Requirements on the information flow for intersystem coexistence and cooperation in the emerging cognitive wireless world

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***Abstract*— The emerging cognitive wireless world considers new networking paradigms that have already started to intrigue the scientific community. In accordance to this, ETSI [10] has proposed the Cognitive Control Network (CCN), which is based on an infrastructure-free network formation and it is an extension of the infrastructure-based Cognitive Wireless Networks (CWN) towards creating a more flexible and resource efficient, global cognitive network structure. The CCN is dynamically created, modified and terminated under the governance of CWN (governance is considered in terms of proper resources assignment, context provisioning and policies enforcement.) These are recognized as difficult management tasks that require the flow of appropriate control information among CWN and CCN and within the CCN. Framed within this statement, our work aims at addressing the requirements with respect to the control information flow for enabling the creation, modification and termination of CCN and thus, for supporting its efficient coexistence and cooperation with CWN in the emerging cognitive wireless world.**

Keywords- cognitive wireless network; cognitive control network; network creation; information flow requirements

I. INTRODUCTION

Intersystem coexistence and cooperation holds a key role into future network environments [1]. The emerging cognitive wireless world will be part of the Future Internet (FI). All kinds of devices and networks will have the interconnection potential. Thus, any object or network element will be able to have communication capabilities embedded within and several objects in a respective environment will create a communication network. Challenges such as flexible spectrum sharing with the use of cognition mechanisms and the need for control channels for cooperation of management systems exist. Moreover, efficient resource provisioning and management [2] needs to be addressed in order to achieve solutions in diversified applications over heterogeneous network issues.

Composite Wireless Network (CWN) is part of the wider Cognitive Radio (CR) concept which introduces cognitive network management system in order to deliver cognition mechanisms to support decision in future wireless networks. Radio resource management is a mechanism which can be described as the management of the common pool of radio resources available in the set of access points or transceivers. In other words, it could comprise the resource management techniques to achieve the dynamic traffic allocation to the transceivers participating in a heterogeneous wireless access infrastructure [3]. The combination of radio resource management with dynamic spectrum management ensures that the composite wireless network becomes context-aware in order to act according to the dynamic operating environment and allocate resources where needed, when needed.

Cognitive Control Network (CCN) on the other hand is an emerging group of functionalities which aim to introduce cognition mechanisms into an era of wireless communications where nodes and terminals engage occasional mobility and routing patterns are dynamically configured. Specifically, the idea of intermittent node edges in an ad-hoc network is addressed, thus challenges arise in terms of efficient and reliable packet conveyance through the network. Resembling ad-hoc, infrastructure-free networks this new group comes with a bundle of benefits that could evolve in areas where infrastructure is difficult to exist or communication demand rises instantly and support is needed for successful handling.

In this paper, the coexistence of CWN and CCN are considered as a basis and requirements for the information flow mechanisms between CWN-CCN for network creation, modification and termination are introduced. Figure 1 (which is influenced by Figure 1 in [10]) illustrates the two major cognitive radio concepts of the emerging cognitive wireless world. Mind the ad-hoc, infrastructure-free network formation in the CCN versus the infrastructure-dependent network of the CWN.

Coexistence of infrastructure-free networks with network infrastructure is empirically analysed in [4], where it is concluded that after a certain point, the benefits of additional infrastructure deployments are minor and the utility of the ad-hoc communication system remains stable. The possibility of extending ad-hoc networks with the support of infrastructure, in the so-called hybrid networks, has also been considered in [5] as a way of improving the connectivity in large-scale ad-hoc networks. Also in [6] the benefits of using a hybrid network architecture over pure ad hoc wireless networks with no infrastructure are theoretically analysed in terms of throughput capacity

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increase. In both cases, the studies are based on a theoretical framework but neither architectural aspects nor considerations on the peculiarities of infrastructure-free networks formation for service provision are addressed. In [7] mobile ad-hoc networks are integrated with a cellular network that provides support to improve both routing and security issues.

This paper focuses on presenting the interconnection between CWN-CCN and the requirements for the information flow. The rest of the paper is structured as follows. Firstly, information flow mechanisms between CWN-CCN are reviewed. Then, functionalities for the management of CCN are introduced. Information flow for enabling network creation, modification and termination in a CCN environment follow. Finally, signaling load considerations with respect to the previously mentioned information flow are addressed.

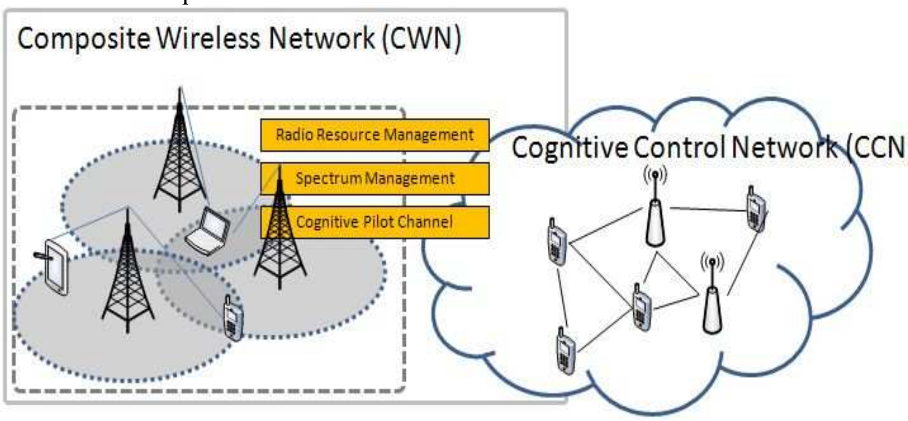

Figure 1. A view of the emerging cognitive wireless world

II. INFORMATION FLOW MECHANISMS BETWEEN CWN – CCN

Under the cognitive concept umbrella, multiradio user equipments can be traced, which have the ability to be aware of their heterogeneous operational environment and act accordingly by implementing software agents technologies. The cognitive pilot channel (CPC) [16] is a control channel which carries control information between infrastructure and devices. The CPC into heterogeneous radio environments is implemented as an enabler for assisting terminals to discover the spectrum allocation and to develop cognition enablers schemes for reconfigurable, cognitive systems focusing on spectrum-sensing and information provision mechanisms [3]. In line with these motivations, ETSI has provided a sample CPC information structure focusing mainly on typical access point attributes such as [10] type (e.g. LTE, UMTS etc.), area of coverage and frequencies. These attributes create a typical set in order to convey standard information to the environment from the access point. Figure 2 illustrates the above mentioned CPC content structure as described in [16].

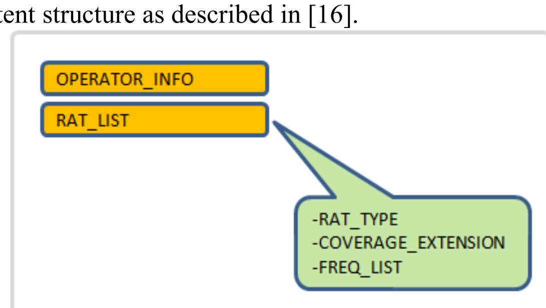

Figure 2. CPC content structure

Moreover, the IEEE 1900.4 standard [8] has also provided contribution related to this field. Specifically, as generally described in IEEE 1900.4 standard, a Network Reconfiguration Manager (NRM) collects context from its managed RANs and sends reconfiguration commands to them (in terms of operating Radio Access Technology (RAT) and spectrum/frequency) via a so called Radio Enabler. In general, Radio Access Network (RAN) context may contain, among others, information on RAN radio and transport capabilities, RAN measurements etc. Radio resource selection policies as well as RAN context information are sent to the Terminal Reconfiguration Manager (TRM) from the NRM, whereas terminal related context information is sent to the opposite direction. Similarly with RAN context, terminal context may include information such as terminal capabilities, required Quality of Service (QoS) levels, terminal measurements, user preferences etc. The benefits for CWN with respect to the CPC could be summed up to the following:

- Nearby network elements, gain awareness on the updated status of a specific access point, thus heterogeneous elements can be managed of manage themselves more effectively
- CPC could support the process of exchanging sensing information between access points in order to facilitate white spaces [9]
- Mobile terminals do have the ability to identify the spectrum availability and make more efficient use of the network resources
- Flexible and context-aware reconfigurability is being enabled, thus a terminal can facilitate specific radio resource management strategies.

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III. FUNCTIONALITIES FOR THE MANAGEMENT OF CCN

As part of the ETSI technical report in [10], it is recognized that logically separated CCN may be used to coordinate and efficiently arrange spectrum allocation of different mesh networks which operate in the same geographical area. Enhanced control channels could implement attributes which specify cognitive control network and infrastructure-free radio environments. Because of the special nature of this kind of environment, the typical attributes that discussed in the previous paragraph are not enough to evaluate the special characteristics of the network and therefore decision making may be insufficient.

Enhanced functionality and collaboration of current cognitive systems is needed for performing the following tasks:

- Determination of the suitability of the CCN. This includes node/ infrastructure discovery, identification of candidate nodes, identification and generation of spectrum opportunities from the infrastructure side, interference coordination through the exploitation of results from off-line studies.
- CCN creation. This includes the selection of the optimal, feasible configuration of the cognitive control networks. A configuration includes the selection of participant nodes, spectrum and routing pattern.
- CCN maintenance. This involves Quality of Service (QoS) control (monitoring and corrective actions) of the data and control flows served by the CCN, and the realization of reconfiguration actions in the case of alterations in the node status, and the spectrum and routing conditions.
- Handling of forced terminations of the CCN. This means to try to preserve the provision of applications as much as possible, even when the ad-hoc network has to be terminated before the data session ends.

IV. INFORMATION FLOW FOR SUITABILITY DETERMINATION OF A CCN

As stated above, suitability determination includes node, infrastructure discovery, identification of candidate nodes and spectrum opportunities. In the area of discovery procedures the basis will be IEEE procedures and 3GPP mobility procedures. For node discovery, IEEE procedures like beacons are a good solution. 3GPP offers also solutions for knowing where specific nodes are located. The ANDSF [11] is defined in 3GPP to provide inter-system mobility policies and access network specific information from the network to the user equipment (UE). The ANDSF is introduced in 3GPP for the support of multi-access network scenarios with intersystem-handovers between 3GPP-networks (e.g. GSM, UMTS, LTE) and non-3GPP networks (e.g. WiMAX, WLAN). In particular, ITU-R has set a requirement for IMT-Advanced technology that it has to be able to do an inter-system handover at least to one IMT system [12].

In the area of the identification of candidate nodes, we shall place focus on obtaining quantitative information and knowledge/experience on the behavior and capabilities of a node, thus establishing the foundation for determining whether the node can participate in the ad-hoc network.

In the area of spectrum opportunities, novel functionality to manage the collected data from such physical processes including sensing could be developed. This also includes exploitation of sensing information for the definition, creation and usage of cognitive databases (e.g. spectrum usage database), and also data exchange between such databases and the ad-hoc networks (database population).

V. INFORMATION FLOW FOR ENABLING NETWORK CREATION IN A CCN ENVIRONMENT

Because of the fact that nodes may be remote and not plugged-in on a fixed power source, energy concerns arise [13], as the battery limits the lifetime of the node. This means that energy-level should be taken into account, in order to know the network where there's a node with a low-energy level and bypass it.

Another important issue lies on the fact that due to mobility reasons, network elements are not always available for communication. This leads to the need for an availability attribute which evaluates spectrum availability in a specific geographical area, the node's online time and quality of the link.

The delivery probability and the buffer congestion level of a node could be broadcast as well, in order to inform the neighboring objects about the actual effectiveness of this particular network element. Figure 3 illustrated the control channel attributes for decision making by separating typical attributes from enhanced ones.

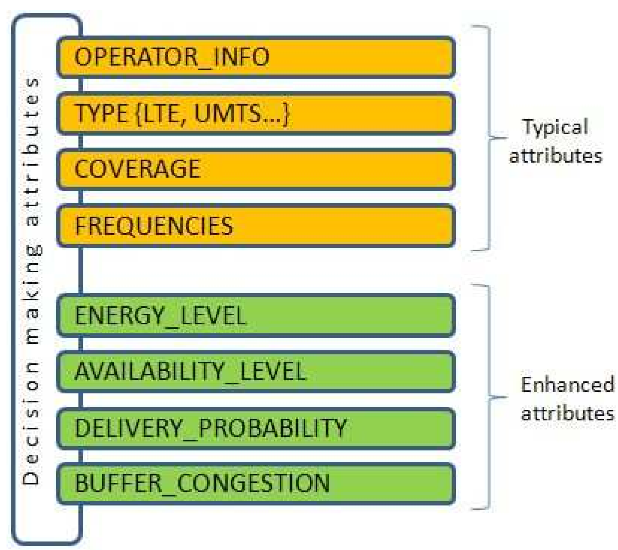

Figure 3. Typical (operator_info, type, coverage, frequencies) and enhanced (energy_level, availability_level, delivery probability, buffer_congestion) attributes for network decision making

A. *Centralized network creation approach*

Centralized approach relies on the fact that a central network management entity is monitoring the network

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elements and receives available data from them. Then the management entity is responsible to evaluate the data and make decisions according to an implemented algorithm. Control information flow is established between the management entity and the network elements in order to ensure context awareness of the elements. As soon as an element receives the evaluated control data, is capable of establishing a connection with the best element that the management entity has denoted and exchange packets.

The benefits of such an approach could be summarized to the following:

- Network elements gain context awareness by communicating with a management entity
- Management entity is responsible for centralized decision making and network monitoring in general
- Network elements implement decisions and do not collect and evaluate control data. Thus processing power is oriented only for packet conveyance

Figure 4 illustrates the previously mentioned approach by establishing links between a management entity and network elements for control data exchange and as soon as the decision is taken by the management entity, connection establishment takes place between networks in order to allow packet flow.

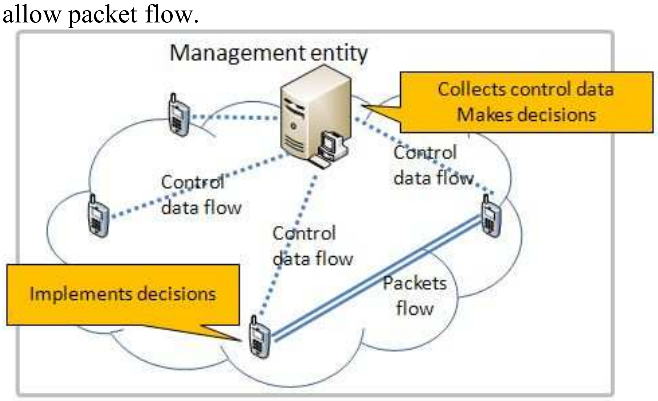

Figure 4. Centralized network creation approach

The specified approach depends to the prerequisite that the whole network creation and monitoring relies on the fact that the management entity functions properly. On the other hand infrastructure-free, ad-hoc networking may have the opportunity to allow flexible choice and monitoring of network elements. So, a distributed approach is taken into account as well.

B. Distributed network creation approach

Distributed approach focuses on the substantial degree of freedom that the network elements may have in order to make their own decisions on creation and self-monitoring of their own neighbors. As a result of this approach each network element is capable of implementing decision making strategies by receiving control data and processing it internally. As soon as there is a successor in range of the element, a link is established and packet flow takes place.

The benefits of such an approach could be the following:

- Network elements could act autonomously without being controlled by a network management entity
- Interconnection of network elements through heterogeneous architectures is made easier to implement.
- Ad-hoc network elements are flexible enough in case of failures to immediately act and find the next best solution/neighbor to continue packet conveyance, thus Quality of Experience (QoE) could be boosted.

It should be noted that the internal decision making procedure may lead to the need of greater processing power for each element. Figure 5 illustrates a distributed creation approach.

VI. Information Flow for Enabling Network Modification and Termination

As the network changes dynamically, monitoring mechanisms should be responsible for modifying it. This means that whichever creation approach is implemented, centralized or distributed, elements should be aware of their working environment in order to establish new, reliable connections with their in range neighbors, according to the available decision attributes. Because of the fact that energy level, availability level, delivery probability and buffer congestion level of each network object continuously change, network objects must collect and evaluate control information at regular time frames in order to decide whether an established link is still efficient, else search for another.

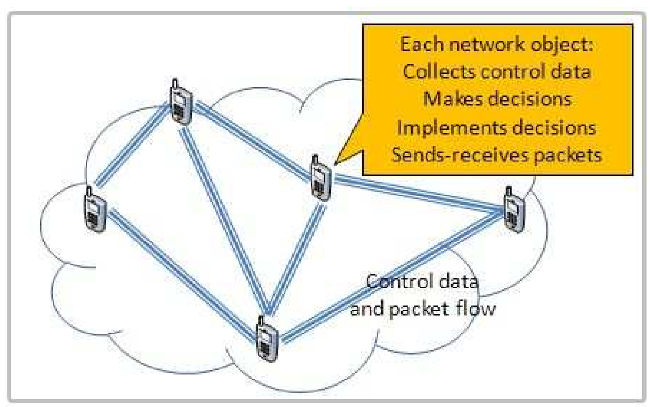

Figure 5. Distributed network creation approach

In terms of release of resources, there may be situations in which the network operator may no longer maintain the assignment of resources to the ad-hoc network. In such cases there can be the forced termination of the network. The issue is to preserve application provision until either the network resources are exhausted, or all applications are reassigned to a network of the infrastructure this time.

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VII. SIGNALING LOAD CONSIDERATIONS

We split signaling load considerations in qualitative and quantitative evaluations. In qualitative terms, in both approaches (i.e. centralized and distributed), the additional control information which is transferred takes into account the "cost" of a particular node. The "cost" value reflects the energy level, the availability level and the delivery probability, but the node does not transmit all these attributes. In order to obtain the "cost" value an internal evaluation takes place according to the protocol's procedures that the node implements. Afterwards, the node transmits its identification data followed by the "cost" value and according to this control signaling, decision is made on whether the node is accepted to participate to the ad-hoc network or it is rejected.

Regarding the quantitative evaluation an approach similar to [14] would be followed. Specifically, the paper evaluated that, in a cognitive wireless world context, a signaling load in the range of few Kbps (~2-3) is created. This load reaches the range of few tens of Kbps (~20) depending on the software technologies for the implementation. The signaling load is for the provision of context information from the terminals to the infrastructure and for the provision of policy information from the infrastructure to terminals. Similar results are obtained in the signaling calculations of [15], [16]. There, a signaling load in the order of 10 Kbps is computed, when information for multiple operators is conveyed. There will be leverage on information exchange strategies for ad-hoc networks in order to control the signaling load impact.

VIII. FUTURE WORK

According to the specified network creation and modification approaches, a number of aspects should be processed, to exploit further the emerging wireless world. For example, extensive measures should be provided in terms of information data flow in order to determine the overall congestion level of the network, because of the continuous exchange of control data [17]. Weights may be assigned to the control channel attributes according to the level of importance, in order to determine the overall decision variable and choose the respective node to add in the list for the creation of the network.

All these parameters should be carefully tailored to the requirements of the emerging wireless world in order to maximize intersystem coexistence and cooperation.

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