Signaling Load Evaluations for Policy-Driven Cognitive Management Architectures

Kostas Tsagkaris, M. Akezidou, A. Galani, and P. Demestichas

University of Piraeus, Department of Digital Systems, Piraeus, Greece
`{ktsagk,akezidou,agalani,pdemest}@unipi.gr`

Abstract. Future networks will need to accommodate a significantly augmented user demand, mainly stemming from the wireless and mobile domains. This will stress network operators for developing mechanisms to confront the challenges and to leverage the opportunities posed by such a versatile radio environment. In particular, the situation calls for adaptive and flexible management paradigms that are able to dynamically manage network elements and terminals thus ensuring the great availability and efficient usage of spectrum and other radio resources. Framed within the above, this paper considers a cognitive management architecture, which is destined to the optimized management of future wireless networks and terminals operating in versatile radio environments and presents a performance evaluation methodology, which was set up for measuring the signaling loads that the operation of the architecture will bring in to the managed network.

Keywords: Cognitive management architecture, Functional entities, ASN.1, Signaling load.

1 Introduction

Future wireless networks will exhibit great levels of complexity and heterogeneity as a result of the (co-)existence of multiple and different kinds of radio access networks, technologies and the advent of new demanding user applications. Moreover, the introduction of flexible spectrum management concept and the adoption of cognitive capabilities to both networks and terminals, seem to be an efficacious response to this accrued complexity as well as a powerful enabler for the accomplishment of both users' and operators' goals. Therefore, the efficient operation of future wireless networks necessitates significant alterations in the way they are managed and call for the adoption and deployment of innovative and scalable management architectures. Such advanced, cognitive management architecture is the subject of this work. The adjective "cognitive" is used here to describe both the ability to operate in different spectrum bands in a dynamic and flexible manner and the possession of some intelligent processing and decision making ability e.g. based on learning.

In particular, the focus of this paper is placed on evaluating the signaling loads, with which the considered cognitive management architecture will burden the network that it manages. First, an evaluation methodology that takes into account and

I. Tomkos et al. (Eds.): BROADNETS 2010, LNICST 66, pp. 213–225, 2012.

analyzes the information that should flow in the interfaces of the architecture is described and secondly and mainly, signaling loads are calculated in various test cases and after applying the above mentioned methodology into an indicative operation scenario. These results are expected to influence the deployment of the management architecture in both legacy and future networks.

Actually, this cognitive architecture falls in the wider scope of the E^3 project [8] and comprises a variant of the Functional Architecture (FA) that has been proposed Interestingly, the proposed architecture has been actually elaborated within the Working Group 3 (WG3) of the Reconfigurable Radio Systems Technical Committee (RRS TC) [2][3]. It should be also mentioned that a relevant functional architecture, which proposes a policy-driven optimization of radio resource usage in heterogeneous wireless networks has been standardized within IEEE and in particular by the P1900.4 Working Group [9]. The elaborated architecture comprises a policy-driven management architecture that amalgamates features of the mentioned works.

Accordingly, the rest of this paper is structured as follows. In Section 2, the considered management architecture, the role and the operation of its functional entities are revisited. Section 3 describes the methodological steps we have followed in order to perform the signaling load evaluations, whereas results from the application of this methodology into indicative test cases are given in Section 4. Finally, the paper is concluded in Section 5.

2 Cognitive Management Architecture

The proposed cognitive management architecture consists of four functional entities that cater for different operational needs and goals and exchange proper information via the interfaces as shown in Fig. 1: (i) the Dynamic Spectrum Management (DSM) (ii) the Dynamic, Self-organizing Planning and Management (DSNPM), (iii) the Joint Radio Resource Management (JRRM), and (iv) the Configuration Control Module (CCM). The functional entities of the architecture may actually span across various network elements, access and core, and MTs, as well. What follows is a brief revisiting of the more thorough description of these functional, management entities given in [1][2].

2.1 Dynamic Spectrum Management (DSM)

The functionality of DSM concerns the spectrum management in medium and long term. Specifically, DSM is responsible: a) for the assignment of operating frequencies to RATs in specific time periods and specific geographical areas and derivation of corresponding directives for DSNPM operation (sent via MS interface), according with constraints for predefined spectrum assignment rules or spectrum utilization metrics and b) for the detection of long-term available frequency bands for sharing or trading with other network operators (NOs).

2.2 Dynamic, Self-organising Planning and Management (DSNPM)

DSNPM's responsibilities include (i) the management and reconfiguration of network elements, (ii) the detection of new elements, (iii) the provision of the essential configuration information of the managed RATs to MTs, for initial network connection, (iv) the derivation of policies for the managed MTs, (v) and the calculation of spectrum utilization metrics. DSNPM's objectives are accomplished by applying optimization functionality, enhanced with learning capabilities, thus strengthening the characterization of the architecture as "cognitive", based on received context and profiles information.

2.3 Joint Radio Resource Management (JRRM)

JRRM is distributed among network (n-JRRM) and MTs (m-JRRM) and is mainly responsible for jointly managing the radio resources belonging to heterogeneous RATs. It performs functionalities such as MT access selection based on requested QoS, radio conditions, user preferences and network policies, neighborhood Information provision for efficient discovery of available accesses, as well as QoS/bandwidth allocation/admission control.

2.4 Configuration Control Module (CCM)

CCM implements the decisions of DSNPM and JRRM in network elements and JRRM in MTs. Specifically, CCM, for both network elements (n-CCM) and MTs (m-CCM), is responsible for the implementation of all the stages of reconfiguration and all the possible related actions (e.g. software download), as well as the provision of the relevant information about the configuration capabilities of the network element or the MT, to the corresponding entity (DSNPM for network elements and m-JRRM for MTs).

3 Signaling Load Evaluation Approach

In this section, we analyze the methodology we have followed in order to evaluate the signaling loads induced in the considered cognitive network management architecture. It must be noted that this analysis is sound only in the case that the described functional entities reside in distinct network entities. Such an attempt to map these entities to the 3GPP LTE-SAE and its respective network interfaces, has been made for instance in [6].

Our purpose is to calculate the signaling loads in the interfaces of the architecture by characterizing the signaling loads that are needed to carry out a set of elementary procedures. Accordingly, the interfaces are first defined in terms of elementary procedures, which is a traditional way used for signaling and protocol analysis of interfaces, and is also the approach that has been followed within E^3 project [4] and inspired this study. Every single operation/scenario in the considered architecture is supposed to be built from a set of elementary procedures taking place in the interfaces of the architecture, thus the term "elementary".

Without loss of generality and in order to demonstrate our method, we follow a scenario-driven approach, that is an analysis based on its application to a specific scenario, a so-called "New spectrum assignment" scenario.

The scenario is described by the Message Sequence Chart (MSC) in Fig. 2. Generally speaking, the scenario considers the case that new frequencies are disposed by a regulator to NOs. The NO, the network of whom is used as reference in the sequel for the description of the operational scenario, requests new frequencies for specific Radio Access Technologies (RATs).

In this scenario, the following procedures have been determined with respect to the interfaces in which they appear. Each procedure is assigned with an index $i=1,2,3...$ (see Table 1 for the value set of i). Moreover, the current methodology also includes the identification of the messages that constitute each of the defined procedures, due to the fact of lacking of a standardized architecture to work with (see Fig. 2).

The next important step is to study and describe the type and number of parameters that each of the messages must convey for satisfying the purpose for which the architecture has been designed for. In order to define the parameters per message, we followed an approach similar to the one we conducted in our studies in [9] for the 1900.4 standardized architecture. These parameters were determined mainly based on the authors' view and experience, albeit in alignment with the respective functionality in each of the functional entities i.e. with respect to the input data that is required for a function to be properly executed within an entity and to the output that the latter is expected to produce.

In the next step, we proceed with the calculation of the length of every message which actually derives as a summation of its constituent parameters' length values. In order to describe the syntax of the messages conveyed between the interfaces of the architecture in a formal way, thus facilitating calculations, we have used Abstract Syntax Notation One (ASN.1) [12]. ASN.1 is a standardised specification language that describes data structures for representing, encoding, transmitting, and decoding data. The part of representation of date concerns what is well known as "abstract syntax". The rest part concerns the so called "transfer syntax". Specifically, in the same standard, i.e. [12], a set of ASN.1 encoding rules, which describe various ways according to which the formatted data is transformed into bit-stream prior to being transmitted into the network, are also provided. These rules include among others, Basic Encoding Rules (BER), Canonical Encoding Rules (CER), Distinguished Encoding Rules (DER), XML Encoding Rules (XER), and Packed Encoding Rules (PER) [13][14][15] etc. The calculations presented later in this work have been conducted by assuming the Basic Encoding Rules (BER) [13]. Although this may not necessarily comprise the best choice to make, it is definitely in line with the primary objective of this work.

It should be also made clear that our intention is neither to define any management protocol nor to designate any possible encapsulation e.g. with respect to the transport part, but just to define messages and their respective parameters and an anticipated length as needed for our analysis. Accordingly, the calculations have been made by taking into account only the encoding overheads as a result of assuming the use of BER for encoding only the defined parameters and not any management protocol (i.e. in terms of Tag-Length-Value (TLV) encoding) and excluding any overheads due to the selection of a specific transport protocol.

An example of such calculation follows. We consider the *Spectrum Usage* procedure which takes place in MS interface by exchanging messages used by DSM in order to request and receive information for the current spectrum usage from DSNPM namely, SpectrumUsageRequest and SpectrumUsageResponse messages (see Table 2). In Table 2 the calculated bytes are given in two separate columns. The first column corresponds to the case that assumes BER-based encoding and the second assumes no encoding at all. As it can be observed, the loads obey some generic formulas comprising a combination of both variable and constant parts. The variable part reveals dependency of the signaling loads upon parameters, which are either specific to each procedure e.g. number of requested frequency bands, denoted as f in current message or more generic ones such as the number of MTs in the managed area.

The derived values correspond to the actual size of the parameters actually conveyed and can be assumed both with BER-based encoding and without encoding at all. The values are supposed to derive after some preliminary dimensioning work we have conducted for defining the limits of each parameter.

Last but not least, special care was taken for the case of the message used to convey the policy(-ies) from the network to mobile terminal(s) side. The term “policies” here refers to radio resource selection policies, which act as directives with the scope to assist MTs to achieve best connectivity. Policies can be characterized as the ability to provide the terminals with access selection information on which of the available accesses to use for a session. Then, MTs take into consideration those policies and finally they decide for their behavior based on their own strategy, being at the same time in compliance with the rules of DSNPM. The policies are formatted as rules of the well known Event-Condition-Action (ECA) type. Once again, the analysis for the formalization of the policy related message is based on ASN.1. In particular, we have been based on the ASN.1 formation of the RRS policies which are part of the in the information model proposed in 1900.4 standard [10][9]. That is to say a RRS policy is actually a statement of the following type: ON <Event> IF <Condition> THEN <Action> where traditionally, the event part specifies the signal that triggers the invocation of the rule, the condition part is a logical test that, if satisfied or evaluates to true, causes the action to be carried out, the action part consists of the actual execution of the modification/update on the resources.

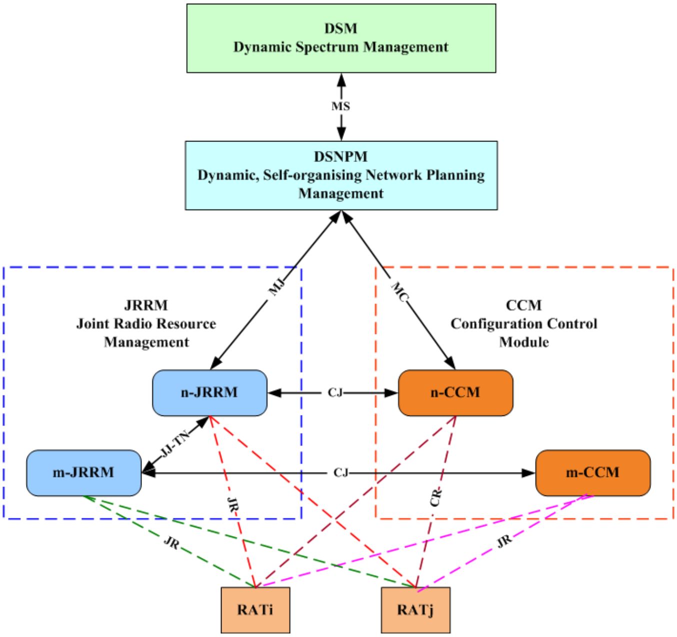


Fig. 1. Overview of Management Architecture

Table 1. Interfaces, procedures and parameters

Interface	*Procedure i*	*Short Description*	*Messages*
MS (DSM – DSNPM)	1	Spectrum Usage	*SpecrtumUsageRequest* *SpecrtumUsageResponse*
	2	Spectrum Assignment	*SpectrumAssignmentRequest*
MJ (DSNPM– n-JRRM)	3	Context Request	*ContextInfoRequest* *ContextInfoResponse*
JR (n-JRRM– RAT)	4	Configuration Request	*Context&ConfigurationRequest* *Context&ConfigurationResponse*
MC (DSNPM – n-CCM)	5	Reconfiguration Request	*ReconfigurationRequest*
	6	Reconfiguration Execution	*ReconfigurationExecutionNotification*
JJ-TN (n-JRRM– m-JRRM)	7	Status Info	*StatusInfoRequest* *StatusInfoResponse*
	8	Policy Derivation	*Policy*

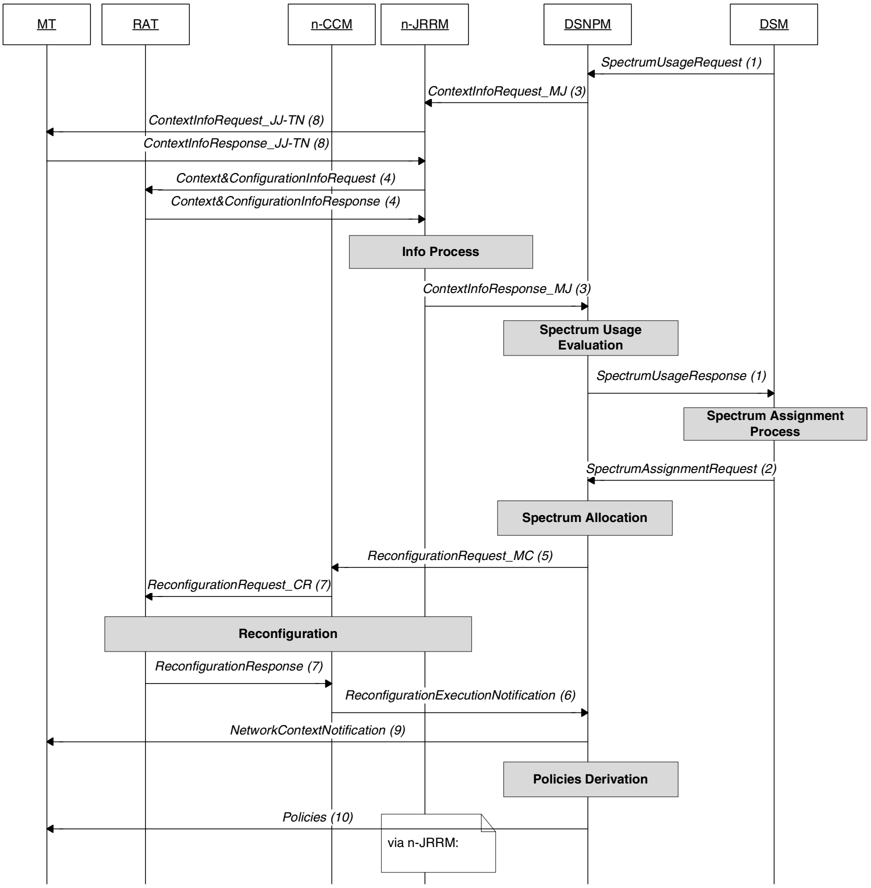
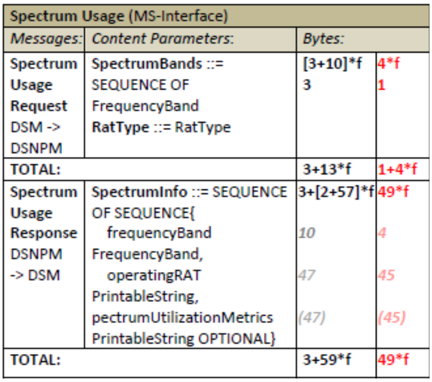


Fig. 2. Message sequence chart for the considered "New spectrum assignment" scenario

Table 2. Spectrum Usage Procedure (MS-Interface) (where *f* is the number of Frequency Bands)



Spectrum Usage (MS-Interface)			
Messages:	*Content Parameters:*	*Bytes:*	
Spectrum Usage Request DSM -> DSNPM	**SpectrumBands** ::= SEQUENCE OF FrequencyBand **RatType** ::= RatType	[3+10]*f 3	4*f 1
TOTAL:		3+13*f	1+4*f
Spectrum Usage Response DSNPM -> DSM	**SpectrumInfo** ::= SEQUENCE OF SEQUENCE{ frequencyBand FrequencyBand, operatingRAT PrintableString, pectrumUtilizationMetrics PrintableString OPTIONAL}	3+[2+57]*f *10* *47* *(47)*	49*f *4* *45* *(45)*
TOTAL:		3+59*f	49*f

4 Test Cases and Results

This section focuses on the actual performance evaluation part, which is used to provide some evidence on the signaling loads associated with the operation of the examined cognitive network management architecture in both the wired and the wireless (air) interfaces of the network.

4.1 Test Case 1: Generic Evaluations

In the first test case we proceed with evaluations of the signaling load by assuming a generic situation with input parameters as summarized in Table 3.

The total produced signaling load is depicted in Fig. 3. The volume at which the air and core parts contribute to this total load is also depicted in Fig. 4. In both figures, the results are depicted when assuming BER-based encoding and when not using encoding at all. In addition, the load per procedure is depicted in Fig. 5, whereas Fig. 6 depicts the signaling load as it appears in each of the interfaces of the architecture. Once again, the results are depicted for both BER-encoded and not encoded cases.

Table 3. Input parameter

Number of active mobile terminals	50
Number of FBSs	3
Number of RATs	2

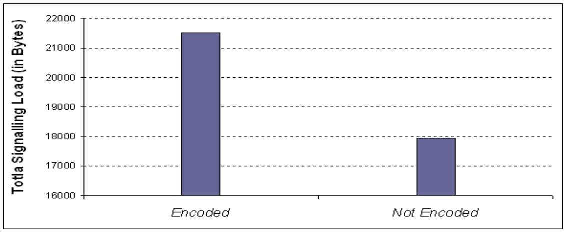


Fig. 3. Total produced signaling load (in bytes) – Test case 1

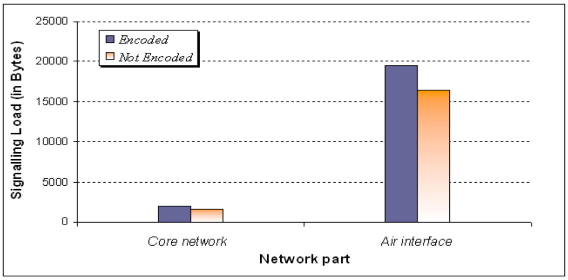


Fig. 4. Air and core signaling loads (in bytes) – Test case 1

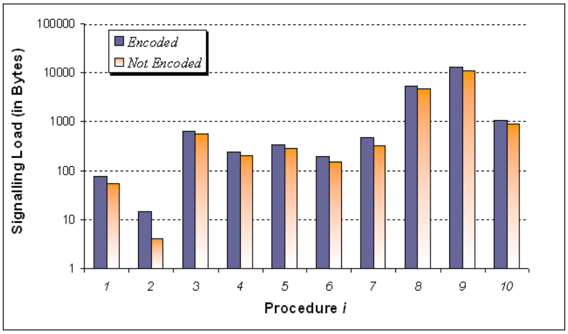


Fig. 5. Signaling load per procedure – Test case 1

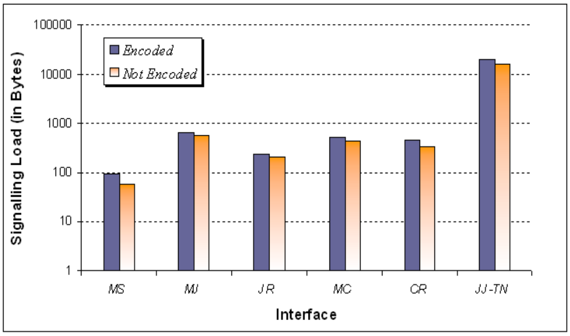


Fig. 6. Signaling load per interface – Test case 1

4.2 Test Case 2: Scalability Issues

A second test case has been set up in order to showcase scalability issues of the architecture. In particular, the goal is to show how the signaling load evolves in function to the number of RATs, of FBSs and of MTs in the managed network. Fig. 7 shows the evolution of signaling load with respect to the number of RATs that are participating in the operational scenario. In a similar way, Fig. 8 and Fig. 9 show the evolution of signaling load with respect to the number of FBSs and MTs in the managed area respectively considered in the operational scenario.

4.3 Test Case 3: Signaling Delays

In this test case we experiment with the signaling delays into the managed network. In particular, the objective is to give some evidence on the delay that the management operations will suffer as a result of the transmission of the produced management signaling information This delay is derived after dividing the volume of signaling

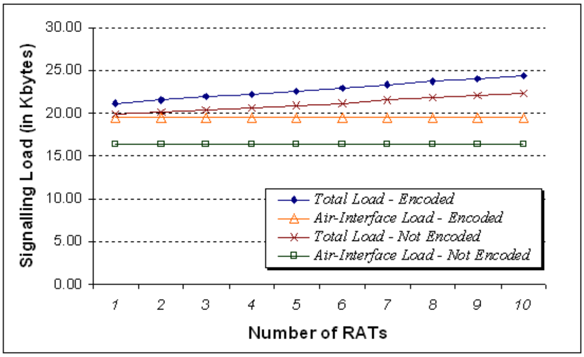


Fig. 7. Evolution of signaling load vs number of RATs – Test case 2

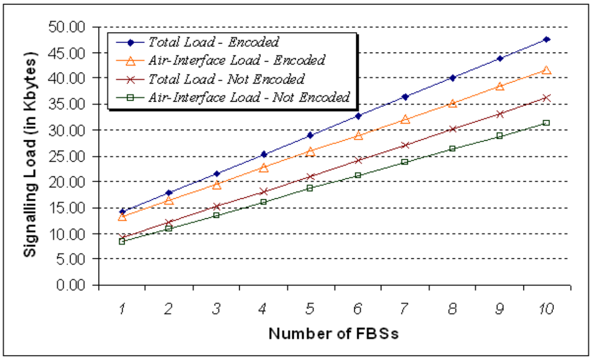


Fig. 8. Evolution of signaling load vs number of FBSs – Test case 2

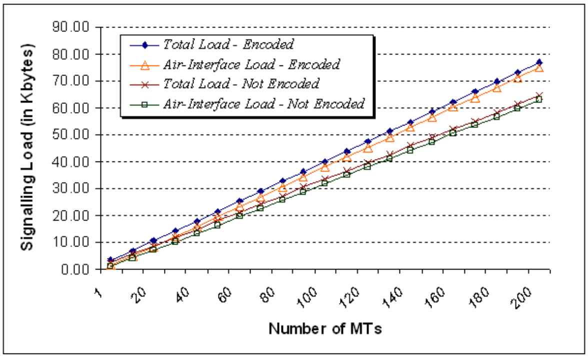


Fig. 9. Evolution of signaling load vs number of MTs – Test case 2

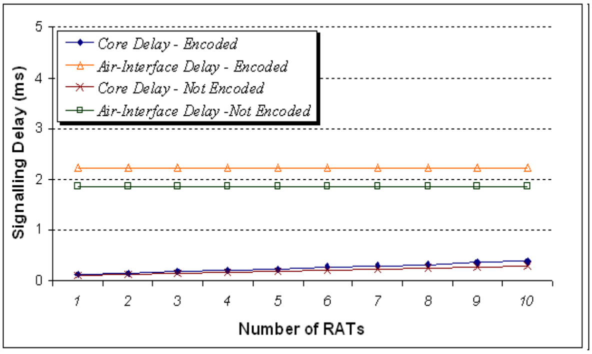


Fig. 10. Evolution of signaling delay vs number of RATs – Test case 3

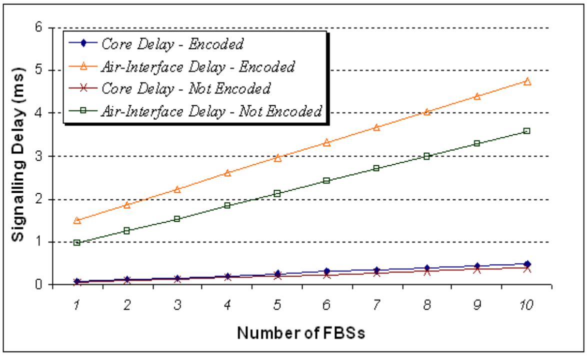


Fig. 11. Evolution of signaling delay vs number of FBSs – Test case 3

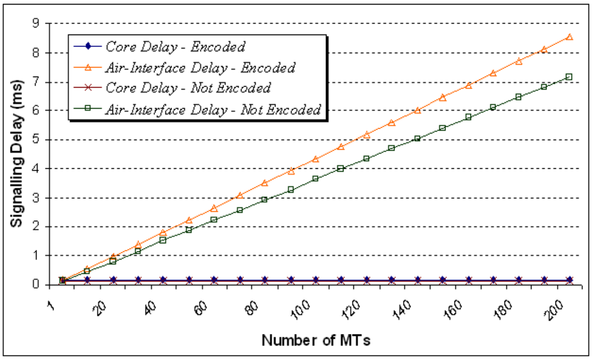


Fig. 12. Evolution of signaling delay vs number of MTs – Test case 3

load measured in each of the functional interfaces, with the capacity of the actual network link to which the specific interface may be implemented. For instance, the signaling load in the interface between DSNPM and n-JRRM, which could be mapped to the S1-MME interface in 3GPP LTE/SAE [6][7], could be conveyed by variant network, wired link types exhibiting different capabilities in terms of offered capacity. The evolution of signaling delays (in ms) with respect to the number of RATs, FBSs and MTs are shown in Fig. 10, Fig. 11 and Fig. 12. For these measurements we have assumed wired and wireless links offering 100Mbps and 70Mbps of capacity, respectively.

5 Conclusion and Future Work

The heterogeneity of future wireless networks requires a dramatic change in the current management operations. Framed within this statement, this paper considers a cognitive management architecture, which is destined to the optimized spectrum and other resource management of future wireless networks operating in versatile radio environments. In particular, the paper presents a performance evaluation methodology, which was set up for measuring the signaling loads that the operation of the architecture will bring in to the managed network. Results that were obtained from the application of the methodology to an indicative scenario were also presented and analyzed and show that the management architecture will not aggravate the overall network operation.

This paper will act as a solid basis for further investigation. First, a more complete set of scenarios will be studied and evaluated. Second, the periodicity of specific procedures-messages will be identified since it will give insight on the expected load that will regularly appear in the managed network as part of the rest legacy management/control procedures e.g. call setup, mobility etc. when designing and/or dimensioning the network. Last but not least, a mapping to existing transport protocols currently used for signaling purposes is also of high importance and will be subject to our future studies.

Acknowledgements. This work was performed in the project E³ (www.ict-e3.eu) which has received research funding from the Community's Seventh Framework programme. The work is evolved in the context of UniverSelf and OneFIT (www.ict-onefit.eu <http://www.ict-onefit.eu/>) Projects. 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.

References

1. ETSI, TC RRS, Reconfigurable Radio Systems (RRS); Functional Architecture (FA) for the Management and the Control of Reconfigurable Radio Systems, Technical Report 102 682 v1.1.1 (July 2009)

2. Dimitrakopoulos, G., Demestichas, P., Saatsakis, A., Tsagkaris, K., Galani, A., Gebert, J., Nolte, K.: Functional Architecture for the Management and Control of Reconfigurable Radio Systems. IEEE Vehicular Technology Magazine 4(1), 42–48 (2009)
3. ETSI, TC RRS, Reconfigurable Radio Systems (RRS); Functional Architecture (FA) for the Management and the Control of Reconfigurable Radio Systems, Technical Report 102 682 v1.1.1 (July 2009)
4. E^3 Project Deliverable D2.3 Architecture, Information Model and Reference Points, Assessment Framework, Platform Independent Programmable Interfaces, Public dissemination (September 2009)
5. 3GPP TR 25.913 v9.0.0, Requirements for Evolved UTRA (E-UTRA) and Evolved UTRAN (E-UTRAN) (Release 9) (December 2009)
6. Kaloxylos, A., Rosowski, T., Tsagkaris, K., Gebert, J., Bogenfeld, E., Magdalinos, P., Galani, A., Nolte, K.: The E3 architecture for future cognitive mobile networks. In: Proc. 20th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2009), Tokyo, Japan, September 13-16 (2009)
7. Nolte, K., Kaloxylos, A., Tsagkaris, K., Rosowski, T., Stamatelatos, M., Galani, A., Bogenfeld, E., Magdalinos, P., Tiemann, J., Arnold, P., Gebert, J., Von-Hugo, D., Alonistioti, N., Demestichas, P., Koenig, W.: The E3 architecture: Enabling future cellular networks with cognitıve and self-x capabilities. in revision (minor) International Journal of Network Management, Wiley
8. FP7-EC ICT Project End-to-End Efficiency (E^3), `https://www.ict-e3.eu`
9. Buljore, S., Harada, H., Houze, P., Tsagkaris, K., Holland, O., Filin, S., Farnham, T., Nolte, K., Ivanov, V.: Architecture and Enablers for Optimised Radio Resource usage: The IEEE P1900.4 Working Group. IEEE Communications Magazine 47(1), 122–129 (2009)
10. IEEE Std 1900.4^{TM}-2009, IEEE Standard for Architectural Building Blocks Enabling Network-Device Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Access Networks (January 2009)
11. Galani, A., Tsagkaris, K., Koutsouris, N., Demestichas, P.: Design and Assessment of Functional Architecture for Optimized Spectrum and Radio Resource Management in Heterogeneous Wireless Networks. International Journal of Network Management, Wiley (to appear)
12. ITU-T X.680: Information technology - Abstract Syntax Notation One (ASN.1): Specification of basic notation (2002)
13. ITU-T X.690: Information technology - Information technology – ASN.1 encoding rules: Specification of Basic Encoding Rules (BER), Canonical Encoding Rules (CER) and Distinguished Encoding Rules (DER) (2002)
14. ITU-T X.691: Information technology - Information technology – ASN.1 encoding rules: Specification of Packet Encoding Rules (PER) (2002)
15. ITU-T X.693: Information technology - Information technology – ASN.1 encoding rules: XML Encoding Rules (XER) (2001)