS signaling is the lowest and is always constant. This is because this approach is neither sensitive to the number of meshes (unlike the Broadcast approach in the E2R II project) nor the number of requests sent by the users (unlike the On-demand proposal in the E2R II project and in our GSM approach).

V. CONCLUSIONS

This paper has proposed the utilization of the logical channels RACH, AGCH and TCH of GSM and the logical BCH (MIB and SIBs) of UMTS to allow the transmission of a Cognitive Beacon Channel (CBC) to mobile users. We have compared the performance (i.e. delay to retrieve the cognitive channel, total user density, cognitive channel range and required net bit rate) of our propositions with the CPC implementations in the E2R II project. As we have shown, our GSM implementation slightly outperforms the On-demand proposition in the E2R II project. However, our proposal using UMTS signaling clearly outperforms the Broadcast approach in the E2R II project; due to the fact that MSs know exactly when to decode their corresponding information. This characteristic also leads to reduction of power consumption in mobile devices. Therefore, mobile users can increase the usage time of their equipment, which is one of the most desirable features of next generation mobile devices. Moreover, the UMTS proposal is neither sensitive to the number of meshes covered by the CBC nor the number of requests sent by the users.

Adapting the utilization of the logical channels of GSM and UMTS to convey the CBC, we can take advantage of two existing technologies, proved to be efficient and accepted worldwide. Furthermore, we have demonstrated by simulations that both technologies also possess the required capabilities to convey signalization with an acceptable throughput in a multi-Radio Access Technology (multi-RAT) environment.

The goal of the utilization of this Cognitive Beacon Channel (CBC) is to achieve efficient spectrum coordination among MSs in heterogeneous networks. Using the information conveyed by the CBC in the GSM or UMTS bands, Dynamic Spectrum Access (DSA) could be accomplished without MSs have to scan the entire spectrum in order to find spectrum usage information. In addition, if a proper detection of spectrum holes in primary users' bands is carried out by spectrum owners, secondary use of the available frequencies can be authorized to mobile users equipped with cognitive radios.

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