Decentralized Spectrum and Radio Resource Management Enabled by an On-demand Cognitive Pilot Channel

O. Sallent, R. Agustí, J. Pérez-Romero, L. Giupponi
Universitat Politècnica de Catalunya (UPC)
c/ Jordi Girona, 1-3, Campus Nord, 08034, Barcelona, Spain
email: [sallent, ramon, jorperez, lorenza.giupponi]@tsc.upc.edu

***Abstract*- This paper presents a framework to achieve an efficient dynamic and decentralized spectrum and radio resource usage in heterogeneous wireless network scenarios. The envisaged technical solution follows a layered approach, where Joint Radio Resource Management (JRRM) and Advanced Spectrum Management (ASM) mechanisms are identified at both intra and inter-operator level. The importance of cognitive network functionalities is highlighted. An on-demand Cognitive Pilot Channel (CPC) is proposed as a radio enabler solution for a decentralized operation with decision making processes executed at the mobile terminal side. The suitability of the proposed solution is shown by comparison with a broadcast CPC approach.**

I. Introduction

It is widely acknowledged that technological innovation has a relevant impact on economic growth. In turn, wireless communications are a key driver for the stimulation of economies, building social networks and facilitating a sustainable development, to the point that wireless communications are nowadays an integral part of modern living. Not surprisingly, wireless technologies are rapidly evolving in order to allow operators delivering more advanced multimedia services to their customers. For example, HSDPA (High Speed Downlink Packet Access) and HSUPA (High Speed Uplink Packet Access) are seen as intermediate evolutionary steps since the first wave of WCDMA-based (Wideband Code Division Multiple Access) networks rollout, E-UTRAN (Evolved UMTS Terrestrial Radio Access Network) being the long term perspective for the 3GPP technology family both in terms of new architecture and radio access technologies. Similar paths are drawn from the 3GPP2 around the evolution of CDMA2000. On the other hand, the IEEE 802 is producing an evolving family of standards, such as 802.11 local, 802.15 personal, 802.16 and 802.20 metropolitan and 802.22 regional area networks.

Furthermore, the regulatory perspective on how the spectrum should be allocated and utilized in such a complex and heterogeneous technology scenario is evolving as well. The evolution is towards a cautious introduction of more flexibility in spectrum management together with economic considerations on spectrum trading. This new spectrum management paradigm is driven by the growing competition for spectrum and the requirement that the spectrum is used more efficiently [1]. For this purpose, a narrow view would be to look to technology as a mean to provide more robust communications systems with increased efficiency. Instead, a broader view is to examine spectrum utilization from a time/location/band/power perspective as suggested in the Federal Communications Commission Spectrum Policy Task Force Report [2].

Indeed, numerous studies support the observation that the usage of radio resource spectrum experiences significant fluctuations. Usually, heavy spectrum utilization takes place in unlicensed bands while some licensed bands often experience low (e.g. TV bands) or medium utilization. Based on these considerations, the TV band Notice of Proposed Rule Making (NPRM) [3] was the natural next step taken by the FCC. The proposition of the NPRM allows unlicensed radios to operate in the TV broadcast bands if no harmful interference is caused to incumbent services (e.g., TV receivers). These events culminated in the formation of the IEEE 802.22, developing an air interface for unlicensed operation in the TV broadcast bands [4].

Several works in the literature have recently dealt with flexible spectrum management strategies. In [5] the DIMSUMNet architecture is presented for coordinated, real-time dynamic spectrum access based on a centralized entity called Spectrum Broker as opposite to other opportunistic, uncoordinated methods. The concepts of coordinated access band and statistically multiplexed access to spectrum are introduced. Further work on this topic is presented in [6], where different formulations for solving the spectrum allocation problem based on linear programming are presented. In [7] a spectrum etiquette protocol for efficient coordination of radio communication devices in unlicensed frequency bands using different radio technologies is proposed. It uses a common protocol for the announcement of radio and service parameters.

The framework envisaged above, characterized by a multiplicity of Radio Access Technologies (RATs) empowered by flexible spectrum capabilities, can only be fully accomplished by further enhancing the Radio Access Networks (RANs) towards Cognitive Networks complemented with Cognitive Radio-based technologies. On one hand, a cognitive network exploits a process that can perceive current network conditions, and then plan, decide and act on those conditions. The network can learn from these adaptations and use them to make future decisions, all while taking into account end-to-end goals [8]. On the other hand, Cognitive Radio technology is built upon software defined radio (SDR) technology and allows individual radios or groups of radios to make choices about their frequency and RAT use based upon their location and the radio use environment [9]. Thus, cognitive radios have the potential to utilize the large amount of unused spectrum in an intelligent way while not interfering with other incumbent devices in frequency bands already licensed for specific uses. Cognitive radios are enabled by the rapid and significant advancements in radio technologies and can be characterized by the utilization of disruptive techniques such as wide-band spectrum sensing, real-time spectrum allocation and acquisition, and real-time measurement dissemination [4].

In this context, this paper firstly presents an integrated layered approach to achieve an efficient dynamic spectrum and radio resource usage in heterogeneous wireless network scenarios, as described in Section 2. Then, Section 3 discusses the suitability that those management strategies include a decentralized operation component with decision making processes executed at the mobile terminal side. Section 4 proposes an on-demand CPC as a radio enabler for the decentralized functionalities. Section 5 shows that the proposed solution compares favourably to a broadcast CPC approach. Finally, conclusions close the paper in Section 6.

II. An Integrated Layered Approach

A number of techniques have been identified, proposed and analyzed in recent years to cope with heterogeneous wireless networks with flexible spectrum management capabilities as it will be further detailed within this section. However, the different resource optimization techniques have to be integrated into a coherent framework, given that the use cases (ranging e.g. from the dynamic allocation of spectrum between the different RATs of one operator to the more complex allocation and management of radio resources between the access networks of different operators) pose individual problems of resource utilization; each requiring a different approach to achieve the optimal resource allocation.

Let assume that a reference operator faces traffic variations on the planned conditions at the short-term, long-term as well as spatially. Traffic variations may respond to the total aggregated offered traffic but also to the offered traffic service mix. Other operators in the same area are characterized in a similar way.

In order to achieve an efficient usage of the spectrum and radio resources, the proposed solution is a layered approach, as depicted in Figure 1, which intends to cope with actual traffic conditions through the most suitable mechanism. To this end, four different layers are identified together with supporting Cognitive Network concepts:

A. *Intra-operator JRRM*

At this layer, current traffic conditions are targeted with algorithms applied over the resources of each operator. JRRM is the process that enables the management (allocation, de-allocation) of radio resources (like time slots, codes, frequency carriers, etc.) between different radio access systems for fixed spectrum bands allocated to each of these systems.

Intra-operator JRRM operates in the inner-loop of the functional architecture, thus acting at the shortest time scale (in the order of one second or below). With the current deployment and resource allocation to cells, intra-operator JRRM is able to provide a significant gain derived from the joint consideration of the pool of radio resources available. Intra-operator JRRM has been identified as an important issue by the 3GPP, which defines some recommendations and architectures for JRRM operation [10][11], as well as by the research community [12][13].

Assuming that a good JRRM algorithm is implemented, if key performance indicators (KPIs) point out degradation in QoS levels, this may indicate that intra-operator JRRM has reached its limits with the current allocation of spectrum in the scenario facing the current traffic conditions. In such case, the operator may question whether the RAT/spectrum mapping to cells is suitable in the actual radio network state. This will be targeted by intra-operator ASM mechanisms at the next layer of the architecture, which will look for a suitable spectrum/RAT allocation fitting the current conditions as detailed in the next subsection. The outcome of the intra-operator ASM algorithm will be to get a more suitable system operation point.

B. *Intra-operator ASM*

At this layer, current traffic conditions are targeted with re-arrangement of the operator-owned spectrum through suitable dynamic spectrum management.

Intra-operator ASM enables the dynamic management (allocation, de-allocation, sharing) of spectrum blocks within a single or between different radio access systems. Here, spectrum bands allocated to each system are not fixed but flexible. In this context, the dynamic spectrum allocation refers to the partitioning of the spectrum that dynamically changes to adapt to the current or future demand on the radio resources resulting in certain gain in spectrum allocation.

In case the synergised operation between intra-operator JRRM and ASM is exhausted, which again could be observed by QoS degradation, it can be concluded that the amount of available resources for the operator is not enough to cope with the offered traffic. In such case, inter-operator mechanisms are envisaged, as a source of getting additional resources coming from complementary operators. This corresponds to the two upper-layers in Figure 1.

C. *Inter-operator JRRM*

At this layer, current traffic conditions are targeted by borrowing/renting some radio resources from another operator. In this way, the potentially dissatisfied user can be given access to the service through another network operator. A trading agent implemented as a “metaoperator” may be the actor that provides the bridge among different operators by making transactions for offering and demanding radio resources. Both operators participating in the trading process are benefited by the establishment of inter-operator agreements. In particular, the operator "renting" radio resources takes advantage of this exchange in the short term, in terms of revenue coming from the service provision for the user. On the other hand, the operator "borrowing" radio resources is benefited in the long term since the user, instead of being blocked, is provided with service in a transparent manner and consequently is not motivated to churn.

D. Inter-operator ASM

At this layer, current traffic conditions are targeted by borrowing/renting substantial pieces of radio spectrum. Inter-operator JRRM and inter-operator ASM are mainly distinguished by the granularity in the amount of resources traded. Both parties may benefit from this deal. The ultimate objective would achieve an automatic, self-adaptive operation, where suitable mechanisms/layers are activated.

The Cognitive Network element monitors and captures the network status at different levels, which are of interest for the different strategies. It is worth noting that the triggering events may advice to skip some of the layers depending on the actual traffic conditions (e.g. intra-operator JRRM triggers intra-operator ASM, which readily realizes that the current intra-operator spectrum is suitably allocated and the required additional capacity has to be reached through inter-operator JRRM and/or ASM mechanisms).

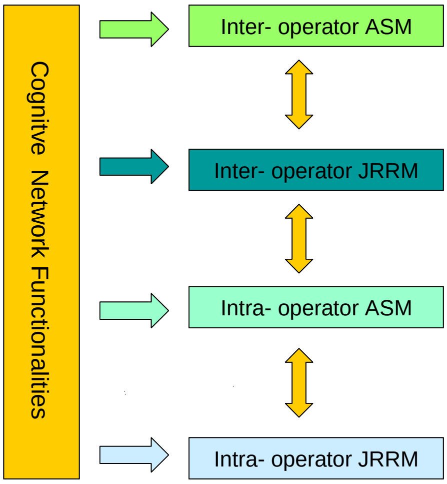

Figure 1 Layered intra/inter-operator and JRRM/ASM approach

III. DECENTRALIZED JRRM/ASM

Traditionally, (J)RRM functions in a wireless cellular network are mainly centralized, i.e. the functions are implemented in a central network node such as RNC (Radio Network Controller) in UTRAN (UMTS Terrestrial Radio Access Network). This can be justified because a central network node may have a more complete picture of the radio access status than a particular node, so that (J)RRM decisions can be made with more inputs. However, a centralized (J)RRM implementation has some drawbacks in terms of increased signaling load or transfer delay of the (J)RRM algorithm's inputs to the central node. This prevents an efficient implementation of short-term (J)RRM functions such as packet scheduling and explains why wireless cellular technology evolution (e.g. HSDPA) exhibits the trend towards implementing (J)RRM functions on the radio access network edge nodes (base stations).

Additionally, the terminal also keeps relevant information that could be of great interest for making smarter (J)RRM/ASM decisions. This is why some (J)RRM/ASM functions, although typically implemented in the network side (either on central or edge nodes), are assisted by mobile terminal measurement reports. Handover algorithm is a clear example, since the knowledge of the propagation conditions from the terminal to the different surrounding cells is key for making the proper decision on what cell(s) the terminal should be connected to.

Indeed, there is a clear trend towards decentralized (J)RRM/ASM functions in the mobile terminals. This approach has claimed to be inefficient in the past because of the limited information available at the terminal side (e.g. the terminal does not know what is the cell load). Nevertheless, this can be overcome if the network is able to provide some information or guidelines to the terminal assisting its decisions. In this way, while a mobile-assisted centralized decision making process requires the inputs from many terminals to a single node, the network-assisted decentralized decision making process requires the input from a single node to the terminals, which can be significantly more efficient from a signaling point of view. In this respect, the on-going IEEE P1900.4 standardization effort would provide the necessary support to this network-assisted mechanism [17].

The objective of the IEEE P1900.4 is to define standardized protocols and corresponding reconfiguration management system architecture for the optimization of resource management, in order to provide improved capacity, efficiency and utility within a heterogeneous wireless network wherein devices support multiple air interfaces, with multi-homing and dynamic spectrum access capabilities in licensed and unlicensed bands. In some more detail, the scope of P1900.4 includes (1) providing protocols carrying information between network resource managers and device resource managers supporting wireless terminal and network reconfiguration management, including the context of heterogeneous networks, (2) providing corresponding reconfiguration management functionalities of the wireless, system for the support of efficient optimization of resource usage, (3) providing corresponding management functions and standardized rules to allow the multimode and/or dynamic spectrum access capable devices make decisions in a distributed fashion whilst providing operators with fair and effective exploitation of network resources thanks to an exhaustive set of rules to be followed by user equipments.

In this framework, Figure 2 depicts how the network-centric layered approach presented in Section 2 would be applicable to a decentralized decision making context thanks to the availability of communication means between the network and the terminal implemented as a Cognitive Pilot Channel (CPC). Cognitive network functionalities would be readily exploited in the layered JRRM/ASM. The knowledge acquired in the network side and properly processed would be transmitted to the terminal through the CPC upon request. With this information available together with information locally acquired at the terminal side (e.g. spectrum measurements, interference conditions, etc.), the mobile terminal could make intelligent choices in various radio-related dimensions: frequency band of operation, RAT and cell site to get connected to, transmitted power level, etc. Certainly, the radio-related information could be properly combined with business-related aspect representing operator and/or user preferences.

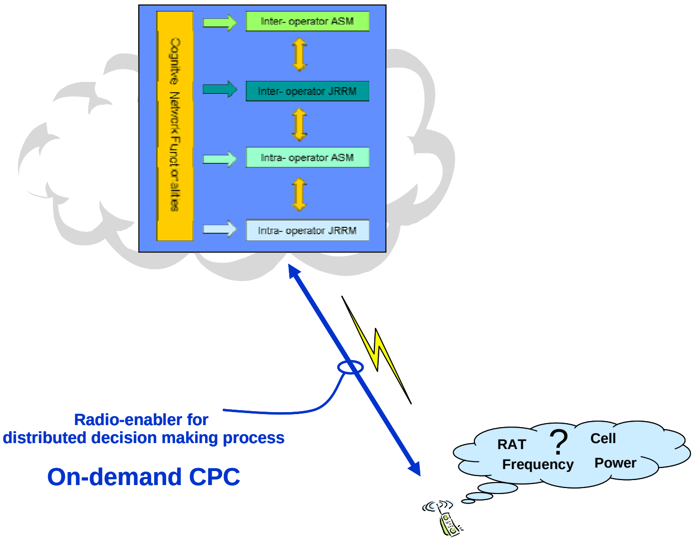

Figure 2 Decentralized JRRM/ASM enabled by an on-demand CPC

IV. Radio Enabler: Cognitive Pilot Channel

Following a similar approach as the Spectrum Information Channel in [4] and the Common Spectrum Coordination Channel in [7], the Cognitive Pilot Channel (CPC) concept was recently conceived as a solution to assist the mobile reconfigurable and cognitive terminal in procedures like the RAT selection in heterogeneous scenarios with different access networks available and varying spectrum allocations [14]-[16]. The CPC basically consists in a channel that carries relevant information for the mobile terminal. Then, terminals can make use of the information transmitted in CPC in order to carry out several procedures, like decentralised RAT selection, optional download of software modules for reconfigurability purposes or identification of temporary unused frequency bands to enable a secondary usage of the spectrum for different types of applications (e.g. establishment of an ad-hoc network, communication of devices in personal area networks, etc.).

Under this framework, the CPC channel can be regarded as a radio enabler of reconfiguration management in cognitive networks, and it is expected that it can provide benefits for the different players involved in the wireless communications arena, as summarised in the following:

a) The CPC helps the mobile terminal to select the proper network depending on the specific conditions (e.g. desired services, RAT availability, interference conditions, etc.). This provides *support to JRRM*, enabling a more efficient use of the radio resources.

b) It provides *support to Reconfigurability* by allowing the terminal to identify the most convenient RAT to operate with and to download in case the necessary software modules to reconfigure the terminal capabilities.

c) It provides *support to Context Awareness* by helping the terminal in identifying the specific frequencies, operators and access technologies in a given region without the need to perform long time and battery consuming spectrum scanning procedures.

d) It helps the network provider to facilitate dynamic changes in the network deployment by informing the terminals of the availability of new RATs/frequencies, thus providing *support to Dynamic Network Planning (DNP) and ASM* strategies.

e) It helps the spectrum regulator to *improve the spectrum utilisation* thanks to enabling a secondary use of the temporary unused frequency bands in a specific region.

The different papers existing in the literature concerning CPC mainly focus on the CPC concept as enabler for reconfiguration management as well as on how it should be mapped onto physical resources. Particularly, in [14] an out-band architecture where the CPC is transmitted in a global harmonized frequency over a certain area, subdivided into smaller portions, denoted as meshes, is presented. The information in the CPC included the operators and technologies available in each mesh and was intended to help the mobile terminal in the RAT and operator selection procedure. In [15][16] another approach including a hierarchical CPC organised into three levels (country, operator and network level) was proposed in order to reduce the amount of information that is sent at each level. Combining in-band CPC (i.e. using some channels of the existing RATs) and out-band CPC architecture is another possibility.

A. CPC Operation Procedure

The CPC operates in a geographical area subdivided into meshes. A mesh is defined as a region where certain radio electrical commonalities can be identified (e.g. a certain frequency that is detected with a power above a certain level in all the points of the mesh, etc.). The mesh is univocally defined by its geographic coordinates, and its adequate size would depend on the minimum spatial resolution where the above commonalities can be identified. For simplicity, square meshes of identical dimension will be considered here. Nevertheless, other approaches could exist based on e.g. dynamic definition of meshes.

The steps of the overall CPC operation procedure are described in the following. After switching on, the terminal determines its geographical information making use of some positioning system and afterwards it detects and synchronises with the CPC. Such CPC detection will depend on whether an out-band CPC (i.e. transmitted in a global harmonised frequency) or an in-band CPC (i.e. transmitted using channels in the existing RATs) is used [14]-[16]. Afterwards, the terminal retrieves the CPC information corresponding to the mesh where it is located, which completes the procedure. Notice that these steps can also be performed periodically to detect changes in the environment due to either variations in the mobile position or network reconfigurations.

B. On-demand CPC

In this sub-section, an on-demand CPC implementation defining how the CPC information is delivered to the terminals is analysed, as opposite to the other possible broadcast CPC approach in which the information for all the meshes is continuously broadcast through a downlink channel. The rationale of the proposed on-demand CPC approach is that, if all the CPC information should be continuously broadcast for all the meshes, this would require either a long time or a wideband channel, particularly, if the mesh size is small. However, depending on the number of terminals that are located in each mesh, this information will be in practice most of the time unused. Consequently, it may become more efficient from both power and bandwidth consumption point of view, to transmit the information only when needed and requested by a terminal [18].

In the proposed approach, the on-demand CPC makes use of both the uplink and downlink components and it consists in the following logical channels:

- Random Access CPC (RACPC): It consists of an uplink slotted channel where the mobiles operating with CPC send requests to retrieve the CPC information corresponding to their meshes. Each request basically contains an indicator of the geographical coordinates of the mobile terminal. An operation according to a simple protocol such as S-ALOHA can be envisaged for this channel.

- Acquisition Indicator CPC (AICPC): This downlink channel follows the same slotted structure of the uplink RACPC and is devoted to indicate that a request has been successfully received. The channel consists in Acquisition Indicators (AI) each one indicating the identifier of the terminal whose request has been received or the value Null if no request has been received.

- Downlink On-Demand CPC (DODCPC): This downlink logical channel is used to transmit the CPC information corresponding to the mesh of each received request from a Mobile Terminal (MT).

The operation of these channels is illustrated in Figure 3. The uplink and the downlink channels are organised in slots of duration $T_{S.}$ The AICPC and the DODCPC are multiplexed on the same time slots by making use of different fields of a certain burst structure. In Figure 3, the terminal MT1 sends a request in slot #1. This request simply contains the geographical coordinates of the terminal and a short random identifier. Since there is no collision in the transmission, the slot #2 in the AICPC indicates that MT1 request has been successfully received by means of the Acquisition Indicator (AI) including the random identifier sent by MT1. Then, the transmission of the CPC information corresponding to the mesh of MT1 starts in the DODCPC during a total of $T_{m,OD}=N_s \cdot T_s$ being N_s an integer number of slots depending on the bit rate of the downlink channel. Similarly, the mobile terminal MT2 sends the request in slot #2 and receives the corresponding AI in the downlink of slot 3. However, since the DODCPC in this slot is transmitting the information of MT1, MT2 should wait until slot #k to start receiving the information of its mesh. In slot #3 a collision occurs between MT3 and MT4, and therefore the AI in the subsequent slots indicate a Null value, reflecting that no request has been received. Then, the terminals will wait a random retransmission time. In the example, MT3 retransmits the request in slot #k+1.

The proposed implementation of the on-demand CPC including both an uplink and a downlink channel enables a wider range of CPC-based applications in addition to the retrieval of the information about operators, RATs and frequency lists. For example, the CPC could eventually be used by the terminals to retrieve other terminal-dependent information, such as software downloads to enhance the reconfigurable terminal capabilities. Furthermore, the uplink channel can also be used to ensure that the information has been delivered correctly thus improving the integrity and the security in the transmitted information.

On the other hand, notice that the interaction with the mobiles in the on-demand CPC allows the network operator and the spectrum regulator having eventually a higher control of the terminals accessing CPC than if the broadcast approach was used. In that sense, it is easier to fit the CPC operation within specific business models and exploitation plans e.g. for a controlled secondary use of the spectrum.

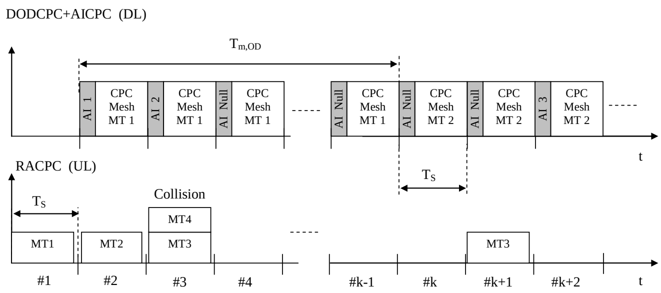

Figure 3 Operation of the on-demand CPC

V. EVALUATION

Let assume a scenario in which each CPC transmitter sends the information corresponding to N_m meshes. A number of wireless devices or terminals require getting the CPC information corresponding to the mesh where they are located.

Then, let λ (requests/s) be the arrival ratio of requests corresponding to these devices in the whole area of one CPC transmitter, assumed to follow a Poisson distribution. Terminals are uniformly distributed in the area and meshes are of the same size, so the arrival rate is the same in all the meshes. Let I_m be the total number of information bits to be transmitted for a single mesh. For comparison purposes, it is assumed that the slot duration T_S and the downlink net bit rate of the CPC channel R_b (i.e. including only information bits, without considering other bits for channel coding, synchronization, etc.) is the same in both the broadcast and the on-demand CPC.

This section presents some illustrative results for the CPC operation. For illustration purposes, results have been obtained considering that the amount of information corresponding to a mesh is I_m=4253 bits [18]. The rest of parameters are a time slot duration of T_S=10 ms and a bit rate of the downlink CPC of R_b=10 kb/s (net bit rate of information bits, without including redundancy bits for channel encoding, synchronisation bits, etc.).

A scenario with a homogeneous user density of η users/km^2 is considered. Each user or wireless device generates a total of λ_u=0.0003 requests/s to access the CPC (i.e. around 1 request per hour). The area covered by a CPC transmitter is assumed to be circular with a radius *R* km.

Figure 4 plots the performance in terms of delay in retrieving the CPC information as a function of the CPC transmitter range *R* for the broadcast and the on-demand CPC. The mesh size is assumed to be fixed and equal to 100m×100m, so the larger the CPC transmitter range the higher the number of meshes. Similarly, the user density is equal to η=2000 users/km^2, and therefore the total load also increases with the range. Figure 4 shows that the increase in the range turns into an increase in the delay for the two approaches, but the delay experienced by the broadcast CPC is in general much higher than that of the on-demand CPC. In the broadcast CPC, the delay increase is due to the higher number of meshes included in the CPC transmitter area when increasing the range. On the contrary, in the on-demand CPC the delay increases with the range due to the larger number of requests, which require a longer queuing waiting time to be served. In that sense, there is a fixed limit given by the M/D/1 performance because it should be fulfilled the condition $\lambda \cdot T_{m,OD}<1$ in order for the system to be stable. This is reflected in the figure by the steep delay increase for ranges above 1.05 km.

From Figure 4, and assuming a performance requirement to retrieve the CPC information with a delay below e.g. 5 s, it can be observed that, for these conditions, the maximum range for CPC operation with the on-demand approach is around 1.08 km. On the contrary, for the broadcast CPC the maximum range would be only about 260m. This observation reflects also that, for a given range, the broadcast CPC would require a higher bit rate than the on-demand CPC in order to achieve comparable performances. Notice that the difference could even be higher if a lower maximum delay bound below 5s was set. This is reflected in Table I, which indicates the maximum CPC range for different values of the maximum delay requirement with the two approaches. It can be observed that the range of the on-demand CPC is much larger than that of the broadcast CPC. Furthermore, the behaviour of the on-demand CPC is less sensitive to the maximum delay bound than the broadcast CPC.

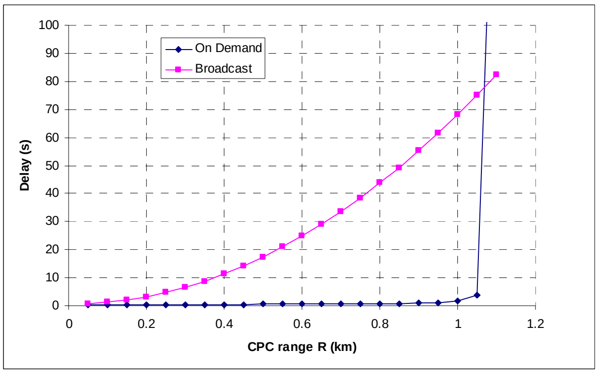

Figure 4 Total delay as a function of the CPC range for a mesh size of 100m×100m

Table I Maximum CPC range for different maximum delay requirements

Delay bound	On-demand CPC	Broadcast CPC
1s	0.91 km	0.08 km
2s	1.00 km	0.14 km
5s	1.08 km	0.26 km
10s	1.08 km	0.37 km
20s	1.08 km	0.53 km

The behaviour of the CPC depending on the value of the bit rate R_b is further analysed in Figure 5, which plots the required downlink CPC bit rate R_b for the two approaches as a function of the CPC transmitter range if a maximum delay of 5s in retrieving the CPC information was set. The same conditions in terms of user density as in Figure 4 are considered. Furthermore, the results are presented for three different mesh sizes, namely 50m×50m, 100m×100m and 200m×200m. It is worth mentioning that the bit rate required for the on-demand CPC does not depend on number of meshes (or equivalently on the mesh size), because only the information of the requested meshes is transmitted. On the contrary, the bit rate required for the broadcast CPC increases very significantly when reducing the mesh size. For a mesh size of 100m and below it can be observed that the broadcast CPC requires a bit rate higher than the on-demand CPC in more than one order of magnitude for comparable delay performance (e.g. the required bit rate of the on-demand CPC is around tenths of kb/s while that of the broadcast CPC is around hundreds of kb/s or even Mb/s if the mesh size is 50m). Consequently, a more efficient CPC implementation with the on-demand CPC follows.

From Figure 5 it is also observed that when increasing the mesh size the bit rate requirement for the broadcast CPC becomes closer to that of the on-demand CPC. The reason is the reduction in the number of meshes and the consequent reduction in the total broadcast period. In that sense, Figure 6 plots the value of the minimum mesh size so that the broadcast CPC requires a lower bit rate than the on-demand CPC for different desired performances in terms of the maximum delay bound *Dmax*. It can be observed that the more stringent the delay bound, the larger the meshes should be in order that the broadcast CPC becomes better efficient solution than the on-demand CPC. Particularly, for maximum delay bounds of 1s the mesh size should be as big as 1km×1km.

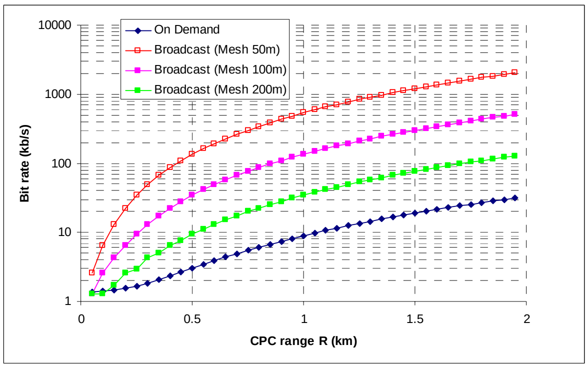

Figure 5 Required CPC net bit rate to ensure a maximum delay of 5s.

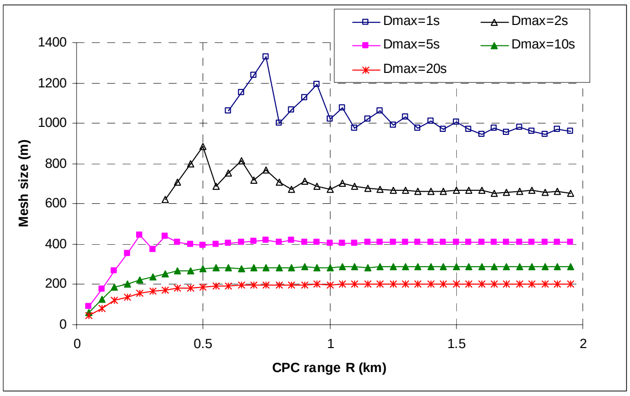

Figure 6 Minimum mesh size so that the required bit rate with the broadcast CPC is below that of the on-demand CPC

VI. CONCLUSIONS

This paper has presented an integrated framework where JRRM and ASM mechanisms operate synergistically towards an optimized dynamic spectrum and radio resource usage in multi-operator heterogeneous wireless networks scenarios. Given the complexity of the problem, the proposed solution follows a layered approach, where both intra and inter-operator levels are also considered. The solution is sustained on cognitive network functionalities.

The interest of decentralized JRRM/ASM functionalities has been identified and the role of the Cognitive Pilot Channel (CPC) as radio enabler has been stressed. In this respect, this paper has proposed an on-demand CPC as opposite to the broadcast mechanism. It has been obtained that the proposed approach is able to achieve the same performance in terms of delay to retrieve the information requiring a significantly lower bit rate of the CPC channel, particularly when a high granularity in the mesh sizes is desired. Specifically, differences in more than one order of magnitude have been observed in the required bit rate for the two approaches.

ACKNOLEDGEMENTS

This work was performed in project E2R II which has received research funding from the Community's Sixth Framework program. This paper reflects only the authors' views and the Community is not liable for any use that may be made of the information contained therein. The contributions of colleagues from E2R II consortium are hereby acknowledged. The work is also partially funded by the Spanish Research Council under COSMOS (Ref. TEC2004-00518) grant.

REFERENCES

[1] J. A. Hoffmeyer, “Regulatory and Standardization Aspects of DSA Technologies – Global Requirements and Perspectives”, Dyspan 2005.

[2] http://www.fcc.gov/sptf/reports.html

[3] Federal Communications Commission (FCC), “Notice of Proposed Rule Making,” ET Docket no. 04-113, May 25, 2004

[4] C. Cordeiro, et al., “IEEE 802.22: The First Worldwide Wireless Standard based on Cognitive Radios”, Dyspan 2005

[5] M. Buddhikot, P. Kolodzy, S. Miller, K. Ryan, J. Evans “ DIMSUMNet: New Directions in Wireless Networking Using Coordinated Dynamic Spectrum Access”, IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (IEEE WoWMoM), Taromina/Giardini Naxos, Italy, June, 2005.

[6] M. Buddhikot, K. Ryan, “Spectrum Management in Coordinated Dynamic Spectrum Access Based Cellular Networks”, 1st IEEE international Symposium on New Directions in Dynamic Spectrum Access Networks (DySPAN), Baltimore, MD, November, 2005.

[7] D. Raychaudhuri, X. Jing “A Spectrum Etiquette Protocol for Efficient Coordination of Radio Devices in Unlicensed Bands”, 14th IEEE 2003 International Symposium on Persona1,lndoor and Mobile Radio Communication Proceedings (PIMRC), Beijing, September, 2003.

[8] R. W. Thomas, et al. , “Cognitive Networks”, Proc. of the First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN 2005), p.p.352- 360, 2005

[9] M. J. Marcus, “Real Time Spectrum Markets and Interruptible Spectrum: New Concepts of Spectrum Use Enabled by Cognitive Radio”, Dyspan 2005

[10] 3GPP TR 25.881 v5.0.0 “Improvement of RRM across RNS and RNS/BSS”

[11] 3GPP TR 25.891 v0.3.0 “Improvement of RRM across RNS and RNS/BSS (Post Rel-5) (Release 6)”

[12] J. Pérez-Romero, O.Sallent, R.Agustí, M. Díaz-Guerra, Radio Resource Management Strategies in UMTS,John Wiley & Sons, 2005.

[13] S. Lincke-Salecker, “The Benefits of Load Sharing when Dimensioning Networks”, Proceedings of the 37th Annual Simulation Symposium (ANSS’04), April, 2004.

[14] P. Houzé, S. Ben Jemaa, P. Cordier “Common Pilot Channel for Network Selection”, IEEE VTC in Spring Conference, Melbourne, May, 2006.

[15] E. Mohyeldin, J. Luo, J. Pan, P. Slanina, “Common Pilot Method Enabling Network Assisted Fast Scanning for Reconfigurable Terminals”, 4th Karlsruhe Workshop on Software Radios, Karlsruhe, March, 2006.

[16] P. Cordier et al., “E2R Cognitive Pilot Channel concept”, IST Summit, Mykonos, June, 2006.

[17] IEEE P1900 Home Page, http://www.ieeep1900.org

[18] J. Pérez-Romero, at al., “A Novel On-Demand Cognitive Pilot Channel enabling Dynamic Spectrum Allocation”, IEEE Dyspan 2007.