Virtualisation Platform for the introduction of cognitive systems in the Future Internet

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Abstract: The continuous evolution of wireless systems has deeply affected the expectations from the deployed infrastructures. The near future network environments need to support the smooth introduction of new networking technologies and devices. It is also very important to facilitate the provision of novel, sophisticated mobile applications at the desired quality levels, avoiding congestions and bottlenecks. Thus, future network infrastructures have to incorporate advanced cognitive management functionalities that will ensure the proper configuration of network elements and user devices and the proper load distribution, according to user and application requirements, context and policies. This paper presents the design and implementation of a service-oriented platform that is able to fulfil the above requirements, facilitating integration and enabling full interoperability between different legacy and emerging mobile and broadband wireless networks.

Keywords: Cognitive Systems, Future Internet, Heterogeneous Environment, Service Oriented Architecture, Virtualisation.

1. Introduction
The Future Internet is envisaged to encompass a great number of devices and networking technologies over which various applications will be provided. Devices may include several different types of equipment ranging from user devices such as phones, PCs, PDAs, networked home appliances to sensors, actuators and other perceptual devices. Networking technologies include a number of diverse options available today such as GSM, GPRS, UMTS, WLAN IEEE 802.11, WiMAX IEEE 802.16, xDSL, Fiber, etc [1][2]. New devices and access technologies will continue to emerge. Obviously, an important requirement for Future Internet systems is to be capable of efficiently addressing the complexity and heterogeneity of the hardware infrastructure, in terms of devices but also, most importantly in terms of networking technologies in order to accommodate several, legacy and emerging, mobile, wireless and broadband technologies in the same environment [3]-[8]. In order to tackle such complexity and cater for today’s wireless world needs, advanced management functionality needs to be introduced in wireless systems, which will enable optimum operation from end-to-end. A lot of research towards the realization of an efficient solution has focused on cognitive systems [7][8]. A cognitive system can be defined as a system that contains self-management functions for perceiving the present environment situation, identifying potential issues/problems and accordingly determining its configuration and behaviour. A very important feature of cognitive systems is the ability to learn and thus build knowledge that can be exploited in future decision making [9][10].
complementary, challenge to enable the realisation of the Future Internet is the development of virtualisation capabilities, i.e. mechanisms that will abstract the complexity of the (hardware and software) infrastructure, by enabling easy introduction of new components, and by facilitating their exploitation, through high-level interfaces (virtualisation). Such components may include network infrastructure elements, devices, self-x algorithms, cognitive management schemes, applications, etc. This paper addresses all the above challenges. Specifically, it presents a management platform that adheres to service-oriented computing principles, and which aims to enable the dynamic integration of a multiplicity of underlying hardware and software resources and ease their management. The paper is structured as follows: Section 2 presents aspects of related work. Section 3 outlines the main requirements for the realisation of viable Future Internet systems and presents the high level design of the platform, outlining the role and functionality of the platform services. Section 4 illustrates the platform’s operation while section 5 presents the current implementation of the platform. Finally, section 6 summarizes the key points of this paper.

2. Related Work

This section aims to provide an overview of selected related work to highlight the innovative aspects of the platform presented in this paper. Starting from previous work in the area of network and service management platforms for B3G wireless systems, in the last decade, a lot of effort has focused on the design and implementation of platforms that enable the complementary use of various access technologies and, to some extent, the co-operation between network operators in terms of load balancing in a composite radio environment [4]-[6]. This work constituted an important step in the direction of proving the feasibility of the co-existence and parallel use of heterogeneous wireless access technologies. More recent work in this direction, building on the previous outcomes, has focused on the realisation of adaptive, reconfigurable and cognitive networks. Since the term cognitive radio was first introduced by Mitola [9]-[10], a great deal of research has been performed in the area of cognitive systems. This work has naturally started from the design and specification of corresponding management platforms for cognitive systems. The IST project E2R [7] investigated the design of an architecture for end-to-end reconfigurable systems that exploited the use of cognition based methods for optimising usage of the available resources and heterogeneous network infrastructure. In [11] the technical requirements and engineering challenges of a cognitive platform for managing reconfigurable elements were addressed. A platform for cognitive networks as well as the requirements for a corresponding implementation were presented in [12]. A platform for cognitive resource management with the aim of enabling distributed cross layer optimization has also been proposed in [13]. On a more practical level, work in the context of cognitive radio networks and systems, has also focused on the implementation of platforms for conducting experiments related to dynamic spectrum access and management. An indicative platform of this type is described in [14], where a testbed, comprising software and hardware elements as well as spectrum dedicated for experimentation purposes, is presented in detail. A number of similar platforms for performing trials on dynamic spectrum management are available. In [15] a cognitive radio testbed that enables experimentation at the physical and link layer is presented. The proposed testbed facilitates the performance assessment of spectrum sensing schemes. In [16] a cognitive engine is described that employs essential cognitive functions of a radio such as awareness-processing, decision-making and learning. This is only a small sample of the research efforts and the derived results in the area of cognitive systems. Yet it is obvious that numerous schemes for co-operative, adaptive, reconfigurable and cognitive systems have been devised. The first steps towards the individual realisation and validation of such
schemes have been realised. The corresponding implemented platforms and test beds currently mainly focus on some aspects of cognitive systems, e.g. on dynamic spectrum management capabilities. As research in this area progresses, the need arises for a platform that can facilitate the integration of existing (software and hardware) solutions and of new, emerging cognitive schemes so as to assess and validate the full potential of cognitive systems. The contribution of this paper is in this direction. More specifically, this paper proposes a platform that facilitates the integration of various cognitive management schemes, abstracts the complexity of the underlying infrastructure and allows the addition, removal or enhancement of both hardware and software components in a dynamic manner. In terms of creating such agile platforms that abstract the complexity of the infrastructure similar concepts, such as [17] exist. However, these focus mostly on the integration of hardware components. The innovation of the platform presented in this paper is that it focuses on the integration of both hardware and software components. Moreover, in terms of software component the main focus is on self-x (-configuration, -management, -optimisation, -healing) and cognitive management functionalities.

3. Design Approach

3.1 Requirements

As was already introduced, in order to realize Future Internet systems, innovative and sophisticated means are required that will facilitate the integration of networking technologies and management schemes (cognitive, reconfigurable/ Software Defined Radio (SDR) and cooperative) as well as evolving technologies (including management functionalities/algorithms) and will allow for faster deployment of new services and applications. An imperative requirement is the openness of the solution that will allow for the introduction of new components and technologies and the removal or replacement of existing elements in a plug ‘n play fashion. This in turn calls for the abstraction of the complexity of the underlying hardware and software infrastructure through high-level interfaces. Service oriented computing is one of the most recent paradigms of distributed computing. In a service oriented world, as the name implies, everything revolves around services. Services are entities that can be described, discovered, used separately or combined with others to form composite services [18][19]. Therefore, service oriented computing inherently meets the requirements outlined in the previous and presents an excellent approach for building a platform that will integrate essential building blocks of Future Internet systems that can be reconfigured and re-assembled according to the current needs. The next sub-section provides a thorough description of the design of the management platform addressed in this paper.

![Figure 1: High-level design](image)
3.2 High Level Design

The platform combines mechanisms for the virtualisation of infrastructure elements (such as devices, networking technologies, sensors, intelligent appliances) and their efficient integration with cognitive management schemes. More specifically, regarding virtualisation every application, service, infrastructure element can be virtualised as a new set of services. Infrastructure elements can offer various services to composite services/applications. Services/applications can issue actions (e.g. reconfiguration services) towards the infrastructure through high-level interfaces. As regards cognitive management, the platform comprises various cognitive functionalities such as autonomous decision-making algorithms, information acquisition and knowledge management and sharing mechanisms.

A high-level view of the different building blocks of the virtualisation platform is presented in Figure 1. Each device/network element in the platform can provide a set of services. For example a Flexible Base Station (FBS) may provide a combination of a Context Service (i.e. Base station status), a Profile Service (i.e. Base station profile) and a Reconfiguration Service (i.e. Base station reconfiguration). In a similar manner services/applications may utilise other services. For example reasoning/decision making services are composite services that utilise Context, Profiles, Knowledge Management and Reconfiguration Services. A key feature of the proposed virtualisation platform is the support for dynamic development, composition, deployment and discovery of services so as to allow devices and services to advertise themselves and describe the capabilities and utilities these offer. Furthermore, service orchestration functionality is essential to ensure smooth interoperation of services and hardware elements, possibly stemming from different vendors.

Table 1: Analysis of platform service categories and mapping to phases of cognitive cycle

<table>
<thead>
<tr>
<th>Platform Services</th>
<th>Observe</th>
<th>Analyse</th>
</tr>
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<tbody>
<tr>
<td>Context services</td>
<td>- User Location, device location</td>
<td>- Learning user preferences</td>
</tr>
<tr>
<td></td>
<td>- Device network status</td>
<td>- Estimating behaviour of available device configurations</td>
</tr>
<tr>
<td></td>
<td>- Network status</td>
<td>- Learn network context</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Context matching</td>
</tr>
<tr>
<td>Profile services</td>
<td>- User profile</td>
<td>Policies services</td>
</tr>
<tr>
<td></td>
<td>- Device profile</td>
<td>- Collection of policies information</td>
</tr>
<tr>
<td></td>
<td>- Network element profile</td>
<td>- Policies derivation</td>
</tr>
<tr>
<td>Reasoning/Decision Making</td>
<td>Plan</td>
<td>Act</td>
</tr>
<tr>
<td></td>
<td>- decision making on optimal device operation</td>
<td>Reconfiguration Services</td>
</tr>
<tr>
<td></td>
<td>- decision making on optimal network operation</td>
<td>- Device reconfiguration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Network element reconfiguration</td>
</tr>
</tbody>
</table>

A more detailed view of the various cognitive functionalities and services encompassed in the proposed platform is presented in Table 1. More specifically the platform includes the following self-x (self-management, self-configuration, self-optimisation, self-healing) services:

- **Profile services** enable the acquisition of profile information, i.e. data related to user location, preferences, requirements and constraints as well as equipment capabilities. Indicative information obtained via profile services includes the set of potential configurations (such as the Radio Access Technologies) that a device/network element is capable of operating with, the associated spectrum and transmission power levels, the set of services that can be used and the sets of Quality of Service (QoS) levels associated with the use of a service, the utility volume (i.e. the level of user satisfaction) associated with the use of a service at a particular quality level, etc.

- **Context services** enable the acquisition of context information. This type of services encompasses mechanisms for a device or a network element to perceive its current status and the conditions in its present environment. More specifically, context
information may include data about available access technologies and operators in a
given area and their corresponding status (e.g. used frequencies, available resources,
coverage, etc.), information about the status of a network element/device (e.g. coverage at the current location, power available, etc.), information about the status of other network elements/devices in the area (e.g. activity, ability to cooperate, etc.).

- **Policies services** enable the acquisition and derivation of policies of various relevant
  entities (network operator, etc.). The data obtained by policies services may refine
  the input provided by the profiles and context services. A certain policy specifies a
  set of rules that should appropriately constrain and/or guide the decision making
  process.

- **Knowledge management services**. These comprise learning functionality for
  building knowledge and experience related to profiles, context, policies and
  decisions made in the past. The derived knowledge is then exploited in order to
  enable reaching reliable decisions faster.

- **Reasoning and decision making services** comprise functionality for selecting and
deciding the optimal configuration action(s) of devices and/or networks taking into
account current context, profiles, policies and knowledge. This functionality may be
triggered either as a reaction to a situation currently encountered (such as a hot-spot)
or in a proactive manner, by making use of experience obtained over time.

- **Reconfiguration services** are mainly responsible for receiving generic interface
  control requests from other platform entities and converting them into
reconfiguration actions/commands understandable by the driver of a specific
network element or user device. Actually this service performs the “translation” of
the technology-independent, virtualized commands into technology-specific ones,
issued to the driver or to the physical interface.

4. **Operation Scenarios**

In order to meet the requirements for the realization of the Future Internet the virtualisation
platform needs to be open, dynamic and scalable. In other words, it should be possible to
extend the platform by adding new components in a plug and play fashion.

![Figure 2: Dynamic addition of a Flexible Base Station](image)

Newly added components may include network infrastructure elements, devices, self-x
algorithms, applications, etc. When a new component is added, other (directly or indirectly)
affected components should be notified. For example, an application that uses a set of
devices to interact with the user should be made aware in case an additional device
becomes available in the vicinity of this user. The platform should also handle failure or
removal of components in a similar dynamic manner. In case of removal or failure of
components, all associated components are notified and actions may need to be taken so
that the system continues to operate as smoothly as possible.

In this context the platform provides support for the following operations:

- Dynamic addition and removal of new devices/network elements
- Dynamic addition and removal of services
- Dynamic addition and removal of cooperating network

Figure 2 presents an overview of the process of the addition of a new FBS into the
infrastructure and the corresponding interactions among various affected components of the
platform.

5. Implementation

As was already introduced, in order to realize Future Internet systems, innovative and
sophisticated means are required that will facilitate the integration of networking
technologies and management schemes (cognitive, reconfigurable/SDR and cooperative) as
well as evolving technologies, management functionalities/algorithms and will allow for
faster deployment of new services and applications. The current implementation of the
addressed virtualisation platform ([8]) comprises heterogeneous network elements, various
terminals and self-management functionalities and facilitates the support of demanding (in
terms of QoS) applications. It offers virtualisation functionalities through high level
interfaces to components. More specifically, each element of the platform, e.g. a network
infrastructure element or terminal, is coupled with a high level interface (based on XML) to
other components. This facilitates integration of various software and hardware components
and thus allows the realization of validation, exploitation and demonstration activities in a
wide range of test cases. The JADE/JADEX agent platform [20] has been utilised for this
implementation. Figure 3 (a) provides a high-level view of the implemented virtualisation
platform used for the demonstration of functionalities for self-optimization of cognitive
networks and devices. An indicative sequence of events in the platform is as follows. When
a Flexible Base Station (FBS) starts up, the corresponding FBS Control agent
communicates with the platform, and more specifically with the Directory Facilitator agent,
which plays the role of the yellow pages of the system (which essentially is part of the
service orchestration engine) and searches for a suitable management service in its area.
Such a service is provided by the Dynamic Self-organizing Network Planning and
Management (DSNPM) agent, which comprises Decision making on optimal network
configuration, Profile, Policies, Context and Knowledge Management services. The FBS
Control agent retrieves the DSNPM agent’s identifier and sends a registration message with
detailed information about the services it offers, namely its capabilities and characteristics,
i.e. the number of SDR transceivers, the supported RATs and frequencies for each
transceiver etc. This message also contains the initial FBS configuration, i.e. information on
the currently operating transceivers. The DSNPM acknowledges the successful registration.
Figure 3 (b) presents a snapshot of messages exchanged between the various components of
the platform. The DSNPM monitors the network context and if necessary (Figure 3 (c)),
exploits the knowledge it has gained from similar situations in the past, and decides on a
potential reconfiguration that will ensure the optimal operation of the network as a whole
(Figure 3 (d)). For this decision, the DSNPM agent may have to interact with the Dynamic
Spectrum Management (DSM) agent, which offers a service for the selection of frequencies
and the minimization of interference. If the DSNPM has to intervene, it runs an
optimization algorithm and sends a related reconfiguration message to the FBS Control
agent, which in turn translates the message contents into the necessary hardware specific
commands and then reports to the DSNPM the successful execution of the reconfiguration.
The next step is the derivation of network policies and the notification of the mobile
terminal about the updated network context, through the Cognitive Pilot Channel (CPC).
This information is utilised by the Autonomic Entity Management (AEM) agent that resides in every terminal in order to decide on the optimal device configuration. The AEM comprises Decision Making for optimal device configuration, Profile, Policies, Context and Knowledge Management services.

![AEM Diagram](image)

- AEM: Autonomic Management Entity
- CPC: Cognitive Pilot Channel
- DSM: Dynamic Spectrum Management
- DSNPM: Dynamic Self-organising Network Planning and Management

A hot spot is created (area in orange) The total traffic demand in the area is
- 28 Voice users (12.2 Kbps)
- 7 Video conference users (in 128Kbps or 256 Kbps)
- 21 Internet browsing users (in 512Kbps, 128 kbps, 64 Kbps)
- DSNPM is notified in order to optimize the area

DSNPM is notified in order to optimize the area

The FBS is reconfigured and the hot spot situation is successfully resolved by the DSNPM’s decision

Figure 3: Overview of current implementation of the Virtualisation platform: (a) Platform components; (b) View of message exchange between platform components; (c) Identification of new context (hot-spot); (d) Reconfiguration of FBS; (e) Demonstration elements

6. Conclusions

This paper presented a virtualisation platform that can be exploited for the introduction of cognitive systems in the Future Internet. The aim of the proposed platform is to facilitate the integration of networking technologies and various management schemes (cognitive, reconfigurable/ SDR and cooperative) as well as evolving (hardware and software) technologies and to allow for faster deployment of new services and applications. In order to achieve these goals, it is crucial to enable the abstraction of the complexity and diversity...
of the underlying software components and hardware infrastructure and support the introduction of new components and technologies and the removal or replacement of existing elements in a dynamic and transparent manner. A service oriented computing approach has been followed for the design of the proposed platform in order to address these requirements for abstraction, virtualisation, openness, easy integration and deployment. The paper presented the design of the proposed platform by briefly describing the services it comprises. An overview of the operations and the current implementation of the platform were provided.

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