Abstract—Every organization faces challenging task in the designing of the communication network in order to make its efficiency smoother by the increasing complexities. Therefore, we have to proposed a concept of cognitive network and how the intelligent agents are deployed to overcome the challenges. With the tremendous expansion of networks across the globe, the deployment of intelligent agents in cognitive networks contributes as an efficient, reliable and challenging task for the researchers. In this paper, we survey the existing research work on cognitive networks and later we provide the artificial intelligent techniques that are potentially suitable for the development of cognitive networks.

Keywords: Artificial Intelligence, Cognitive network, Intelligent agents.

I. INTRODUCTION:

One of the fastest growing areas is the information and communication technologies. These changes have an immediate impact on diverse aspects of the modern society, which includes inter-human relations, economy, education & entertainment. In this respect, the development of reliable, flexible and future-proof infrastructure should be capable of increasing the users’ quality of life by providing services such as e-health, e-learning and e-payments. In order to meet the demand of the increased complexity, future networks should be easily maintainable and their capabilities should be continuously improved and upgraded by relying as little as possible on human intervention. Therefore the network research community proposed a new concept of networking: The Cognitive Network. What is a Cognitive Network and how are the intelligent agents deployed is what we have presented here.

Cognitive networks

In this section, we analyze several existing definitions for cognitive networks, and we argue that two elements are essential for developing a cognitive network (CN): the knowledge representation and the cognition loop. Next, we discuss the framework proposed in [2] for introducing cognition to communication networks. The main part of the section focuses on methods from AI that seem applicable for developing CNs. We provide a summary of several types of intelligent agents (IAs), map them to the functional states of the cognitive loop. As we go along, we also refer to existing research on CNs which makes use of the respective type of IA, where available. How it started? The word cognitive refers to an entity that is able to perform some kind of conscious intellectual activity such as thinking, reasoning, learning or remembering in order to make sense of its surroundings. This word was first used in communication networks to refer to a technology by Mitola as he introduced the cognitive radio [4].
We would like to emphasize that, according to the dictionary [9], the word cognitive used as an adjective to a noun means: of, relating to, being, or involving conscious intellectual activity (as thinking, reasoning, or remembering); based on or capable of being reduced to empirical factual knowledge.

In [2], 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 the decisions in the future.

This definition of CN does not explicitly mention the knowledge of the network; it only describes the cognitive loop and adds end-to-end goals that would distinguish it from CR or so called cognitive layers [2]. We consider this definition of CN incomplete since it lacks knowledge which is an important component of a cognitive system as discussed so far in this paper and also in [2,4,6,8].

The cognitive process can operate in a centralized way, spanning over a large network, or in a totally distributed manner at a device level. In the first case, it might be too expensive to centralize all the network specific information that the cognition loop requires, while in the second case there might be too little knowledge available to pursue end-to-end network goals. In reality, the deployment of the cognitive functionality in a network will depend on the network specific problems and will be an engineering decision. However, it is important that the cognitive framework is designed in such way as to be modular, easily upgradeable and scalable in order to be able to accommodate existing as well as next generation technologies and applications.

The capabilities of a Cognitive Network can be highly distributed or extremely centralized. In general, a Cognitive network is formed of a set of distributed cognitive entities (agents) which are somehow “smart” as they have certain reasoning capabilities to be connected to the network. The entities in such a network interact with each other, they can cooperate, act selfishly or a combination of the two. While functioning in this environment, the entities are able to learn and take decisions in such way as to reach an end-to-end goal. These end-to-end goals are dictated by the business and user requirements [2,4]. Developing and maintaining such a network is an extremely challenging task and has enormous potential, especially in the area of network management.

A Cognitive Network needs to evolve overtime: its set of technologies has to be updated by removing deprecated and adding new ones; its set of tools that help managing complexity should be added and removed in a plug and play fashion. Thus, the architecture of cognitive network should be flexible and should lead to a modular and highly scalable infrastructure. Furthermore, the cognitive network must be self aware: it should be able to determine appropriate actions to achieve goals and to learn while doing all these. It should be self-configuring, self-optimizing, self-healing and self-protecting in a cognitive way.

In this paper, we analyze some recent trends in the development of communication networks and investigate in more detail the concept of cognitive network. Cognitive networks are promising to be the major step towards efficient and automatic management of increasing complexity of communication networks.

Cyclic Process in Cognitive Network.

All systems that are able to adjust their functioning according to changes in their environment are based on feedback information. Cognitive networks are no exception in this respect, so they will also use a control loop, also called cognition cycle [7, p. 7], feedback loop [2], context based adaptation loop [8]. According to Thomas et al. [2], the loop employed by a cognitive network should be based on the concept of the Observe-Orient-Decide-Act loop originally used in the military, augmented by learning and following end-to-end goals to achieve cognition. In [8], the loop also has a communicating capability for communicating with other loops in a distributed environment.
The cognition cycle as described by Mitola [7, p. 8] features the following states: observe, orient, plan, decide, act and learn. It uses the orient module for classifying stimuli and does not explicitly encompass policies.

Cycle management:

In [10], the authors investigate a cognitive agent for wireless network selection which is designed to hide the complexity of the wireless environment from the user. The selection problem is decomposed into four elements that enhance the agent to select the network which is most suitable to user preferences. First, user’s feedback that the decision making process will be used is captured. Second, the available services are evaluated against learned user preferences. Third, the agent decides when to change services and which new service to select based on user’s preferences, context and goals.

Fourth, the value of previously unseen services is predicted. Using this approach, the agent continuously monitors the wireless environment and selects the best service according to the current model of user preferences. However, when the user is unsatisfied (or changes preferences), The model is updated and a new selection is made to satisfy preferences. A Cognitive Resource Manager (CRM) and its conceptual architecture are introduced in [14]. The CRM’s functioning is based on a cognition cycle adapted from Mitola [7] and aims at enabling autonomic optimization of the communication stack as a whole, thus acting as an intelligent vertical calibration (Fig.1). The intelligence would be based upon methods from the field of AI.

**Loop for security**

The CycSecure application [12] makes use of an incomplete cognitive loop. It uses daemons installed on machines in the network that collect local information and send it to the server when polled. A human operator can examine and modify the network model, query and view network statistics. The system is able to generate possible attack plans based on the information gathered from the system and the internal knowledge base. Based on these attack plans, the human operator can decide for remedy measures to increase the security of the system.

**Communication Requirements and research directions**

In the history of telecommunications, development has always been driven by humans need to communicate, i.e. reliably transmit ever increasing amount of information across increasing distances. However, communication networks became increasingly complex and more difficult to manage, requiring increasingly specialized tools and human operators for their maintenance, configuration and optimization. From the user’s point of view the necessities in the world of telecommunications, as it is today, are: higher bandwidth or alternative solutions capable of accommodating the traffic. These necessities derive from the user’s thirst for digital content.

From the network operators’ point of view, some of the main necessities are: complexity, management, security, scalability, fault tolerance, fast integration of new technologies and a good business model [6]. The network operator has to create adequate premises for delivering the digital content.

These user’s and network operators necessities are actually forming the basis for research activities currently underway in the area of cognitive networks. In general, research directions in communications can be classified in 8 broad categories: theory, signal processing, networks, software, user satisfaction, security, management and next generation protocols and architectures. In an attempt to obtain an objective big picture of the trends in research areas as well as quantitative estimation of the ongoing work, we used ontogeny, a semi-automatic ontology editor [6] to analyze the

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**Fig 1. Open Systems Interconnection (OSI) model**
Artificial intelligence:

Artificial intelligence is concerned with intelligent behavior in artifacts. Intelligent behavior, in turn, involves perception, reasoning, learning, communicating, and acting in complex environments. Artificial Intelligence has as one of its long-term goals the development of machines that can do these things as well as humans can, or possibly even better. Another goal of AI is to understand behavior whether it occurs in machines or in humans or other animals.

Intelligent agents developed in a couple of streams of work, among them is cybernetics [Wiener 1948], cognitive psychology, Computational linguistics [Chomsky 1914], and adoptive control theory [Widrow & Hoff 1960], also contributed to the intellectual matrix developed by Artificial intelligence.

Intelligent Agents:

Intelligent agents in Artificial intelligence react, plan, reason and learn in an environment more or less compatible with its abilities and goals. Here we shall see how the actions of other agents can be anticipated in each agents own planning, and indeed, how an agent can even affect the actions of other agents in the service of its own goals. To predict what another agent will do, we need methods for one agent to model another; to affect what another agent will do. There are two kinds of models used by agents, iconic and feature based. An iconic model of the environment attempts to simulate relevant aspects of the environment; a feature-based model attempts to describe the environment—perhaps by formulas in the predicate calculus. The agents that we deploy can use either an iconic or a feature-based model of the other agents cognitive structure. And the other agent itself might be presumed to be using either an iconic or feature-based model. The four possibilities are shown in table 1 along with the modeling strategy each one provokes.

The starting point towards developing a CN is the intelligent agent (IA). This section presents existing and emerging AI techniques that can prove useful for developing agents for CNs. According to Russell and Norvig [13, p. 42], an agent is central to AI. It is an entity that perceives the environment through sensors and acts upon that environment through actuators. This is the so called “weak” definition of agency while “stronger” definitions take into account functions and characteristics of the agent [14, p. 8,13, p. 42]. Among different classifications of agents, we will consider as a reference, the one established at IBM, which uses three dimensions to describe agents (see Fig.6). The first dimension is the Agency, which determines the degree of “autonomy and authority vested in the agent”. The second dimension is the Intelligence, which describes the degree of reasoning and learned behavior. Finally, the third dimension is Mobility, which specifies the degree to which agents travel through the network [14, p. 9]. Current networks operate via message passing (i.e. IP packets between two routers or primitives between TCP and IP) where the receiver takes an action as a consequence of the received message. This type of operation is asynchronous and is characteristic to expert systems [14, p. 9,15]. This approach permitted loose coupling of complex systems (e.g. communication networks). However, this approach permits the lowest degree of autonomy according to Fig. 1. On the Intelligence axis, some of the current communication systems do not even reach the lowest level as they do not even allow specification of preferences (e.g. QoS specifications). In this respect, CNs are expected to enhance the level of intelligence of current communication systems by incorporating so called
Intelligent Agents (IAs) in the KP. On the Agency axis, IAs can perform actions on behalf of the user, more specifically they can interact with data, applications or services. On the Intelligence axis, IAs can hold a model (i.e. user, system, environment, etc.), perform reasoning, planning and learning. These actions are exactly the same as the ones desired from CN and can be found in the states of the cognition loop (see Plan, Decide, Act, Learn and Policy Fig.4).

Networks of the future will make use of agents to improve their performance with respect to all three axes in Fig 1.

In the case of CNs, the main improvement is achieved with respect to the Intelligence axis. Therefore, in the remainder of the section we focus on describing utility of Intelligent Agents for these networks. We also emphasize the correspondence between Intelligent Agents and the states of the cognition loop. From the intelligence point of view, the minimal requirement for an Intelligent Agents in general is to hold a model and be able to reason based on this model. These IAs (Intelligent Agents) are also called knowledge-based agents. Reasoning can take place upon two types of knowledge: certain (true, false and unknown) and uncertain. Reasoning under certain knowledge is accomplished by logical agents. In this respect, agents “can form representations of the world, use a process of [logical] inference to derive new representations about the world, and use these new representations to deduce what to do” [13, p. 191]. Logical agents use symbolic knowledge representations, so called artificial languages, and typically first-order logic to infer new facts. These representations also support semantic querying. Agents that have incomplete or uncertain information use decision theory and are also called decision theoretic agents. These agents use knowledge representations specific for uncertain domains (i.e. full joint distributions can constitute the knowledge base) to reason. Then they perform probabilistic inference, which is the computation of posterior probabilities from the observed evidence.

Conclusions

The recently emerging CN concept is promising to be the right answer to emerging challenges of the network management. In this paper we surveyed existing work on CNs. We first analyzed recent research trends in communications. We mapped existing AI techniques to the states of the cognition loop and identified challenges for research in AI from which CNs could benefit. We concluded the paper with identification of standardization activities related to or potentially benefiting from the research in the area of CNs.

The discussions in this paper indicate that the way forward in developing CNs is to bring together the experts from the areas of communication networks and AI. Communication networks are faced with great complexity challenges and several AI techniques proved to handle complexity well. Furthermore, AI is searching for areas of applications, and communication networks are underexploited in this respect. However, due to the vastness in Artificial Intelligence field, we hope to upgrade more in terms of Cognitive Networks and other methods & tools of AI.


References:


AUTHORS PROFILE

I am currently employed in Jazan University, Jazan, K.S.A Department of Computer Networks. My area of Research is Artificial Intelligence, Data Mining, Network Security. I have published few papers in International Journals. I wish to do research more into these fields.