DOI: 10.2298/CSIS121110034C

Cognitive RBAC in Mobile Heterogeneous Networks

Hsing-Chung Chen*,[1], Marsha Anjanette Violetta[2], Chien-Erh Weng[3], and Tzu-Liang Kung[4]

[1]Department of Computer Science and Information Engineering, Asia University, Taichung City 41354, Taiwan Members, IEEE & IET
cdma2000@asia.edu.tw also shin8409@ms6.hinet.net

[2]Institute of Computer Science and Information Engineering, Asia University, Taichung City 41354, Taiwan
marsha.violette@gmail.com

[3]Department of Electronic Communication Engineering, National Kaohsiung Marine University, Kaohsiung City 81157, Taiwan
ceweng@mail.nkmu.edu.tw

[4]Department of Computer Science and Information Engineering, Asia University, Taichung City 41354, Taiwan
tlkung@asia.edu.tw

Abstract. In communication networks, a cognitive network (CN) is a new type of data network which is used to solve some of the problems that face current networks. Cognitive radio (CR) is part of a cognitive network and a smart wireless communication system. CR is conscious of its surrounding environment, and learns from the environment. It adapts its internal states by making corresponding real-time changes in certain operating parameters. In this paper, we propose a novel Cognitive RBAC (Role-Based Access Control) scheme which can be applied to Mobile Heterogeneous Networks (MHNs). The MHNs consist of mobile communication systems and Wi-Fi systems. The required new definitions for the RBAC model are proposed in this paper. They can improve the ability of conventional RBAC model to meet new challenges. In our scheme, we assume that a Cognitive Server (CS) provides and manages the permissions of services, and Network Providers support and manage a variety CRs and CNs, individually. For more efficiently managing CR and CN and meeting the large scale heterogeneous networks, we let mobile user can perceive network candidate actively to access services, in which the permissions are depending to the contract made by CS with each Network Provider. In this paper, the new generalized cognitive RBAC model and their definitions are proposed, and could be applied to new applications in a MHNs environment.

Keywords: cognitive radio, cognitive networks, role based access control, heterogeneous networks, mobile communication system, contract RBAC.

1. Introduction

A cognitive radio (CR) is a transceiver that automatically changes its transmission or reception parameters in such a way so as to allow opportunistic selection of available wireless channels. The main process is also known as dynamic spectrum management. A cognitive radio, as defined by the researchers at Virginia Polytechnic Institute and State University, is a software defined radio with a cognitive engine brain. The Cognitive Server (CS) [20] and the Network Provider(s) (Called as Operator(s), hereafter) are becoming a more and more popular means for a mobile user's local machine to access content from the databases, e.g. some databases of agents [22, 24], even those belonging to heterogeneous networks [1, 2, 5, 6]. The two cognitive processes derived from the CS and Operator(s) are both associated with perceiving the current access network conditions that are learned from consequences of end user actions. One process is the Cognitive Network (CN), and the other is the CR. One of the core techniques in a CS and Operator(s) are Access Control (AC), which is the means by which the availability of data and resources accessible by users in a system is restricted and which both defends against illegal access by malicious attackers and prevents honest users from gaining inappropriate access and possibly causing administrative errors. A new AC technique, Role-based Access Control (RBAC) [1, 5] has established itself as a generalized approach for handling access control in large organizations. It differs from conventional identity-based access control models in that it takes advantage of simplifying access control policies by using the concept of role relations [1, 5]. Based on the aforementioned [1, 5], the RBAC model's manners of constraining users' access to computer systems and the maturity of its models have been widely investigated [20].
The future trend is to access multiple large scale heterogeneous networks (LHNs), e.g., GPRS/3G-GPRS, WiMax, Wi-Fi [7, 23], on the same time. The new challenges will often arise when users' smart devices, such as cellular phones and personal digital assistants (PDAs) are suddenly handover to another access network in a Mobile Heterogeneous Networks (MHNs), which is a kind of LHNs, on while accessing the same resources. It is thus important to decide the best network that can fulfill user requirements based on QoS and individual consideration. Wireless cognitive technologies are used to adaptively select a better access network and the related wireless access radio channel for visiting various resources. Therefore a better quality of

*Correspondence: Hsing-Chung Chen (Jack Chen), Department of Computer Science and Information Engineering, Asia University, Taichung Country, Taiwan 41354, Fax, +886-4-23305737, E-Mails: shin8409@ms6.hinet.net also cdma2000@asia.edu.tw.

accessing services will be obtained by adaptively selecting wireless access radio channels, and also improving access capability.

However, conventional RBAC model [1, 5] does not address the model of CN and CR via the cognitive processes, in which current access network situations are perceived and learned from the consequences of end users' actions. Therefore, in order to cope with the CN and CR on a conventional RBAC model, we propose a novel Cognitive RBAC model to meet the new management requirements in MHNs. In this paper, we assume that the services of a CS also support the RBAC mechanism, which can assign and manage the access privileges depending on the user's corresponding permissions [6]. In this model, the CS and Operator(s) are assumed to have the contract that will enable their system to detect to which authenticated user the device belongs to. The Operator(s) will then allocate the specified access network as well as available access radio channel to role(s) corresponding to pre-registered user(s). Subsequently, dynamic cognitive access network environments will be provided that are necessary for the required Quality of Service (QoS).

The rest of this paper is organized as follows: the related works of CR, CN and RBAC are addressed in Section 2. In Section 3 we review the Cognitive RBAC model in a Small Heterogeneous Networks (SHNs) proposed by Hsing-Chung Chen and Marsha Anjanette Violetta. We then propose a new generalized Cognitive RBAC for MHNs. The new definitions for CS and Operator(s) are described in Section 4. There are three application scenarios in Section 5. The comparisons are provided in Section 6. Finally, we make our conclusions in Section 7.

2. Related Works

2.1 Cognitive Radio

With the growing number of wireless devices and increased spectrum occupancy, the unlicensed spectrum is getting increasingly. Additionally, large portions of the licensed spectrum, even in urban areas, are underutilized. To address the potential spectrum exhaustion problem, new wireless communication paradigms have been proposed for future wireless communication devices. The CR [3, 11, 13, 20, 21] concept is a new wireless communication approach that improves spectrum usage efficiency by exploiting the existence of spectrum holes [20].

The concept of cognitive radio was first proposed by Mitola *et al.* in a seminar at the Royal Institute of Technology in Stockholm, in 1998 [11]. The research article, which was published by Mitola *et al.* in 1999 [11], describes a novel approach to wireless communications in which: "*The point in which wireless smart devices and the related networks are sufficiently computationally intelligent about radio resources and related computer-to-*

computer communications to detect user communications needs as a function of use context, and to provide radio resources and wireless services most appropriate to those needs" [13]. CR is considered to be an ideal goal towards which a software-defined radio platform should evolve: *i.e.* a fully reconfigurable wireless transceiver that automatically adapts its communication parameters to network and user demands [11, 13, 20].

CR is the wireless communication technology having cognitive and reconfigurable properties and the capability to detect unoccupied spectrum holes and change frequency, thus enhancing computer-to-computer communications. In most of the existing proposals there are three steps for the basic functionality of CR. Observing and sensing is the first step of the cognitive process. The next step is to identify and analyze the spectrum. The last step is that of sharing the spectrum information and executing spectrum assignments [12, 20].

2.2 Cognitive Network

In communication networks, a CN is a new type of data network that makes use of cutting edge technology from several research areas; *i.e.* machine learning, knowledge representation, computer network, and network management, to solve some problems current networks are faced with. CN is different from CR as it covers all the layers of the OSI model, not only layers 1 and 2, as with CR [14, 20].

One of the attempts to define the concept of a cognitive network was made in 2005 by Thomas, Da Silva and Mac Kenzie [15] and is based on the older idea of the Knowledge Plane described by Clark *et al* [16]. Since then, several research activities in the area have emerged. A survey [17] and an edited book [18] reveal some of these efforts.

The Knowledge Plane is "a pervasive system within the network that builds and maintains high level models of what the network is supposed to do, in order to provide services and advice to other elements of the network" [16]. The concept of a large scale cognitive network was made in 2008 by Song [19], where such a Knowledge Plane was clearly defined for large scale wireless networks as the information about the availability of radio spectrum and wireless stations [20].

In [15], the authors define the CN as a network with a cognitive process that can perceive current network conditions, plan, decide, act on those conditions, learn from the consequences of its actions, all while following end-to-end goals. This loop, the cognition loop, senses the environment, plans actions according to input from sensors and network policies, decides which scenario fits best its end-to-end purpose using a reasoning engine, and finally acts on the chosen scenario as discussed in the previous section. The system learns from the past (situations, plans, decisions, actions) and uses this knowledge to improve decisions in the future [12].

CRs have been mentioned in previous papers [3, 11, 13, 20]. Mitola *et al.* [11] makes brief mention of how his cognitive radios could interact within the system-level scope of a cognitive network. CNs are the future of information technology, in which the movement of network intelligence from controlling resources to understanding users' needs will help to manage the networks by facing out towards further network intelligences. CNs are with respect to future, one of the core technologies of mobile IP networks, and it is probable that the context sensitivity of these networks could have an interesting application in the field as cognitive radios. A CN should provide, over an extended period of time, better end-to-end performance than a non-cognitive network. Cognition could be used to improve resource management, Quality of Service (QoS), security, access control, and many other network goals [10, 20].

2.3 Role Based Access Control

RBAC is a well-known method for easily managing users to access resources via her/his authorized role. The main function of RBAC is to prevent unauthorized user from gaining information to which they are not entitled. Access rights are grouped by role name, and the use of resources is restricted to individuals authorized to assume the associated role. The use of roles to control access can be an effective means for developing and enforcing enterprise-specific security policies, and for streamlining the security management process.

Basic RBAC [1, 5] model is defined in terms of four model components: Core RBAC, Hierarchical RBAC, Static Separation of Duty Relations, and Dynamic Separation of Duty Relations. This basic model includes user-role assignment and permission-role assignment relations. Core RBAC includes sets of five basic data elements such as Users (U), Roles (R), Objects (OBJ), Operations (OPT) and Permissions ($PRMS$). Users are considered as human being, machines, networks, or intelligent agents that can perform some activities. Roles are described as a set of permissions necessary to access the resources. Permissions are approvals to execute operations on one or more objects. Operations are some executions for a program or a specific function which is invocated by a user. Objects are the entities that contain or receive information, or have exhaustible system resources. Furthermore, Core RBAC introduces the concept of role activation as part of a user's session within a computer system [1, 5].

3. Cognitive RBAC in SHNs

The Cognitive RBAC in SHNs was first proposed by Hsing-Chung Chen and Marsha Anjanette Violetta [20]. In their proposed scheme, it is assumed that a smart mobile device can take on cognitive characteristics, and be able to integrate various types of access networks in the SHNs. The intelligent capabilities [4] for the SHNs are located in the CS [20]. Assigned networks and the available channels are two important aspects. For the SHNs, assigned networks and available channels are integrated as access resources. There were three phases proposed in [20] for a user using her/his device(s) to register and access a CS: the user registration is illustrated in Fig. 1; the device registration is illustrated in Fig. 2; the access phase is illustrated in Fig. 3.

The proposed scheme addressed the new basic concept for a Cognitive RBAC model [20], which consists of the following component sets: Users (U), Roles (R), Permissions ($PRMS$), Sessions (S), Devices ($D\upsilon$), Channels (CH), and Networks ($N\varepsilon$), representing the set of users, roles, permissions, sessions, devices, channels, and networks set. Users are a set U considered as authenticated users who can establish (wireless) communication with the resources of the CS to perform some activities. Roles are described as a set R of permissions to access the resources of the CS. Permissions are a set $PRMS$ of approvals to execute operations on one or more objects of the CS. Sessions are a set S of the mappings between networks $N\varepsilon$ and an activated subset of the set of roles R. Devices are a set $D\upsilon$ considered as the mobile units used by assigned users to activate the roles and access permissions. Channels are a set CH considered as conveyers of the information signals from senders to receivers for the operation. Networks are a set $N\varepsilon$ considered as computers interconnected by communication channels that allow sharing of resources and information [12].

It is assumed that the CS can identify the device whether it is registered or not, and determine who is the device owner. The CS also assigns and manages all of the access networks and available channels for each role, and dynamically adapts the access networks and available radio channels, depending on their environment, as needed for application performance. The generalized model of cognitive RBAC is described in *Definition 1* [20].

Definition 1: *The generalized model of Cognitive RBAC;*

- *Users (U), Roles (R), Permissions ($PRMS$), Sessions (S), Devices ($D\upsilon$), Channels (CH), and Networks ($N\varepsilon$), representing the set of users, roles, permissions, sessions, devices, channels, and networks set which are assigned by the CS, respectively;*
- $UA \subseteq U \times D\upsilon \times R$ *, the user assignment relation that associates users with their devices will be assigned the available roles after successful user and device authentication;*
- $r\_au(r \in R) \rightarrow 2^{U \times D\upsilon}$ *, the mapping of a role r onto a power set of authenticated users with their devices where function $r\_au(\bullet)$ is defined as* $r\_au(r \in R) = \{(u, d\upsilon) \in U \times D\upsilon \mid (u, d\upsilon, r) \in UA\}$*;*
- $N\varepsilon_{\psi'}$*, a set of networks, where ψ' is a CS system;*
- $CH_{\eta\varepsilon}$ *is a the set of channels and corresponding to a network $\eta\varepsilon$;*
- $ch \in CH_{\eta\varepsilon}$ *,* $CH_{\eta\varepsilon} \in N\varepsilon_{\psi'}$ *, is an available channels in a channel set which belongs to a set of networks;*

- $d\upsilon \subseteq D\upsilon$, $CHA_{\eta\varepsilon} \subseteq CH_{\eta\varepsilon} \times D\upsilon$ *the channel assignment relation that the available channels,* $CH_{\eta\varepsilon}$, *assigned to a smart device,* $d\upsilon$, *via a network* $\eta\varepsilon$ *which is managed by a CS;*
- $PA \subseteq R \times N\varepsilon_{\psi} \times CH_{\eta\varepsilon} \times PRMS$, *the role assignment relation that assigns permission to an available role, network and channel;*
- $r\_p(r \in R, \eta\varepsilon \in N\varepsilon_{\psi}, ch \in CH_{\eta\varepsilon}) \rightarrow 2^{PRMS}$ *, the mapping of a role* r *, a network* $\eta\varepsilon$ *and a channel* ch *onto a power set of permissions where the function* $r\_p(\bullet)$ *is defined as* $r\_p(r, \eta\varepsilon, ch) = \{p \in PRMS | (r, \eta\varepsilon, ch, p) \in PA\}$*;*
- $r\_n(r \in R) \rightarrow 2^{N\varepsilon_{\psi}}$ *is the mapping of a role onto a power set of networks;*
- $ch\_r(ch \in CH_{\eta\varepsilon}) \rightarrow 2^{R}$ *is an assigning function for available channels in a network onto a power set of roles;*
- $u\_s((u, d\upsilon) \in U \times D\upsilon) \rightarrow 2^{S}$ *is the mapping of a user with his a device,* $(u, d\upsilon)$*, onto a power set of sessions;*
- $s\_r(\varsigma \in S) \rightarrow 2^{R}$ *is the mapping of a session to a power set of roles;*
- $avail\_s\_p(\varsigma \in S, , \eta\varepsilon \in N\varepsilon_{\psi}, ch \in CH_{\eta\varepsilon}) \rightarrow 2^{PRMS}$ *is the mapping of a power set of available permissions from a network* $\eta\varepsilon$ *and a channel* ch *in a session* ς *; the user finally gets the permissions,* $\bigcup_{r \in s\_r(\varsigma)} r\_p(r, \eta\varepsilon, ch)$.

□

Hierarchies in the Cognitive RBAC model are defined as an inheritance relationship between two roles managed by the CS, such that a role, $r_i \in R$, inherits the permissions from role, $r_j \in R$, if all permissions of r_j are also the permissions of r_i. We present a hierarchical Cognitive RBAC model for the CS in *Definition 2* [20]. In this model, permissions are assigned to a role.

Definition 2: *Role hierarchies in a Cognitive RBAC model;*

- $RH \subseteq R \times R \times N\varepsilon_{\psi} \times CH_{\eta\varepsilon}$ *is a partial order of roles, called the ascendancy relation combined with networks and channels , written as '*$\succeq$*' , where* $r_i \succeq r_j$*, is such that role,* $r_i \in R$*, inherits all permission,* $r_j \in R$ *, are assigned to all the users of* r_i *which are also assigned to all the users of* r_j*;*
- $r\_p(r_i \in R, \eta\varepsilon_m \in N\varepsilon_{\psi}, ch_c \in CH_{\eta\varepsilon}) \rightarrow 2^{PRMS}$ *is the mapping of a role,* r_i *, a network* $\eta\varepsilon_n$ *and a channel* ch_c *onto a power set of permissions. The permission set is assigned directly together with the permissions which are assigned to its successive roles, specifically:* $r\_p(r_i, \eta\varepsilon_m, ch_c) = r\_p(r_i) \cup \left\{ \bigcup \forall r_j : r_i \succeq r_j \; r\_p(r_j, \eta\varepsilon_n, ch_e) \right\}$*;*

- $r\_au(r_i \in R) \rightarrow 2^{U \times D\upsilon}$ *is the mapping of a role , r_i , onto a power set of authenticated users with their devices in the presence of a role hierarchy, specifically:* $r\_au(r_i) = \{(u, d\upsilon) \in U \times D\upsilon \mid r_i \succeq r_j, (u, d\upsilon, r_i) \in UA\}$*;*
- $r\_n(r_i \in R) \rightarrow 2^{N\varepsilon_{\psi'} \times Ch}$ *is the mapping of a role , r_i, onto a power set of network together with channel. The set of network together with channel assigned directly to its successive roles, specifically:*
- *From the above sub-definitions, it follows that if* $r\_p(r_j, \eta\varepsilon_n, ch_e) \subseteq r\_p(r_i, \eta\varepsilon_m, ch_c)$ *and* $r\_au(r_j) \subseteq r\_au(r_i)$.

□

Separations of Duties are defined in *Definition 3* [20] and *Definition 4* [20] as those are to be enforced on a set of roles that may not be executed simultaneously by a user. Their model would be similar to the well-known RBAC model.

1) Static Separation of Duty (SSD) relations place constraints on the assignments of users to roles. Membership of one role may prevent the user from being a member of one or more other roles, depending on the SSD enforced rules.

Definition 3: *SSD relation in the Cognitive RBAC model;*

- SSD , $SSD \subseteq 2^R \times 2^{N\varepsilon_\psi} \times 2^{CH_{\eta\varepsilon}} \times N$ *is a collection of four* $(\alpha, \beta, \chi, n) \in \left(2^R, 2^{N\varepsilon_\psi}, 2^{CH_{\eta\varepsilon}}, N\right)$ *for CS where each* $\alpha \in 2^R$ *is a role set,* $\beta \in 2^{N\varepsilon_\psi}$ *is a network set,* $\chi \in 2^{CH_{\eta\varepsilon}}$ *is a channel set and* $n \in N$ *is a natural number,* $n \geq 2$ *with the property that no user can be assigned to* n *or more roles from the set* α *in any network* β *or channel* χ *. Specifically:*
  $\forall (\alpha, \beta, \chi, n) \in SSD, \forall \eta \in \alpha, \beta, \chi : |\eta| \geq n \Rightarrow \bigcap_{r \in \rho} r\_au(r) = \varnothing$.

2) Dynamic Separation of Duty (DSD) relations differ from SSD relations by the context in which these limitations are imposed. DSD requirements limit the availability of the permissions by placing constraints on the roles that can be activated within or across a user's sessions.

Definition 4: *DSD relation in the Cognitive RBAC model;*

- DSD , $DSD \subseteq 2^R \times 2^{N\varepsilon_\psi} \times 2^{CH_{\eta\varepsilon}} \times N$ *is a collection of four* $(\alpha, \beta, \chi, n) \in \left(2^R, 2^{N\varepsilon_\psi}, 2^{CH_{\eta\varepsilon}}, N\right)$ *for CS where each* $\alpha \in 2^R$ *is a role set,* $\beta \in 2^{N\varepsilon_\psi}$ *is a network set,* $\chi \in 2^{CH_{\eta\varepsilon}}$ *is a channel set and* $n \in N$ *is a natural number,* $n \geq 2$ *with the property that no user may activate* n *or more roles from the set* α *in any network* β *or channel* χ *. Specifically:*

$$\forall(\alpha,\beta,\chi,n)\in DSD,\forall\varsigma\in S,\forall\rho\subseteq s\_r(\varsigma)\cap\alpha,\beta,\chi:|\rho|\geq n\Rightarrow\bigcap_{r\in\rho}r\_au(r)=\varnothing$$

.

□

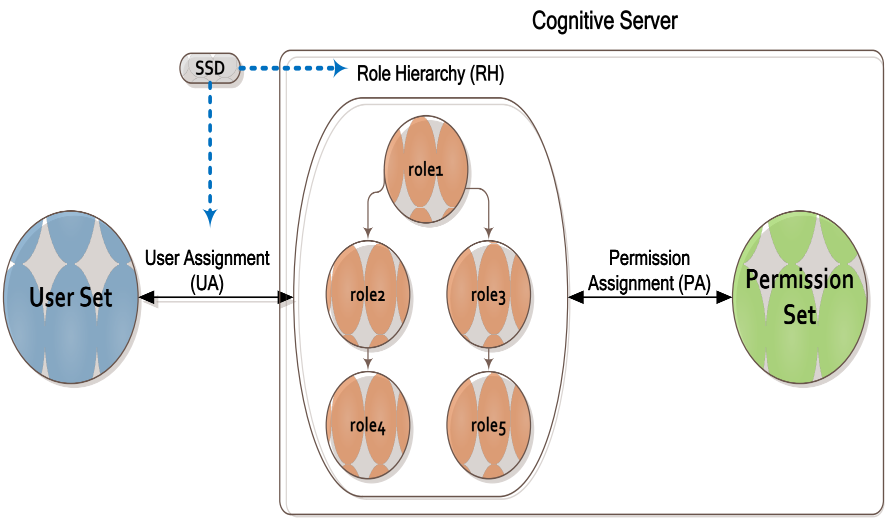

Fig. 1. User registration phase

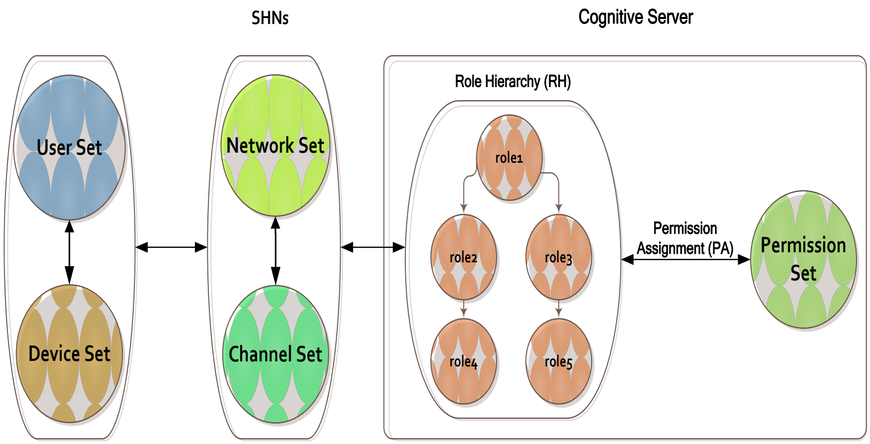

Fig. 2. Device registration phase

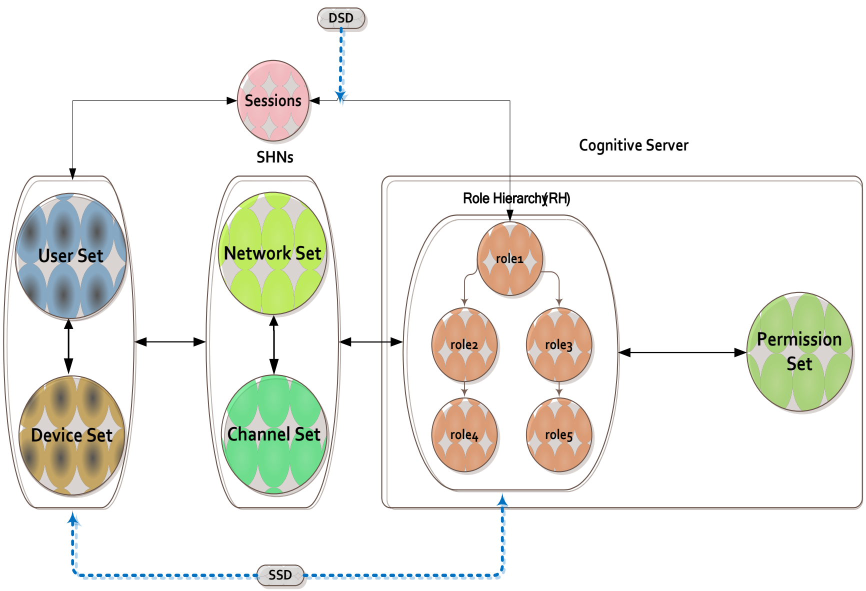

Fig. 3. Access phase

4. Generalized Cognitive RBAC model in MHNs

In order to deal with the CR and CN on a LHNs environment, we propose a novel Generalized Cognitive RBAC model to meet the new management requirements in MHNs. The MHNs will take on cognitive radio characteristic, and are able to integrate various types of access networks. This model can provide cognitive network characteristics such as QoS, better end-to-end performance, security, and access control. Registered devices, assigned networks, available channels and contract roles are four important aspects. In the MHNs, assigned networks and available channels are integrated and managed by Operator(s); permissions are assigned are managed by the CS for getting resources and services. We first propose a new role is 'contract role' which can achieve to flexibly manage the role mapping in MHNs. The contract role is depending on the contract made by the CS together with each Operator.

At first, we give the basic definition for the generalized Cognitive RBAC model combined with the contract concept as below.

4.1 The basic definition of the generalized Cognitive RBAC model in MHNs

The basic concept of the generalized Cognitive RBAC model consists of the following component sets: Users (U), Contract Roles (CR), Roles of Operator (Ro), Roles of CS (Rs), Permissions ($PRMS$), Sessions (S), Devices ($D\upsilon$), Channels (CH), Networks ($N\varepsilon$), and Contract ($CT^{(k)}$) representing the sets of users, contract roles, roles of operator, roles of CS, permissions, sessions, devices, channels, networks and contract. Users are a set of U considered as the authenticated users who can through the system of Operator, *e.g.* mobile communication system or Wi-Fi system, to access the resources of the CS. Roles of Operator are described as a set of roles, Ro, with the privileges to obtain the network(s) and channel(s) from the mobile communication or Wi-Fi system from an Operator. Roles of CS are described as a set of roles, Rs, with the permissions to access the resources of the CS.

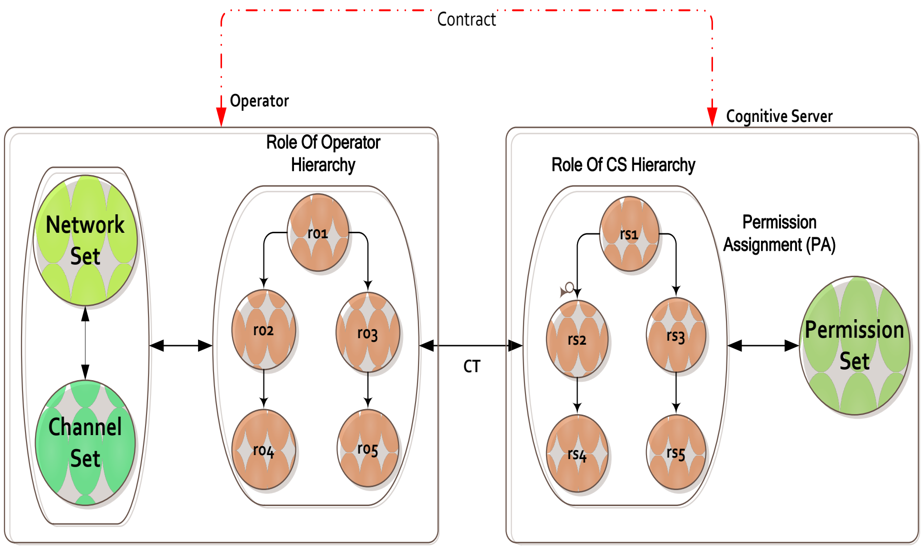

Fig. 4. Cognitive RBAC Model with the contract made by CS and one Operator in MHNs.

Contract Roles are combined the mapping roles from both Roles of CS and Roles of Operator, representing as a set of Contract Roles, CR, depending on the contract made by each Operator and the CS (See Fig. 4 and Fig. 5), individually. To access resources of CS through the assigned network(s) and the corresponding to radio channel(s) is managed by the Operator(s). Permissions, based on the contract roles set, CR, are a set of approvals to execute operations on one or more services of the CS. Sessions, based on the contract roles set, CR, are a set S of the mappings between networks, $N\varepsilon$, and an activated subset of the set of the contract roles set, CR. Devices are a set of $D\upsilon$ which are considered as the mobile units used by assigning users to activate the contract roles and access the permissions constrained by the contract. Channels, based on the contract roles set, CR, is a set of CH considered as conveyers of the information signals from senders to receivers for the operation.

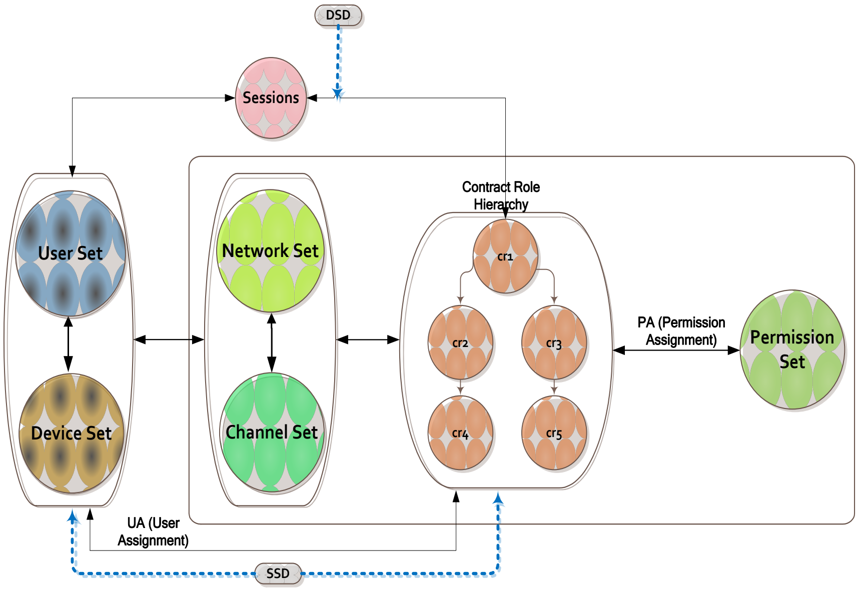

Fig. 5. Generalized Cognitive RBAC Model with combined roles which corresponding to the contract made by CS and one Operator in MHNs.

Networks, based on the contract roles set, CR, is a set of $N\varepsilon$ considered computers interconnected by communication channels that allow sharing of resources and information [12]. Contract is the agreement between CS and Operator(s) (See *Table 1*, *Table 2*, and *Table 3*). It is assumed that the CS and the Operator(s) can identify the device whether it is registered or not, and determine who is the device owner. Each Operator assigns and manages all of the access networks and available channels for each contract role, and dynamically adapts the access networks and available radio channels, depending on their environment and contract for getting better QoS. The CS manages the permissions which let mobile user can access resources from its server. The generalized model of Cognitive RBAC in MHNs is described in *Definition 5*.

Definition 5: *The generalized model of Cognitive RBAC in MHNs;*

- *Users (U), Contract Roles (CR), Roles of Operator (Ro), Roles of CS (Rs), Permissions ($PRMS$), Sessions (S), Devices ($D\upsilon$), Channels (CH), Networks ($N\varepsilon$),and Contract ($CT^{(k)}$) representing the set of users, contract roles, Roles of Operator, Roles of CS, permissions, sessions, devices, channels, networks and contract set which are corresponding the contract* *made by CS and one Operator k, respectively (See Fig. 4 and Fig. 5);*

- $UA \subseteq U^{(k)} \times D\upsilon^{(k)} \times CR^{(k)}$ *the user assignment relation that associates users with registered devices to contract roles ;* $CR^{(k)} = Ro^{(k)} \times Rs^{(k)}$*;* k *is the name the name of serving Operator;*
- $r\_au^{(k)}\left(d\upsilon^{(k)} \in D\upsilon^{(k)}, cr^{(k)} \in CR^{(k)}\right) \rightarrow 2^{U^{(k)}}$*, the mapping of a device,* $d\upsilon^{(k)}$*, and a contract role,* $cr^{(k)}$*, onto a power set of authenticated users where function* $r\_au^{(k)}(\bullet)$ *is defined as* $r\_au^{(k)}\left(d\upsilon^{(k)}, cr^{(k)}\right) = \left\{u^{(k)} \in U^{(k)} \middle| \left(u^{(k)}, d\upsilon^{(k)}, cr^{(k)}\right) \in UA\right\}$*;*
- $PA \subseteq Rs^{(k)} \times PRMS^{(k)}$ *, the permission assignment relation that assigns permissions to available contract roles;*
- $r\_p^{(k)}\left(rs^{(k)} \in Rs^{(k)}\right) \rightarrow 2^{PRMS^{(k)}}$ *,the mapping of a role of CS,* $rs^{(k)}$ *, onto a power set of permissions where the function* $r\_p^{(k)}(\bullet)$ *is defined as* $r\_p^{(k)}\left(rs^{(k)}\right) = \left\{p^{(k)} \in PRMS^{(k)} \middle| \left(rs^{(k)}, p^{(k)}\right) \in PA\right\}$*;*
- $CRPA^{(k)} \subseteq CR^{(k)} \times PRMS^{(k)}$*, the contract role permission assignment relation that assigns permissions to available contract roles;*
- $CRPRMS^{(k)} \subseteq 2^{PRMS^{(k)}}$ *is the permission set of contract role;*
- $CR^{(k)} \subseteq Ro^{(k)} \times Rs^{(k)}$*, the contract role relation that associates Roles of Operator with Roles of CS to Contract Roles;*
- $r\_r^{(k)}\left(ro^{(k)} \in Ro^{(k)}, rs^{(k)} \in Rs^{(k)}\right) \rightarrow 2^{CR^{(k)}}$ *is the mapping of a role of operator and a role of CS onto a power set of contract roles, where function* $r\_r^{(k)}(\bullet)$ *is defined as* $r\_r^{(k)}\left(ro^{(k)}, rs^{(k)}\right) = \left\{cr^{(k)} \in CR^{(k)} \middle| \left(cr^{(k)}, ro^{(k)}, rs^{(k)}\right) \in CR^{(k)}\right\}$*;*
- $D\upsilon^{(k)}$*, the set of devices;*
- $\left\{d\upsilon^{(k)}\right\} \subseteq D\upsilon^{(k)}$*,* $CH_{\eta\varepsilon}{}^{(k)} \in d\upsilon^{(k)}$ *is the available channels which are belonging to a networks set for registered device;*
- $N\varepsilon_{\psi}{}^{(k)}$*, the set of networks;* ψ *is a system of Operator;* $\eta\varepsilon^{(k)} \in N\varepsilon_{\psi}{}^{(k)}$ *;* $m, w \in \psi$ *; m represented as a mobile communication system; and w represented as a Wi-Fi system;*
- $r\_n^{(k)}\left(ro^{(k)} \in Ro^{(k)}\right) \rightarrow 2^{N\varepsilon_{\psi}{}^{(k)}}$ *is the mapping of a role of operator onto a power set of networks;*
- $CH_{\eta\varepsilon}{}^{(k)}$ *, the set of channels;* $\eta\varepsilon$ *represented as a network;*
- $\left\{ch^{(k)}\right\} \subseteq CH_{\eta\varepsilon}{}^{(k)}$*,* $CH_{\eta\varepsilon}{}^{(k)} \in N\varepsilon_{\psi}{}^{(k)}$ *is the available channels in a channel set which belongs to a networks set;*
- $ch\_r^{(k)}\left(ch^{(k)} \in CH_{\eta\varepsilon}{}^{(k)}\right) \rightarrow 2^{Ro^{(k)}}$ *is an assigning function for available channels in a network onto a power set of roles of operator;*
- $u\_s^{(k)}\left(u^{(k)} \in U^{(k)}\right) \rightarrow 2^{S^{(k)}}$ *is the mapping of a user onto a power set of sessions;*
- $s\_r^{(k)}\left(\varsigma^{(k)} \in S^{(k)}\right) \rightarrow 2^{CR^{(k)}}$ *is the mapping of a session onto a power set of contract roles;*

- $avail\_s\_p^{(k)}\left(\varsigma^{(k)} \in S^{(k)}, \eta\varepsilon^{(k)} \in N\varepsilon_{\psi}{}^{(k)}, ch^{(k)} \in CH_{\eta\varepsilon}{}^{(k)}\right) \rightarrow 2^{SRPRMS^{(k)}}$ *is the mapping of a power set of available permissions from a network* $\eta\varepsilon^{(k)}$ *and a channel* $ch^{(k)}$*, in a session* $\varsigma^{(k)}$ *constrained by the assigned contract role* $\forall cr^{(k)} \in CR^{(k)}$ *; and the user gets her/his permissions as* $\bigcup_{cr^{(k)} \in s\_r^{(k)}(\varsigma^{(k)})} \left\{r\_p^{(k)}\left(cr^{(k)}, \eta\varepsilon^{(k)}, ch^{(k)}\right)\right\}$.

□

4.2 Hierarchical role in Generalized Cognitive RBAC in MHNs

Hierarchies in the Cognitive RBAC model are defined an inheritance relationship between the role of CS, $rs^{(k)}$, such that a role of CS, $rs_x{}^{(k)} \in Rs^{(k)}$, inherits the permissions from a role of CS, $rs_y{}^{(k)} \in Rs^{(k)}$, if all permissions of $rs_y{}^{(k)}$ are also the permissions of $rs_x{}^{(k)}$. We also define an inheritance relationship in Roles of Operator for the Operator(s), such that a role of operator, $ro_m{}^{(k)} \in Ro^{(k)}$, inherits all the networks and the channels from a role of operator $ro_n{}^{(k)} \in Ro^{(k)}$, if all networks and the channels of $ro_n{}^{(k)}$ are also the networks and the channels of $ro_m{}^{(k)}$. We present a hierarchical Cognitive RBAC model for the CS and the Operator(s) in *Definition 6*, such that a contract role, $cr_i{}^{(k)} \in CR^{(k)}$, inherits the permissions, access networks and available channels from a contract role, $cr_j{}^{(k)} \in CR^{(k)}$.

Definition 6: *Role hierarchies in a Cognitive RBAC model in MHNs;*

- $RH \subseteq CR^{(k)} \times CR^{(k)}$ *is a partial order of contract roles, called the ascendancy relation, written as "* $\succeq$ *", where* $cr_i{}^{(k)} \succeq cr_j{}^{(k)}$*, means that a contract role,* $cr_i{}^{(k)} \in CR^{(k)}$*, inherits all the permissions from a contract role,* $cr_j{}^{(k)} \in CR^{(k)}$*, and all the users who are assigned the role,* $cr_i{}^{(k)}$*, also can access the permissions of* $cr_j{}^{(k)}$*;*
- $r\_p^{(k)}\left(rs^{(k)} \in Rs^{(k)}\right) \rightarrow 2^{PRMS^{(k)}}$ *is the mapping of a role of CS,* $rs_x{}^{(k)}$*, onto a set of permissions. The permission set will be assigned directly to its successive Roles of CS,* $Rs^{(k)}$*, specifically:* $r\_p^{(k)}\left(rs_x{}^{(k)}\right) = r\_p^{(k)}\left(rs_x{}^{(k)}\right) \cup \left\{ \bigcup_{\forall rs_y{}^{(k)} : rs_x{}^{(k)} \succeq rs_y{}^{(k)}} r\_p^{(k)}\left(rs_y{}^{(k)}\right) \right\}$;
- $r\_au^{(k)}\left(d\upsilon^{(k)} \in D\upsilon^{(k)}, cr^{(k)} \in CR^{(k)}\right) \rightarrow 2^{U^{(k)}}$ *the mapping of a device,* $d\upsilon^{(k)}$*,*

and a contract role $cr^{(k)}$ *and onto a set of authenticated users in the presence of a contract role hierarchy, specifically:* $r\_au^{(k)}\left(d\upsilon^{(k)},cr^{(k)}\right)=\left\{u^{(k)}\in U^{(k)}\middle|cr_i^{(k)}\succeq cr_j^{(k)}\left(u^{(k)},d\upsilon^{(k)},cr_i^{(k)}\right)\in UA\right\}$;

- $r\_n^{(k)}\left(ro^{(k)}\in Ro^{(k)}\right)\rightarrow 2^{N\varepsilon^{(k)}}$ *is the mapping of a role of operator,* $ro_m^{(k)}$*, onto a set of network. The networks set assigned directly together with the networks assigned to its successive Roles of Operator,* $Ro^{(k)}$*, specifically:* $r\_n^{(k)}\left(ro_m^{(k)}\right)=r\_n^{(k)}\left(ro_m^{(k)}\right)\cup\left\{\bigcup_{\forall ro_n^{(k)}:ro_m^{(k)}\succeq ro_n^{(k)}} r\_n^{(k)}\left(ro_n^{(k)}\right)\right\}$;
- *From the above definitions, it follows that if* $r\_p^{(k)}\left(rs_y^{(k)}\right)\subseteq r\_p^{(k)}\left(rs_x^{(k)}\right)$, $r\_n^{(k)}\left(ro_n^{(k)}\right)\subseteq r\_n^{(k)}\left(rs_m^{(k)}\right)$ *and* $r\_au^{(k)}\left(d\upsilon^{(k)},cr_j^{(k)}\right)\subseteq r\_au^{(k)}\left(d\upsilon^{(k)},cr_i^{(k)}\right)$.

□4.3 Separation of duties constrained in the Cognitive RBAC in MHNs

Separations of Duties are defined in *Definition 7* and *Definition 8* as those are to be enforced on a set of contract roles that may not be executed simultaneously by a user. Our model would be similar to the well-known RBAC model, but we add a registered device in this concept.

1) SSD relations place constraints on the assignments of users and their devices to contract roles. Membership in one contract role may prevent the user with her/his devices from being a member of one or more other contract roles, depending on the SSD enforced rules for all networks.

Definition 7: *SSD relation in the Cognitive RBAC model in MHNs;*

- $SSD^{(k)}$, $SSD^{(k)}\subseteq 2^{CR^{(k)}}\times 2^{D\upsilon^{(k)}}\times N^{(k)}$ *is a collection of three* $(\alpha,\upsilon,n)\in\left(2^{CR^{(k)}},2^{D\upsilon^{(k)}},N^{(k)}\right)$ *for CS and Operator(s) where each* $\alpha\in 2^{CR^{(k)}}$ *is a contract role set,* $\upsilon\in 2^{D\upsilon^{(k)}}$ *is a device set and* $n\in N^{(k)}$ *is a natural number,* $n\geq 2$ *with the property that no user can be assigned to* n *or more contract roles from the set* α *using any device from the set* υ*.*
 Specifically:
 $\forall(\alpha,\upsilon,n)\in SSD^{(k)},\forall d\upsilon^{(k)}\in\upsilon,\forall\eta\subseteq\alpha:|\eta|\geq n\Rightarrow\bigcap_{cr^{(k)}\in\eta} r\_au^{(k)}\left(cr^{(k)},d\upsilon^{(k)}\right)=\varnothing$.

2) DSD relations differ from SSD relations by the context in which these limitations are imposed. DSD requirements limit the availability of the permissions by placing constraints on the contract roles that can be activated within or across a user's sessions when contract roles can be activated by the user's devices through all networks and channels.

Definition 8: *DSD relation in the Cognitive RBAC model in MHNs;*

- $DSD^{(k)}$, $DSD^{(k)}\subseteq 2^{CR^{(k)}}\times 2^{D\upsilon^{(k)}}\times N^{(k)}$ *is a collection of three*

$(\alpha,\upsilon,n)\in\left(2^{CR^{(k)}},2^{D\upsilon^{(k)}},N^{(k)}\right)$ for CS and Operator(s) where each $\alpha\in 2^{CR^{(k)}}$ is a contract role set, $\upsilon\in 2^{D\upsilon^{(k)}}$ is a device set and $n\in N^{(k)}$ is a natural number, $n\geq 2$ with the property that no user may activate n or more contract roles from the set α using any device from the set υ. Specifically:

$$\forall(\alpha,\upsilon,n)\in DSD^{(k)},\forall d\upsilon^{(k)}\in\upsilon,\forall\varsigma^{(k)}\in S,\forall\rho\subseteq s\_r(\varsigma)\cap\alpha:|\rho|\geq n$$
$$\Rightarrow\bigcap_{cr^{(k)}\in\rho}r\_au^{(k)}\left(cr^{(k)},d\upsilon^{(k)}\right)=\varnothing.$$

□4.4. Contract and Registration Phase, and Access Phase

In this subsection, the phase for CS and the Operator(s) can be divided into two sub-phases: the first one is the *Contract and Registration Phase*, and the second phase is the *Access Phase*. In this subsection, we introduce the two phases for the generalized Cognitive RBAC model in MHNs.

4.4.1. Contract and Registration Phase

A contract is an agreement entered into voluntarily by two or more parties with the intention of creating a legal obligation, which may have some contract items in writing, though contracts can be made formally. Registration is having formally submitted a document to, and received approval for a specific activity from, the appropriate official or authority. In this phase, we will describe the contract and registration which is suitable for this application scenario.

1) **CS makes contract with Operator(s)**

In our assumption, CS is a kind of permissions provider for some specific applications, and Operator(s) should be an access network(s) provider which provides either mobile communication network or Wi-Fi network. The CS and Operator(s) will make the contracts that provide permissions to access the CS through the system of Operator. They will share information of registered users and registered devices. For examples, there are a CS server and three Operators: A, B, C, shown in *Table 1*, *Table 2*, and *Table 3*. The permissions are mapping from CS to networks and channels which belong to the distinct Operator.

Table 1. An example to illustrate the contract between CS and Operator(s) by $CT^{(A)}$

Role	Privileges				
	Operator A			Cognitive Server	
$CR^{(A)}$	Roles of Operator $Ro^{(A)}$	Network Set $N\varepsilon_{\psi}{}^{(A)}$	Channel Set $CH_{\eta\varepsilon}{}^{(A)}$	Roles of CS $Rs^{(A)}$	Permission $PRMS^{(A)}$
$cr_1{}^{(A)}$	$ro_1{}^{(A)}$	$m_1{}^{(A)}$ $m_2{}^{(A)}$ $w_3{}^{(A)}$	$\{ch_1, ch_2\} \subseteq CH_{m_1}{}^{(A)}$ $\{ch_1, ch_2\} \subseteq CH_{m_2}{}^{(A)}$ $\{ch_1, ch_3\} \subseteq CH_{w_3}{}^{(A)}$	$rs_1{}^{(A)}$	$prms_1{}^{(A)}$ $prms_2{}^{(A)}$ $prms_3{}^{(A)}$
$cr_2{}^{(A)}$	$ro_2{}^{(A)}$	$m_4{}^{(A)}$ $w_5{}^{(A)}$	$\{ch_2, ch_3\} \subseteq CH_{m_4}{}^{(A)}$ $\{ch_3, ch_5\} \subseteq CH_{w_5}{}^{(A)}$	$rs_2{}^{(A)}$	$prms_4{}^{(A)}$ $prms_5{}^{(A)}$
$cr_3{}^{(A)}$	$ro_3{}^{(A)}$	$m_6{}^{(A)}$ $w_7{}^{(A)}$	$\{ch_4\} \subseteq CH_{m_6}{}^{(A)}$ $\{ch_5, ch_6\} \subseteq CH_{w_7}{}^{(A)}$	$rs_3{}^{(A)}$	$prms_6{}^{(A)}$ $prms_7{}^{(A)}$
$cr_4{}^{(A)}$	$ro_4{}^{(A)}$	$w_8{}^{(A)}$ $m_9{}^{(A)}$	$\{ch_7, ch_8\} \subseteq CH_{w_8}{}^{(A)}$ $\{ch_8, ch_9\} \subseteq CH_{m_9}{}^{(A)}$	$rs_4{}^{(A)}$	$prms_8{}^{(A)}$ $prms_9{}^{(A)}$
$cr_5{}^{(A)}$	$ro_5{}^{(A)}$	$m_{10}{}^{(A)}$	$\{ch_9, ch_{10}\} \subseteq CH_{m_{10}}{}^{(A)}$	$rs_5{}^{(A)}$	$prms_{10}{}^{(A)}$

Table 2. An example to illustrate the contract between CS and Operator(s) by $CT^{(B)}$

Role	Privileges				
	Operator B			Cognitive Server	
$CR^{(B)}$	Roles of Operator $Ro^{(B)}$	Network Set $N\varepsilon_{\psi}{}^{(B)}$	Channel Set $CH_{\eta\varepsilon_{\psi}}{}^{(B)}$	Roles of CS $Rs^{(B)}$	Permission $PRMS^{(B)}$
$cr_1{}^{(B)}$	$ro_1{}^{(B)}$	$w_1{}^{(B)}$ $m_2{}^{(B)}$ $m_7{}^{(B)}$	$\{ch_1, ch_2\} \subseteq CH_{w_1}{}^{(B)}$ $\{ch_1, ch_2\} \subseteq CH_{m_2}{}^{(B)}$ $\{ch_1, ch_2\} \subseteq CH_{m_7}{}^{(B)}$	$rs_1{}^{(B)}$	$prms_1{}^{(B)}$ $prms_2{}^{(B)}$ $prms_3{}^{(B)}$
$cr_2{}^{(B)}$	$ro_2{}^{(B)}$	$w_3{}^{(B)}$ $m_4{}^{(B)}$	$\{ch_2, ch_3\} \subseteq CH_{w_3}{}^{(B)}$ $\{ch_3, ch_5\} \subseteq CH_{m_4}{}^{(B)}$	$rs_2{}^{(B)}$	$prms_4{}^{(B)}$ $prms_5{}^{(B)}$
$cr_3{}^{(B)}$	$ro_3{}^{(B)}$	$m_6{}^{(B)}$ $m_{10}{}^{(B)}$	$\{ch_1, ch_2\} \subseteq CH_{m_6}{}^{(B)}$ $\{ch_9, ch_{10}\} \subseteq CH_{m_{10}}{}^{(B)}$	$rs_3{}^{(B)}$	$prms_6{}^{(B)}$ $prms_7{}^{(B)}$
$cr_4{}^{(B)}$	$ro_4{}^{(B)}$	$m_8{}^{(B)}$ $m_9{}^{(B)}$	$\{ch_7, ch_8\} \subseteq CH_{m_8}{}^{(B)}$ $\{ch_8, ch_9\} \subseteq CH_{m_9}{}^{(B)}$	$rs_4{}^{(B)}$	$prms_8{}^{(B)}$ $prms_9{}^{(B)}$
$cr_5{}^{(B)}$	$ro_5{}^{(B)}$	$m_6{}^{(B)}$ $m_{10}{}^{(B)}$	$\{ch_1, ch_2\} \subseteq CH_{n_6}{}^{(B)}$ $\{ch_9, ch_{10}\} \subseteq CH_{m_{10}}{}^{(B)}$	$rs_5{}^{(B)}$	$prms_{10}{}^{(B)}$

Table 3. An example to illustrate the contract between CS and Operator(s) by $CT^{(C)}$

Role $CR^{(C)}$	Privileges				
	Operator C			Cognitive Server	
	Roles of Operator $Ro^{(C)}$	Network Set $N\varepsilon_{\psi}^{(C)}$	Channel Set $CH_{\eta\varepsilon_{\psi}}^{(C)}$	Roles of CS $Rs^{(C)}$	Permission $PRMS^{(C)}$
$cr_1^{(C)}$	$ro_1^{(C)}$	$m_1^{(C)}$ $m_2^{(C)}$ $w_7^{(C)}$	$\{ch_1, ch_2\} \subseteq CH_{m_1}^{(C)}$ $\{ch_1, ch_2\} \subseteq CH_{m_2}^{(C)}$ $\{ch_1, ch_2\} \subseteq CH_{w_7}^{(C)}$	$rs_1^{(C)}$	$prms_1^{(C)}$ $prms_2^{(C)}$ $prms_3^{(C)}$
$cr_2^{(C)}$	$ro_2^{(C)}$	$m_3^{(C)}$ $w_4^{(C)}$	$\{ch_2, ch_3\} \subseteq CH_{m_3}^{(C)}$ $\{ch_3, ch_5\} \subseteq CH_{w_4}^{(C)}$	$rs_3^{(C)}$	$prms_4^{(C)}$ $prms_5^{(C)}$
$cr_3^{(C)}$	$ro_3^{(C)}$	$m_6^{(C)}$ $w_{10}^{(C)}$	$\{ch_1, ch_2\} \subseteq CH_{m_6}^{(C)}$ $\{ch_9, ch_{10}\} \subseteq CH_{w_{10}}^{(C)}$	$rs_2^{(C)}$	$prms_6^{(C)}$ $prms_7^{(C)}$
$cr_4^{(C)}$	$ro_5^{(C)}$	$w_8^{(C)}$ $m_9^{(C)}$	$\{ch_7, ch_8\} \subseteq CH_{w_8}^{(C)}$ $\{ch_8, ch_9\} \subseteq CH_{m_9}^{(C)}$	$rs_4^{(C)}$	$prms_8^{(C)}$ $prms_9^{(C)}$
$cr_5^{(C)}$	$ro_4^{(C)}$	$m_6^{(C)}$ $w_{10}^{(C)}$	$\{ch_1, ch_2\} \subseteq CH_{m_6}^{(C)}$ $\{ch_9, ch_{10}\} \subseteq CH_{w_{10}}^{(C)}$	$rs_5^{(C)}$	$prms_{10}^{(C)}$

2) User and Device(s) Registration from the System of Operator

At first time, each user will be asked to go to the office centre of Operator, e.g. the Mobile Communication Company. Then, the contract will be signed by both the user and the Operator in order to finish the user registration via face to face. After the user gets his/her user ID, $uID_u^{(k)}$,she/he further enters the information of device(s), in an online system, in order to do the device registration(s) through the system of Operator, e.g. the mobile communication system or Wi-Fi system, which is depended on the signed contract. In the online system, the system of Operator(s) will check whether the user and her/his device(s) registration have been finished the registration or not according to *Algorithm 1*. If all the requirements of the user's contract are satisfied, the system of Operator will assign a contract role $cr_i^{(k)} \in CR^{(k)}$ to the user and her/his device(s), where the role will be mapped to (1) the role of operator consisting of the network(s) and available channel(s), (2) the role of CS consisting of permissions. We show an example to illustrate how users and their devices are mapped to the contract roles, for examples in *Table 4*.

Algorithm 1: User and Device(s) Registration Phase

Input: *user ID,* $uID_u^{(k)}$*; device information;*

Output: *contract role* $cr_i^{(k)} \in CR^{(k)}$ ***;*** *a default network* $N\varepsilon_{\psi}^{(k)}$ *; a default channel* $ch^{(k)} \in CH_{\eta\varepsilon}^{(k)}$*;*

Begin

The user enters the information of device(s), in an online system, in order to do the device registration(s) through the system of Operator;

If (the system of Operator received $uID_u^{(k)}$ *and device(s) information) then*

If (check $uID_u^{(k)} \notin U^{(k)}$*) then*

a. the system of Operator notifies the user need to do user registration;

b. the User and Device(s) Registration Phase should be ended;

Else

the system of Operator will find out the signed contract;

End If;

While (all device(s) are registered in the system of Operator)

Do {

a. the user inputs the information of device one by one;

b. the system of Operator issues the device ID, $uID_u^{(k)}$ *to user according to the contract;*

c. the system of Operator assigns the contract role $cr_i^{(k)} \in CR^{(k)}$ *to the user, where contract role with the role mapping:*

i. the role of operator $ro_m^{(k)}$ *mapping to network,* $N\varepsilon_{\psi}^{(k)}$ *,also available channels,* $ch^{(k)} \in CH_{\eta\varepsilon}^{(k)}$*;*

ii. the role of CS $rs_x^{(k)}$ *mapping to* $p_p^{(k)} \in PRMS^{(k)}$*;*

d. the system of Operator assigns a default network $N\varepsilon_{\psi}^{(k)}$ *and a default channel* $ch^{(k)} \in CH_{\eta\varepsilon}^{(k)}$ *to each device according to the assigned contract role;*

};

End While;

Return*;*

Table 4. An example to illustrate how users and their devices are mapped to the contract roles

$U^{(k)}$	$D\upsilon^{(k)}$	$CT^{(A)}$	$CT^{(B)}$	$CT^{(C)}$
$u_1^{(k)}$	$d\upsilon_1^{(k)}, d\upsilon_2^{(k)}, d\upsilon_3^{(k)}$	$cr_1^{(A)}$	$cr_3^{(B)}$	$cr_2^{(C)}$, $cr_4^{(C)}$
$u_2^{(k)}$	$d\upsilon_4^{(k)}, d\upsilon_5^{(k)}, d\upsilon_6^{(k)}$	$cr_3^{(A)}$	*None*	*None*
$u_3^{(k)}$	$d\upsilon_7^{(k)}, d\upsilon_8^{(k)}$	*None*	$cr_2^{(B)}$, $cr_3^{(B)}$	$cr_4^{(C)}$
$u_4^{(k)}$	$d\upsilon_9^{(k)}$	$cr_5^{(A)}$	$cr_5^{(B)}$	$cr_3^{(C)}$
$u_5^{(k)}$	$d\upsilon_{10}^{(k)}$	$cr_5^{(A)}$	*None*	*None*

4.4.2 Access Phase

The user uses her/his registered device through a default channel $CH_{\eta\varepsilon}^{(k)}$ of the network $N\varepsilon_{\psi}^{(k)}$ which is constrained by the assigned contract role $cr_i^{(k)} \in CR^{(k)}$ activates an access request to the CS. In *Algorithm 2*, the contract role and the device authenticated by the system of Operator are legal or not. After passing the authentication, the user can activate multiple contract roles via an available channel of assigned network in order to access the resources from CS. For supporting cognitive network and cognitive radio (channel) to get better QoS, the device will sense received strength and quality of alternative channels of networks, periodically. After analysing the measured report, when the best strength and quality are better than the threshold values compared to the serving channel of network, the device will activate a new access request via the new channel of network which is having the best QoS according to the contract role. The CS will continue the services via new channel of network with the same permissions to the device.

Algorithm 2: Access Phase

<u>Input:</u> *contract role* $cr_i^{(k)} \in CR^{(k)}$***;*** *default network,* $N\varepsilon_{\psi}^{(k)}$*; default channel* $ch^{(k)} \in CH_{\eta\varepsilon}^{(k)}$*;*

<u>Output</u>: *activate the contract role* $cr_i^{(k)} \in CR^{(k)}$ *to access the resources from CS ;*

Begin

User activates an access request to the CS by using his/her contract role $cr_i^{(k)} \in CR^{(k)}$ *through the default channel* $CH_{\eta\varepsilon}^{(k)}$ *of the default* *network* $N\varepsilon_{\psi}{}^{(k)}$*;*

If (the contract role and the device authenticated by the system of Operator are illegal)
reject the access request for system of Operator and CS;
Else
activate the contract role $cr_i^{(k)} \in CR^{(k)}$ *to access the resources from CS via the default channel* $CH_{\eta\varepsilon}{}^{(k)}$ *of the default network* $N\varepsilon_{\psi}{}^{(k)}$;
End If;
While ((the device sense best $RSS_{c_i} + RSS_{TH}$ (dBm) *and* $RQ_{c_i} + RQ_{TH}$ *of alternative channel of network) > (* $RSS_{c_i} + RSS_{TH}$ (dBm) *and* $RQ_{c_i} + RQ_{TH}$ *));*
DO {
If (the alternative channel of network belongs to the contract role $cr_i^{(k)} \in CR^{(k)}$*)*
a. the device activate a new access request via the new channel of network $ch^{(k)} \in CH_{\eta\varepsilon}{}^{(k)}$ *to CS;*
b. the CS will continue the services via the new channel of network $ch^{(k)} \in CH_{\eta\varepsilon}{}^{(k)}$ *with the same permissions* $p^{(k)} \in PRMS^{(k)}$ *to the device;*
End If;
};
End While;
Return*;*
----
where
RSS = receiving signal strength;
RQ = receiving signal quality;
c_i = channel i, $i = 1,2,3,\ldots$;
RSS_{TH} = treshold value of RSS;
RQ_{TH} = treshold value of RQ.

5. Application Scenarios

Assume that there are a CS and three distinct Operators managed by distinct Providers: $CT^{(A)}$, $CT^{(B)}$, and $CT^{(C)}$ (the notations are defined for the simple), respectively. We then assume that the users u_1, u_2, u_3, u_4, u_5 and $d\upsilon_1, d\upsilon_2, d\upsilon_3, d\upsilon_4, d\upsilon_5, d\upsilon_6, d\upsilon_7, d\upsilon_8, d\upsilon_9, d\upsilon_{10}$, after registration procedure in the

CS and the Operators according to *Algorithm 1*, have satisfied the UA relations $UA^{(A)}$, $UA^{(B)}$, and $UA^{(C)}$ where the relations are defined according to *Definition 5* as follows: $u_1(d\upsilon_1^{(A)}, d\upsilon_2^{(A)}, d\upsilon_3^{(A)}) \in UA^{(A)}, u_2(d\upsilon_4^{(A)}, d\upsilon_5^{(A)}, d\upsilon_6^{(A)}) \in UA^{(A)}$, $u_4(d\upsilon_9^{(A)}) \in UA^{(A)}$,and $u_5(d\upsilon_{10}^{(A)}) \in UA^{(A)}$ where $UA^{(A)} \subseteq U^{(A)} \times D\upsilon^{(A)} \times CR^{(A)}$; Also $u_1(d\upsilon_1^{(B)}, d\upsilon_2^{(B)}) \in UA^{(B)}$, $u_2(d\upsilon_5^{(B)}, d\upsilon_6^{(B)}) \in UA^{(B)}$, and $u_4(d\upsilon_9^{(B)}) \in UA^{(B)}$ where $UA^{(B)} \subseteq U^{(B)} \times D\upsilon^{(B)} \times CR^{(B)}$; Finally, $u_1(d\upsilon_3^{(C)}) \in UA^{(C)}$, $u_3(d\upsilon_7^{(C)}, d\upsilon_8^{(C)}) \in UA^{(C)}$ and $u_4(d\upsilon_9^{(C)}) \in UA^{(C)}$ where $UA^{(C)} \subseteq U^{(C)} \times D\upsilon^{(C)} \times CR^{(C)}$. We illustrate cases with the following.

***Case 1*:** The users: u_2 using $d\upsilon_4, d\upsilon_5, \text{or } d\upsilon_6$, and u_4 via $d\upsilon_9$ shown in *Table 3*, are assigned the contract roles as $cr_3^{(A)}$ and $cr_5^{(A)}$, respectively, by the $CT^{(A)}$, where the two contract roles satisfy the ascendancy relation as $cr_3^{(A)} \succeq cr_5^{(A)}$. In other words, according to *Definition 6*, the user u_2 using $d\upsilon_4, d\upsilon_5, \text{or } d\upsilon_6$ can access not only the resources with the permissions $prms_6^{(A)}$ and $prms_7^{(A)}$ via the available channels $\{ch_4\} \subseteq CH_{m_6}^{(A)}$ and $\{ch_5, ch_6\} \subseteq CH_{w_7}^{(A)}$ and the assigned networks $m_6^{(A)}$ and $w_7^{(A)}$ set of the contract role, $cr_3^{(A)}$, but also the resources with the permissions via the available channels and the assigned networks set of the contract role, $cr_5^{(A)}$. On the contrary, however, the user u_4 using $d\upsilon_9$ cannot access the resources with the permissions $prms_{10}^{(A)}$ via the available channels $\{ch_9, ch_{10}\} \subseteq CH_{m_{10}}^{(A)}$ and the assigned networks $m_{10}^{(A)}$ of the contract role, $cr_3^{(A)}$. This implies that the user u_4 is assigned to the contract role $cr_5^{(A)}$, that is, the user u_4 is not assigned to another contract role $cr_3^{(A)}$. In *Table 2*, if the $CT^{(B)}$ server enforces these two contract roles $cr_2^{(B)}$ and $cr_3^{(B)}$, such that these two contract roles share a SSD relation according to *Definition 7*, and if these two contract roles are conflicting, then the user u_2 using $d\upsilon_5$ or $d\upsilon_5$ may never assign to these two contract roles $cr_2^{(B)}$ and $cr_3^{(B)}$, i.e. $\left(\{cr_2^{(B)}, cr_3^{(B)}\} \mid \{d\upsilon_5^{(B)}, d\upsilon_6^{(B)}\}, 2\right) \in SSD^{(B)}$. In *Table 3*, according to *Definition 8*, no users using any devices are allowed to activate both contract roles $cr_2^{(C)}$ and $cr_4^{(C)}$ in a single session, i.e. $\left(\{cr_2^{(C)}, cr_4^{(C)}\} \mid \{d\upsilon_3^{(C)}\}, 2\right) \in DSD^{(C)}$. The fact is that no DSD constraint on $cr_2^{(C)}$ and $cr_4^{(C)}$ is specified for the other contract roles. Only the $CT^{(C)}$ server enforces the DSD constraint that the user u_1 via $d\upsilon_3$ may never activate these two contract roles for a single user's session. Finally, after successfully performing a user's authentication by way of $CT^{(k)}$, a user can be allowed to access this CS via registered devices through available channels and assigned networks according to the contract roles.

***Case 2*:** A user, u_5, who uses her/his device, $d\upsilon_{10}$, is accessing the services from the network of $CT^{(A)}$ via current channel $ch_{10} \in CH_{m_{10}}{}^{(A)}$ by activating the assigned contract role, $cr_5{}^{(A)}$. On the meantime, the device performs *Algorithm 2.* Once the device detects an alternative channel of network, which having the better receiving strength and quality. The device will reselect the new channel, e.g. $ch_9 \in CH_{m_{10}}{}^{(A)}$, and requests it to the network of $CT^{(A)}$. Therefore, the network of $CT^{(A)}$ can reallocate the new channel to the device $d\upsilon_{10}$. After receiving response from the network of $CT^{(A)}$, the device, $d\upsilon_{10}$, will access the same services with the same permissions $prms_{10}{}^{(A)}$ via new channel $ch_9 \in CH_{m_{10}}{}^{(A)}$ by using according the contract role $cr_5{}^{(A)}$.

6. Discussions

The important characteristics in our generalized Cognitive RBAC model are analysed in the following. The CS may define Roles of CS (Rs) and Permissions ($PRMS$), the Operator(s) may define Roles of Operator (Ro), allocate Channels (CH), and assign Networks ($N\varepsilon$), and the contract between them may concern about Users (U), Contract Roles (CR), Sessions (S), Devices ($D\upsilon$), and Contract ($CT^{(k)}$)representing the set of users, contract roles, Roles of Operator, Roles of CS, permissions, sessions, devices, channels, networks and contracts set respectively; and furthermore, the CS and Operator(s) may also define the relationship UA, PA, RH, SSD and DSD.

6.1. Dynamic Changing Contract Role(s)

We assume that the CS and the system of Operator(s) make the contract(s), so that when system of Operator wants to delete and update a contract, in which the roles-mapping table should be reconstructed depending on the new contract, again. Therefore, the system of Operator is able to make sure that no user can activate the old contract role in any session to access permissions in the CS using any device through the channel of network. We propose two functions: $AddRole(\bullet)$ and $DeleteRole(\bullet)$ shown as *Function 1* and *Function 2* below, to support dynamic changing the contract role(s) mapping tables, e.g. *Table 1*, *Table 2* and *Table 3*.

Function 1. $AddRole(\bullet)$

$$AddRole\left(cr^{(k)}, ro^{(k)}, rs^{(k)} : Name\right)$$

$$cr^{(k)} \notin CR^{(k)}, ro^{(k)} \notin Ro^{(k)}, rs^{(k)} \notin Rs^{(k)}$$
$$CR'^{(k)} = CR^{(k)} \cup \left\{cr^{(k)}\right\}$$
$$Ro'^{(k)} = Ro^{(k)} \cup \left\{ro^{(k)}\right\}$$
$$Rs'^{(k)} = Rs^{(k)} \cup \left\{rs^{(k)}\right\}$$
$$assigned\_user' = assigned\_user \cup \left\{cr^{(k)} \mapsto \varnothing\right\}$$
$$assigned\_network' = assigned\_network \cup \left\{ro^{(k)} \mapsto \varnothing\right\}$$
$$assigned\_channel' = assigned\_channel \cup \left\{ro^{(k)} \mapsto \varnothing\right\}$$
$$assigned\_permission' = assigned\_permission \cup \left\{rs^{(k)} \mapsto \varnothing\right\}$$

Function 2. $DeleteRole(\bullet)$

$$DeleteRole\left(cr^{(k)}, ro^{(k)}, rs^{(k)} : Name\right)$$

$$cr^{(k)} \notin CR^{(k)}, ro^{(k)} \notin Ro^{(k)}, rs^{(k)} \notin Rs^{(k)}$$
$$\varsigma^{(k)} \in S^{(k)} \bullet r^{(k)} \in s\_r\left(\varsigma^{(k)}\right) \Rightarrow DeleteSession$$
$$UA' = UA\{u : U, d\upsilon : D\upsilon \bullet u, d\upsilon \mapsto cr\}$$
$$assigned\_user' = assigned\_user\{cr \mapsto assigned\_user(cr)\}$$
$$PA' = PA\{PRMS \bullet prms \mapsto rs\}$$
$$assigned\_permission' = assigned\_permission\left\{r \mapsto assigned\_permission\left(rs^{(k)}\right)\right\}$$
$$assigned\_network' = assigned\_network\left\{r \mapsto assigned\_network\left(ro^{(k)}\right)\right\}$$
$$assigned\_channel' = assigned\_channel\left\{r \mapsto assigned\_channel\left(ro^{(k)}\right)\right\}$$
$$CR'^{(k)} = CR^{(k)}$$
$$Ro'^{(k)} = Ro^{(k)}$$
$$Rs'^{(k)} = Rs^{(k)}$$

6.2. Comparisons

Finally, our Cognitive RBAC model is compared to influential research paper [1, 20] mentioned above. R. S. Sandhu *et al.*'s [1] proposed RBAC Models and Hsing-Chung Chen and Marsha Anjanette Violetta [20] proposed Cognitive RBAC in SHNs. To distinguish them with our model, we make table to compare some influential research papers with our scheme. The comparisons among Conventional RBAC, Cognitive RBAC in SHNs and MHNs are listed in *Table 5*.

Table 5. Comparison among Conventional RBAC, Cognitive RBAC in SHNs and MHNs

Items	Schemes		
	RBAC	Cognitive RBAC in SHNs [20]	Cognitive RBAC in MHNs
Multiple Assigned Networks	Not Addressed	Addressed	Addressed
Available Channels	Not Addressed	Addressed	Addressed
QoS	Not Addressed	Addressed	Addressed
Multiple Registered Devices	Not Addressed	Not Addressed	Addressed
SSD and DSD Constraint	User	User and Device	User and Device
Role Contract	Not Addressed	Not Addressed	Addressed between CS and Operator(s)
Cognitive Area Networks	Not Addressed	Home Area Network Local Area Network	Wi-Fi, Mobile Communication Network

7. Conclusions

In this work, we propose the generalized cognitive RBAC model in MHNs. In our scheme, a registered device constrained by its contract role(s) can intelligently sense the environment of networks, and choose a better access network as well as radio channel depending on its needed for the required performance of applications. A CS can support the services with cognitive RBAC management in LHNs the environment of networks. The contract should be made by the CS and each Operator, individually. The Operator can be as a mobile communication system provider or Wi-Fi provider. However, the MHNs consist of more than one mobile communication networks of operators and Wi-Fi of operators. In the model, we divide into two phases; there are the Contract and Registration Phase and the Access Phase. We also propose the SSD and DSD constraint based on not only a user but also on registered device(s). The cognitive RBAC model that we proposed has satisfied the requirements, in which the device can sense a better channel or network via a role, then the serving CS and the Operator can adaptively assign the better channel or the better network as well as its corresponding available radio channel to the role depended on the contract. Finally, the device can get the services from the CS using the role via accessing the new network as well as the new channel. Therefore, we then propose a very convenient RBAC model which can achieve more efficient management for

LHNs, and let mobile user can active perceive current network situations to get permissions and access corresponding services under the contract have made by CS with Network Providers.

Acknowledgements. This work was supported in part by Asia University, Taiwan, under Grant 101-asia-28, also by the National Science Council, Taiwan, Republic of China, under Grant NSC99-2221-E-468-011.

References

1. R. S. Sandhu, E.J. Coyne, H.L. Feinstein, and C.E. Youman, "Role-Based Access Control Models," *IEEE Computer*, vol. 29, no. 2, pp. 38 – 47, Feb. 1996.
2. Y. Cai, K. A. Hua, G. Cao., T. Xu, "Real-time Processing of Range-Monitoring Queries in Heterogeneous Mobile Databases," *IEEE Trans. on Mobile Computing*, vol. 5, no. 7, pp. 931 – 942, Jul. 2006.
3. G. Baldini, S. Braghin, I. Nai Fovino, A. Trombetta, "Adaptive and Distributed Access Control in Cognitive Radio Networks," *Proc. of The 24th IEEE International Conference on Advanced Information Networking and Applications (AINA 2010)*, pp. 988 - 995, 2010.
4. G. Chen, Z. Yong, M. Song, X. Wang, "Cognitive Access Control in Cognitive Heterogeneous Networks," *Proc. of IEEE International Conference on Communications Technology and Applications (ICCTA -2009),* pp. 707 - 711, 2009.
5. D. F. Ferraiolo, R. Sandhu, S. Gavrila, D.R. Kuhn, and R. Chandramouli, "Proposed NIST Standard for Role-Based Access Control," *ACM Trans. on Information and System Security*, vol. 4, no. 3, pp. 224 – 274, Aug. 2001.
6. H.-C. Chen, S.-J. Wang, J.-H. Wen, and C.-W. Chen, "Temporal and Location-Based RBAC model," *Proc. of the Fifth International Joint Conference on INC, IMS and IDC (MCM 2010)*, pp. 2111 – 2116, Seoul, Korea, Aug. 25 – 27, 2009.
7. X. Cai, F. Liu, "Network Selection for Group Handover in Multi-Access Networks," *Proc. of IEEE International Conference on Communications,* pp. 2164-2168, 2008.
8. H.-Y. Cui, Q.-J. Yan, "Heterogeneous Network Selection using a Novel Multi-Attribute Decision Method," *Proc. of the Third International Conference on Communications and Networking in China*, pp.153-157, 2008.
9. X. Dong, J. Wang, Y. Zhang, M. Song, R. Feng, "End to End QoS Provisioning in Future Cognitive Heterogeneous Networks," *Proc. of IEEE International Conference on Communications Technology and Applications (ICCTA -2009),* pp. 425 – 429, 2009.
10. R. W. Thomas, D. H. Friend, L. A. DaSilva, A. B. MacKenzie, "Cognitive Networks: Adaptation and Learning to Achieve End-to-End Performance Objectives," *IEEE Communications Magazine*, vol. 44, no. 12, pp. 51 – 57, 2006.
11. J. Mitola, III Maguire, G.Q., Jr. R., "Cognitive Radio: Making Software Radios More Personal," *IEEE Personal Communications*, vol. 6, no 4, pp. 13 – 18, Aug. 1999.
12. Wikipedia, "Cognitive Network," http://en.wikipedia.org/wiki/Cognitive_network, 2012.
13. H. Nan, Z.-G. Cao, "Wireless Cognitive Networks: Concept and Instance," *Computer Engineering and Applications*, vol. 45, no.2, pp. 1-6 , 2009.
14. J. Mitola, "Cognitive Radio – An Integrated Agent Architecture for Software

Defined Radio," Ph.D. Dissertation, Royal Institute of Technology, Kista, Sweden, May 8, 2000.

15. R. W. Thomas, L. A. Da Silva, A. B. Mac Kenzie, "Cognitive Networks," *Proc. of the First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks*, Baltimore, MD, USA, Nov. 8–11, 2005.
16. D. D. Clark, C. Partrige, J. C. Ramming, J. T. Wroclawski, "A Knowledge Plane for the Internet," *Proc. of the SIGCOMM*, Karlsruhe, Germany, Aug. 25–29, 2003.
17. C. Fortuna, M. Mohorcic, "Trends in the Development of Communication Networks: Cognitive Networks," *Computer Networks*, 2009.
18. Q. Mahmoud, "Cognitive Networks: Towards Self-Aware Networks," *John Wiley and Sons*, 2007.
19. S. Liang, "Cognitive Networks: Standardizing the Large Scale Wireless Systems". *Proc. of the 5th IEEE Consumer Communications and Networking Conference (CCNC 2008)*, pp. 988-992, Jan. 2008.
20. H.-C. Chen and M.-A. Violetta, "Cognitive RBAC in Small Heterogeneous Networks," *Proc. of the Sixth International Conference on Innovative Mobile and Internet Services in Ubiquitous Computing (IMIS-2012)*, pp. 494 – 499, Palermo, Italy, Jul. 4- 6, 2012.
21. R. Yu, Y. Zhang, S. Gjessing, C. Yuen, S. Xie, M. Guizani, "Cognitive-Radio-Based Hierarchical Communications Infrastructure for Smart Grid," *IEEE Network*, Sept. 2011.
22. Li, L., Yan, H., Li, H., Zhang, C., "Velocity Adaptation for Synchronizing a Mobile Agent Network," *Computer Science and Information Systems*, vol. 8, no. 4, pp.1303-1315, Oct. 2011.
23. D. Mitrović, M. Ivanović, Z. Budimac, M.Vidaković, "Supporting Heterogeneous Agent Mobility with ALAS," *Computer Science and Information Systems*, vol. 9, no. 3, pp. 1203-1230, Sept. 2012.
24. M. Ganzha, A. Omelczuk, M. Paprzycki, M. Wypysiak, "Information Resource Management in an Agent-based Virtual Organization—Initial Implementation," *Computer Science and Information Systems*, vol. 9, no. 3, pp. 1307-1330, Sept. 2012.

Dr. Hsing-Chung Chen received the B.S. degree in Electronic Engineering from National Taiwan University of Science and Technology, Taiwan, in 1994, and the M.S. degree in Industrial Education from National Normal University, Taiwan, in 1996, respectively. He received the Ph.D. degree in Electronic Engineering from National Chung Cheng University, Taiwan, in 2007. During the years 1991-2007, he had served as a Mobile Communication System Engineer at the Department of Mobile Business Group, Chunghwa Telecom Co., Ltd. During February 2008–present, he has served as the Assistant Professor of the Department of Computer Science and Information Engineering at Asia University, Taiwan. Currently, he is interested in researching Information Security, Cryptography, Role-based Access Control, Wireless Heterogeneous Networks, Mobile Communications, and Medical Image Processing. He was Workshop Co-Chair of NCM-2009, NCM-2010, ITAUC-2011, ITAUC-2012, ITAUC-2013, SMEUCE-2012, SMEUCE-2013, ATIMCN-2012, ATSME-2012, NGWMN-2010, NGWMN-2011, and NGWMN-

2012, Track Co-Chair of NBiS-2012 and NBiS-2013, Web & Local Arrangement Co-Chair of ISIC-2012. He was Program Committee Co-Chair of EMC-2012. Presently, he is also the Program Committee Co-Chair of CISIS-2013 and IMIS-2013. He is a member of IEEE, IET, CCISA, and ICCIT. He was as the Leader Guest Editor of SI: "Recent Advances in Networked Computing" of *Journal of Networks*. From July 2012 – present, Dr. Chen is also the Editor-in-Chief of *Newsletter of TWCERT/CC (From February 2013, it has been re-named as 'Taiwan Information Security Newsletter').*

Marsha Anjanette Violetta received the BS degree in Information System from Amikom College, Indonesia, in 2010, and the MS degree in Computer Science and Information Engineering from Asia University, Taiwan, in 2013. She is current a PhD Student studying in Asia university, Taiwan, from September 2013. She is also a lecturer in the Department of Informatics Engineering, Islamic University of Indonesia and also the Department of Information System, Amikom College, Indonesia. Her research interests include Role-Based Access Control, E-mail Phishing, Database Security, and Cloud Computing.

Dr. Chien-Erh Weng received the M.S. degree in Electrical Engineering from the National Yunlin University of Science & Technology, Yunlin, Taiwan, and the Ph.D. degree in electrical engineering from the National Chung Cheng University, Chiayi, R.O.C., in 2000 and 2007, respectively. Since Sep. 2010, he joined the Department of Electronic Communication Engineering at National Kaohsiung Marine University, Kaohsiung, Taiwan, R.O.C., as an Assistant Professor. His research interest is in the fields of performance study of UWB communication systems, wireless sensor networks and cooperative radio networks.

Dr. Tzu-Liang Kung received the BS degree in industrial administration from the National Taiwan University in 1997, the MS degree in statistics from the National Chiao Tung University, Taiwan, in 2001, and the PhD degree in computer science from the National Chiao Tung University in 2009. From 2001 to 2004, he served as a Senior Engineer at the Behavior Design Corporation, Taiwan. He is currently an assistant professor in the Department of Computer Science and Information Engineering, Asia University. His research interests include multivariate data analysis, machine translation, natural language processing, interconnected systems, fault-tolerant computing, algorithm design, and wireless networks.

Received: November 10, 2012; Accepted: March 25, 2013