COGNITIVE CONTROL CHANNELS FOR THE COOPERATION OF OPPORTUNISTIC AND COMPOSITE WIRELESS NETWORKS

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ABSTRACT

Opportunistic networks (ONs) are considered as coordinated extensions of a radio access network infrastructure, which are dynamically and temporarily created in an infrastructure-less manner in order to increase service reachability, improve resource utilization efficiency and facilitate localised service provisioning. The realization of the ON concept relies on the existence of control channels which will provide necessary signalling for the coordination of the ON nodes. Proposed control channels are conceived as an evolution of the already established cognitive pilot channel concept. As a result, new interfaces are discussed in order to convey information from the infrastructure to the terminals and vice versa or between terminals. Finally, the business benefits of the aforementioned approach are provided in order to strengthen the notion of the proposed control channels and consider future expansions.

1. INTRODUCTION

Opportunistic Networks (ONs) are temporary, localized network segments that are created under certain circumstances. According to that vision, ONs are always governed by the radio access network (RAN) operator (which provides the resources, the policies and the knowledge – profiles, context, etc.), so they can be considered as coordinated extensions of the infrastructure network. ONs comprise both nodes of the infrastructure and infrastructure-less devices. The main objective of the current work is to study ONs as a solution for the efficient application provisioning in the Future Internet (FI) era by especially focusing on cognitive control channels for the cooperation of Cognitive Management Systems (CMS) entities.

CMS entities are part of the proposed functional architecture and are used for the management and control of operator-governed ONs. The cooperation of CMS entities will require existence of well-defined control messages and protocols/ channels for their exchange. To that respect, Control Channels for the Cooperation of the Cognitive Management Systems (C^4MS) will deal with that in order to enable the necessary signalling between the CMS entities.

The rest of the paper is structured as follows. Section 2 mentions indicative business scenarios which can be applied in the context of opportunistic networking. Section 3 analyzes the ON approach, while Section 4 provides necessary discussion on the functional architecture in order to define the CMS entities and the need for C^4MS. Section 5 follows with the analysis of the control channels and the identification of the required interfaces according to the functional entities involved and the part of network that communication is established (e.g. terminal side or infrastructure side). Finally, the business benefits of the proposed approach are listed while the paper wraps-up with future considerations and concluding remarks.

2. BUSINESS SCENARIOS

Five business scenarios have been identified, where ONs would pose a promising solution namely, the opportunistic coverage extension, the opportunistic capacity extension, the infrastructure supported opportunistic ad hoc networking, the opportunistic traffic aggregation in the radio access network and the resource aggregation in the backhaul [1].

Specifically, the opportunistic coverage extension describes a situation in which a device cannot connect to the network operator's infrastructure, due to lack of coverage or a mismatch in the Radio Access Technologies (RATs). The proposed solution includes one or more additional connected users that, by creating an ON, they establish a link between the initial device and the infrastructure, and act as a data relay for this link.

On the other hand, the opportunistic capacity extension depicts a situation in which a device cannot access the operator's infrastructure due to the congestion of the available resources at the serving access node. So, the redirection of the access route through an ON that avoids the congested network segment is proposed.

Also, the infrastructure supported opportunistic ad hoc networking deals with the creation of an infrastructure-less ON between two or more devices for the local exchange of information (e.g. peer-to-peer communications, home networking, location-based service providing, etc.). The infrastructure governs the ON creation and benefits from the local traffic offloading, as well as on new opportunities for service providing.

Another situation where an ON would be applied refers to the opportunistic traffic aggregation in the radio access network where a local ON is created among several devices in order to share a reduced number of infrastructure links towards a remote service-providing server or database. This situation allows some degree of traffic aggregation and caching that is useful to improve the overall network performance. Finally, the resource aggregation in the backhaul network depicts how ONs can be used to aggregate both backhaul bandwidth and processing/ storage resources on access nodes. In this case, the ON is created over access points rather than user terminals, thus offering a new focus on system performance improvement. Fig. 1 represents graphically a selection of the business scenarios as described above and more specifically the opportunistic coverage (ON1) and capacity extension (ON2) as well as the opportunistic traffic aggregation (ON3).

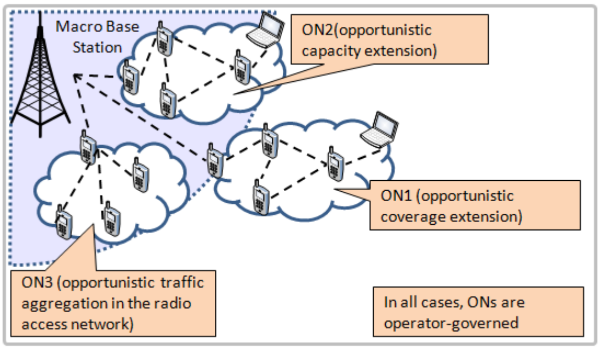

Figure 1 – Opportunistic networking business scenarios.

3. THE ON APPROACH

Four discrete phases are recognized as part of the ON approach. These are the suitability determination, the creation, the maintenance and the termination phases. Specifically, the suitability determination phase is responsible for assessing whether an ON is suitable of being created by taking into account monitoring parameters of the radio environment such as node/ infrastructure discovery, identification of candidate nodes and identification of spectrum opportunities from the infrastructure side. The output of the suitability determination phase could trigger the request for the creation of the ON along with the set of candidate solutions. The creation phase evaluates the data received from the suitability determination and continues with the selection of the participant nodes, the selection of links / spectrum /RATs and the routes. As a result, an ON can be established. Furthermore, the post-creation stage deals with the monitoring and possible reconfiguration procedures if QoS levels tend to drop significantly. For the monitoring and reconfiguration of the ON, the responsibility lies in the maintenance phase. Finally, the termination phase is responsible for handling termination procedures when the ON is no longer needed.

Challenges of each ON phase have also been identified. To that respect, the suitability determination phase has to deal effectively with the identification of opportunities with respect to nodes as the operator needs to be aware (by discovery procedures) of the nodes' related information such as capabilities, energy level, available interfaces etc. Also, the identification of opportunities with respect to potential radio paths is important as ONs will operate in a dynamically changing environment, where inter-ON interference may be possible and finally the suitability determination phase has to be capable of assessing potential gains from the possible formation of an ON. These gains may be achieved through the application provisioning with a fair QoS, the efficient spectrum utilization and the lower transmission powers, which can lead to lower energy consumption for terminals and operator's BS.

On the other hand, the challenges of the creation phase are focused on the development of mechanisms that will lead to the inter-connection of selected nodes, the optimization of routes and the usage of the selected spectrum followed by the signalling procedure establishing the ON. Further on, in the maintenance phase, monitoring mechanisms have to be introduced in order to monitor nodes, spectrum, policies, QoS and decide whether it is suitable to proceed to a reconfiguration of the ON. Finally, main challenges of the termination phase are the introduction of mechanisms which will handle effectively the release of the resources used by the ON and the handover to infrastructure for those services that need to survive ON's termination.

4. FUNCTIONAL ARCHITECTURE OVERVIEW

The management and control functionalities for ONs shall be an addition to existing functionalities in today's networks. Thus, the proposed Function Architecture (FA) is an extension of an existing architecture, namely the "Functional Architecture for the Management and Control of Reconfigurable Radio Systems" as defined by ETSI in the TR 102 682 [2], [3]. The resulting FA for the Management and Control of Reconfigurable Radio Systems as well as for the Management and Control of infrastructure governed ONs is shown in Fig. 2 [4]. Main additions are the functional entities of the Cognitive Management System for the Coordination of the Infrastructure (CSCI) and the Cognitive Management System for the Opportunistic Network (CMON). For the efficient coordination of these two CMSs, control channels would be introduced as an evolution of the Cognitive Pilot Channel (CPC) concept which is analyzed in [5].

4.1 Cognitive Management System for the Coordination of the Infrastructure (CSCI)

The CSCI is located both in the operator's infrastructure and the terminal side. Main responsibilities of the CSCI are the coordination with the infrastructure even when infrastructure is not necessarily part of the ON (e.g., opportunistic ad hoc networking business scenario previously described) and the detection of situations where an ON may be useful in conjunction with the ON suitability determination phase.

Generally, the CSCI involves context awareness, operator policy derivation and management, and profile management, which provide the input to decision making logic for ON suitability determination. Cognition capabilities within CSCI are built upon a knowledge management functionality which complements previously mentioned policy and context information with additional data acquired through learning processes and observation from previous decisions outcomes in order to improve future decision-making. In case that the conditions (dictated by the policy engine) or the potential gains by the operation of the ON are satisfied, the CSCI will come up with an ON blueprint design and pass it to the CMON for the execution.

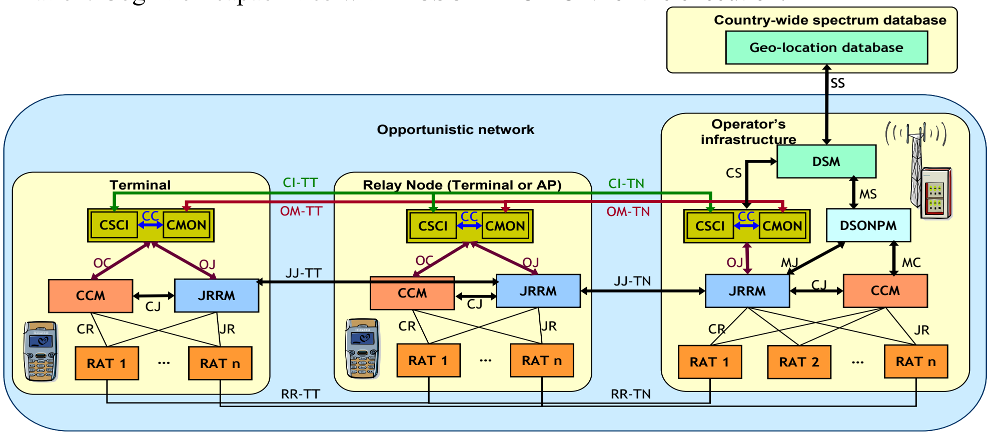

Figure 2 – Functional Architecture for the Management and Control of infrastructure governed Opportunistic Networks as an evolution of the ETSI/E^3 FA.

4.2 Cognitive Management System for the Opportunistic Network (CMON)

The CMON is also located in both the operator's infrastructure and the terminal side. The CMON is responsible for the coordination of the accepted nodes to the ON, the execution of the ON creation, the ON maintenance and finally the decision and execution of the ON termination.

Generally, the CMON involves context awareness, policy acquisition and profile management, which provide the input to the decision making logic for ON creation, maintenance and termination. Like CSCI, CMON also relies on cognition features enabled by a knowledge management functionality in order to make better decisions in the future, according to the learned results from the operation of ONs. The contextual and performance parameters collected by the CMON during the life cycle of an ON are used for learning and improvement of its management functions/logic. Equally these data are passed onto the CSCI for improving the governance functions/logic hosted by the CSCI.

5. CONTROL CHANNELS

The cooperation of the two CMSs spread over terminals and operator's infrastructure will require existence of well-defined control messages and protocols/ channels for their exchange. That is the role of the Control Channels for the Cooperation of the Cognitive Management Systems (C^{4}MS). C^{4}MS is introduced in order to enable the necessary signalling between CSCI and CMON functional entities. The C^{4}MS can be seen as a combination and extension of the CPC concept [5] and the Cognitive Control Radio (CCR) concept as described in [6]. The CPC will be the basis for the coordination of the infrastructure with the ONs. It is defined as a channel (logical or physical) which conveys the elements of necessary information facilitating the operations of Cognitive Radio Systems and can be seen as an enabler for providing information from the network to the terminals, e.g., frequency bands, available RATs, and spectrum usage policies. The CCR will be the basis for the exchange of cognition-related information between the peer nodes of the ON. The proposed channels themselves are not cognitive, but they enable the cognitive management.

Based on Fig. 2, the interfaces which are involved in the C^{4}MS are the CI (i.e. the interface between CSCI instances), the OM (i.e. the interface between CMON instances) and the CC (i.e. the interface between the CSCI and CMON). Fig. 3 illustrates the potential C^{4}MS information flows between the CSCI and CMON entities along with the involved interfaces.

5.1 The CI (Coordination with the Infrastructure) interface

The CI interface is located between different CSCI-instances. It is used by the infrastructure network to inform terminals (or other infrastructure network elements) about the suitability of an ON and to provide context and policy information which are needed for the later creation and maintenance of the ON. Via this interface, the network can also collect context information from the terminals to enable the ON suitability determination.

The CI interface can be split between the CI-TT interface connecting the CSCI instances of two terminals, the CI-TN interface connecting the CSCI in a terminal with the CSCI on Network side and the CI-NN interface connecting the CSCI instances of two network entities.

5.2 The OM (Opportunistic Management) interface

The OM interface is located between different CMON-instances. Via this interface, nodes can first negotiate about the creation of an ON. During the negotiation, node capabilities and user preferences can be exchanged and the QoS capabilities of an ON can be negotiated. After the negotiation, this interface is also used for the exchange of ON-creation, ON-maintenance and ON-release messages.

The OM interface can be split between the OM-TT interface connecting the CMON instances of two terminals, the OM-TN interface connecting the CMON in a terminal with the CMON on infrastructure side and the OM-NN interface connecting the CMON instances of two network entities.

5.3 The CC interface

The CC interface connects the CSCI in a node with the CMON in the same node. This interface is used e.g. to send a trigger for the creation of an ON from the CSCI to the CMON and to provide information about the resources which can be used by the ON.

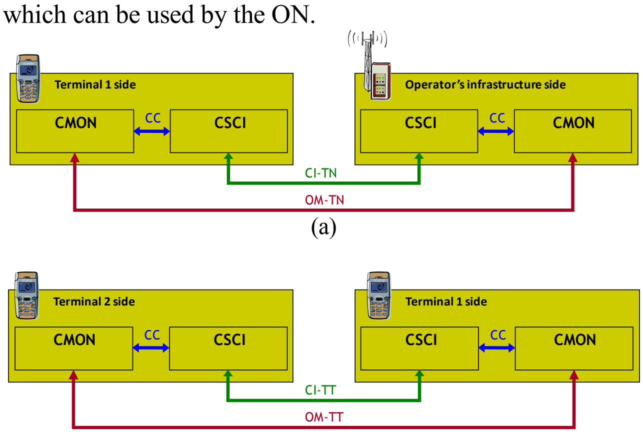

Figure 3 – C^{4}MS information flow (a) between operator's infrastructure and terminals, (b) between terminals.

5.4 Indicative message exchange through C^{4}MS

Messages are being exchanged through CSCIs and CMONs in each phase of the ON lifecycle. Considering as a reference the opportunistic coverage extension business scenario pointed out in Section 2, ‚as soon as a user's equipment (i.e. UE#1 in Fig.4) is out of the coverage of the infrastructure and no broadcast signals or beacons are received, the CSCI in that UE decides to initiate the ON suitability determination phase.

As a result, the UE#1 starts a discovery procedure to know about possible neighbouring terminals. This may be e.g. done by sending probe requests or by listening to beacons from neighbouring devices. When other UEs that support ONs are discovered in the vicinity and the CSCI in UE#1 decides that an ON may be suitable through e.g., UE#2, the Create_ON with other UE and network infrastructure BS (e.g. BS#1) message is transmitted from the CSCI of UE#1 to the CMON of UE#1 via the CC interface. Afterwards, an ON_Negotiation.Request including the capabilities and requirements from UE#1 is sent from UE#1 to UE#2 via the OM-TT, while UE#2 adds its own context information to the ON_Negotiation.Request and sends this message to BS#1 via the OM-TN interface. Inside BS#1, the CMON coordinates with the CSCI via the CC interface in order to provide additional information from the infrastructure to the negotiation procedure. As soon as the BS#1 evaluates the ON_Negotiation.Request sends back an ON_Negotiation.Answer including a list of nodes (e.g. UE#1, UE#2 and BS#1) which should form the ON via the OM-TN interface. The ON_Negotiation.Answer is forwarded by UE#2 to UE#1 via the OM-TT interface. From the negotiation procedure, the UE#1 has now all relevant information from the involved nodes.

Further on, the ON_Creation.Request is sent from the CMON in UE#1 to the CMON in UE#2 via the OM-TT. The ON_Creation.Request is then forwarded to BS#1 via OM-TN and the BS#1 sends back an ON_Creation.Answer indicating that it is now included in the ON via the OM-TN. The UE#2 forwards via the OM-TT the ON_Creation.Answer with an additional indication that UE#2 is now also part of the ON to UE#1. After authentication and registration signalling, which is not part of the C^{4}MS, the application session starts. As soon as the application session has ended, the CMON determines that the ON is no longer needed and an ON_Release.Request is sent from UE#1 to UE#2 via OM-TT interface. The termination phase is then initiated. UE#2 forwards the ON_Release.Request to BS#1 via OM-TN interface and BS#1 answers back via the OM-TN that the ON can be released. In turn, UE#2 forwards the ON_Release.Answer to BS#1 via the OM-TT interface.

Of course it is worth mentioning that, during the ON phases plenty of other messages are transmitted via the signalling channels, but these messages are between entities such as the Joint Radio Resource Management (JRRM) or the RAT. To that respect, these messages are not considered as part of the C^{4}MS approach because of the fact that they do not involve communication or signalling between CSCIs and CMONs.

6. BUSINESS BENEFITS

The proposed approach is expected to result in substantial benefits for different stakeholders such as network operators, end-users and service/ content providers. Specifically, the network operators will benefit from the coverage and capacity extension of their network as well as from the offloading potential. Moreover, sometimes traffic congestion problems arise in the backhaul network rather than in the RAN nodes, due to an imperfect planning and dimensioning, and the funnelling effect of backhaul connections. Thus, ONs can provide a solution to this aspect. Network operators can also benefit from an optimal (from resource efficiency point of view) support of localized and temporary applications, based on social networks and other communities.

The end-users on the other hand, can benefit from better QoS, and social-networking enabled services, while the service/ content providers can provide localized services to a geographically limited area or to a limited time span. Also, they can provide services that are restricted to a limited number of users and may communicate among them with a smart usage of infrastructure resources. Indicative examples are Virtual Private Network (VPN) or trunking services.

7. CONCLUDING REMARKS AND FUTURE WORK

Core objective of this work is the exploitation of cognitive control channels for the cooperation of cognitive management systems in the context of ONs and composite wireless infrastructures. Specifically, ONs pose new challenges on the requirements on the information flow which can be addressed through the introduction of C^4MS. C^4MS cooperates with the new ON-based proposed entities, the CSCI and the CMON. To that respect, three new interfaces CI, OM and CC between CSCIs and CMONs functional entities are defined and explained. As multiple instances of CSCI and CMON entities are to be distributed over terminals and infrastructure nodes, a further distinction is made in each interface according to the involved communication endpoints. As a result, interfaces between CSCI entities (CI) and between CMON entities (OM) are further split attending to interactions between terminals, between terminals and operator's infrastructure and between different operator's infrastructure nodes.

Finally, specific messages which are exchanged through the C^4MS, as well as their sequence during the ON lifecycle (from suitability determination and actual creation to termination) are displayed and explained, in order to emphasize the new aspects of the proposed control channels. Future steps include further exploitation of the proposed control channels in order to enhance control signalling and enable efficient coordination between the CSCI and CMON.

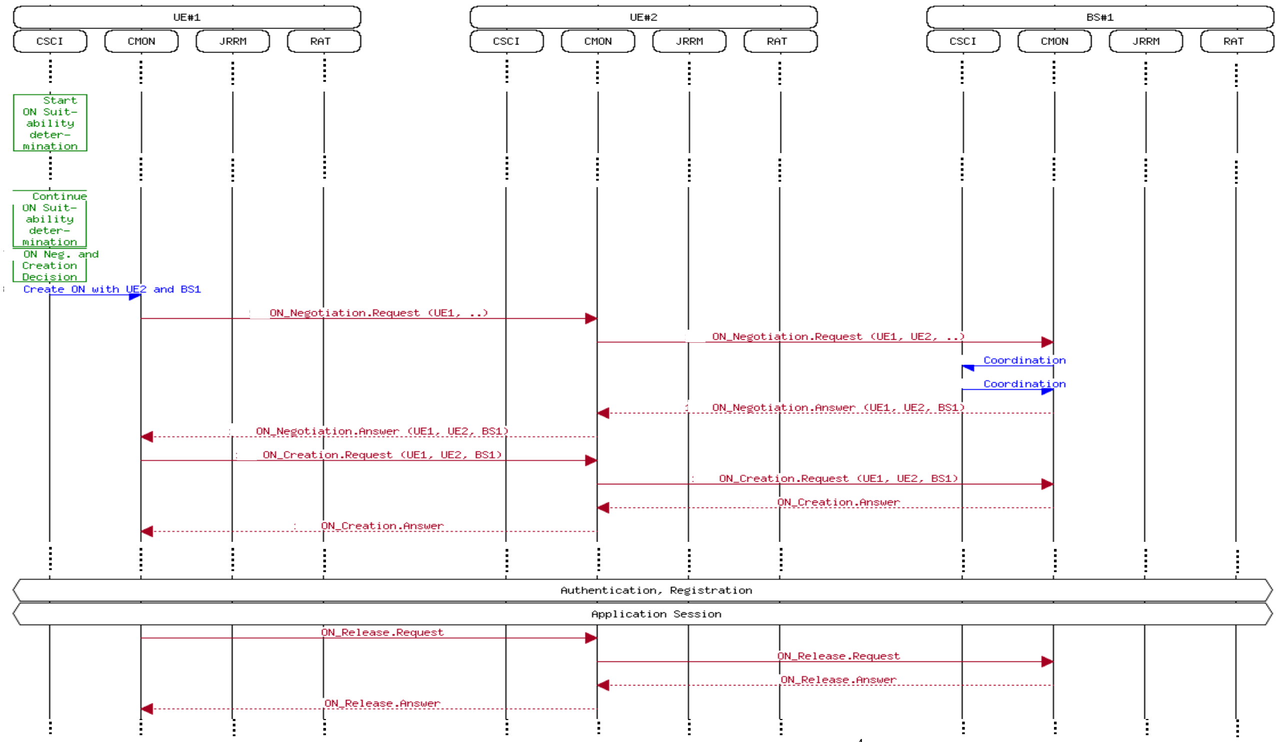

Figure 4 – Indicative message exchange through C^4MS.

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REFERENCES

[1] OneFIT Deliverable D2.1 "Business scenarios, technical challenges and system requirements", October 2010

[2] ETSI, TR 102.682 "Functional Architecture for the Management and Control of Reconfigurable Radio Systems (RRS)"

[3] ICT-2007-216248 End-to-End Efficiency (E3) Project, https://ict-e3.eu/

[4] OneFIT Deliverable D2.2 "Functional and system architecture", February 2011

[5] ETSI, TR 102.683 "Reconfigurable Radio Systems (RRS) -Cognitive Pilot Channel (CPC)"

[6] E^3 Deliverable D4.4 "Final solution description for autonomous CR functionalities", September 2009