## Towards a Cognitive TCP/IP Network Architecture

C. Facchini, F. Granelli Dept. of Information Eng. and Comp. Science (DISI) University of Trento Via Sommarive 14, I-38123 Trento, Italy Email: {facchini,granelli}@disi.unitn.it

The principal aim of cognitive networking is to equip traditional networks with some sort of intelligence, in order to make them evolve and achieve higher levels of performance than those that can currently be achieved [1].

Typical characteristics of cognitive networks are the ability to monitor the environment they are deployed in, to take reasoned actions based on current conditions towards an end-to-end objective, and to learn from past experience. Such enhanced networks will likely be characterized by a non-negligible complexity, which can be tolerated if accompanied by relevant benefits, such as performance increase or mitigation of management burden.

Different cognitive proposals have been proposed thus far in the literature, ranging from general framework definitions [2], to cognitive node architectures [3,4], to specific implementations [5].

This contribution aims to illustrate the concepts we advanced in previous works [6-8], in which we described how the cognitive networking paradigm can fill the gap between service-oriented architectures and network, and extend them, by enabling reasoning with external information, i.e. information that is not locally available and is sensed elsewhere in the network. This enables the cognitive process to achieve a global vision of the network, which should facilitate the achievement of better end-to-end performance.

The principal components that constitute the proposed architecture are represented in Figure 1. Specifically, they are:

- acting and sensing variables;
- acting and sensing entities;
- the cognitive management protocol;
- the cognitive entity.

An acting variable represents the interface to tune a particular aspect of a node. The interface is simple on purpose: any element can be reconfigured using only a pair of instructions. The meaning of the instructions, however, depends on the specific element to be reconfigured. For instance, if we want to control the congestion window, the command pair will be 'increase' and 'decrease'. If we want to regulate the fragmentation of packets, the instructions will mean 'turn on' and 'turn off'.

The main role of a sensing variable is to keep the environment monitored so as to capture important events. When a relevant change happens, the sensing variable sends an update to the cognitive entity. In order to lower as much as possible the complexity of the architecture, we have decided to implement only push-type notifications. As a consequence, the cognitive entity cannot request any measurement to the sensing variables and must reason exclusively using the available information.



Figure 1. High-level view of the proposed cognitive network architecture

In order to distinguish relevant updates from non-relevant ones, we employed an exponentially weighted moving average (EWMA) control chart [9]. In brief, for each source of information a control chart is drawn. The controlled quantity is an estimate of the mean value, computed as an EWMA of the actual mean, while upper and lower control limits are proportional to the standard deviation. Only when the estimate crosses either one of the boundaries, an update is sent.

The function of acting and sensing entities is to aggregate acting and sensing variables, respectively. Their main task is to minimize communication overhead, while supporting the cognitive functionality of the network.

All nodes must implement the so-called cognitive management protocol, which is used to transmit across the network both the information collected by the sensing variables and the commands to reconfigure the acting variables. It is worth to notice that while a cognitive node must implement the cognitive management protocol, there is no need for it to have any sensing or acting variables at all. For instance, a centralized wireless access point may be equipped only with reasoning capabilities, and receive updates from and send commands to the associated wireless stations.

The role of the cognitive entity is to perform reasoning tasks, specifically by providing the collected information to and interrogating a specific reasoning formalism, so to eventually guide the acting variables in the network. We have purposely decided to separate the cognitive entity from the reasoning formalism, in order not to constrain network designers in any way.

As for the reasoning formalism, following the encouraging results we had obtained in previous investigations, we used fuzzy cognitive maps (FCMs) [10], which are directed labeled graphs that can be used for causal reasoning. However, we would like to stress that the adoption of the specific reasoning scheme can naturally be replaced with other approaches.

It is worth to notice that no constraints are placed on the number of cognitive entities: we allow the possibility of having multiple in the same network. In fact, being a cognitive network characterized by a global scope, it is likely that many a node have to adapt themselves jointly, in order for some effect to take place. This means that nodes have to able to coordinate themselves to carry out a common goal, or in more general terms, to extend the cognitive process to the whole network.

Consequently, future research will focus on the analysis of the presence of multiple reasoning entities in the same network and will be targeted on the study of advantages and drawbacks of both centralized and distributed reasoning processes.

## References

- R. W. Thomas, D. H. Friend, L. A. DaSilva, and A. B. MacKenzie, "Cognitive Networks: Adaptation and Learning to Achieve End-to-End Performance Objectives," Communications Magazine, IEEE, vol. 44, no. 12, pp. 51-57, 2006.
- [2] R. W. Thomas, L. A. DaSilva, and A. B. MacKenzie, "Cognitive Networks," in 1st Intl. Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN), pp. 352-360, 2005.
- [3] P. Mahonen, M. Petrova, J. Riihijarvi, and M. Wellens, "Cognitive Wireless Networks: Your Network Just Became a Teenager," in Proceedings of the 25th Conference on Computer Communications, 2006.
- [4] P. Sutton, L. E. Doyle, and K. E. Nolan, "A Reconfigurable Platform for Cognitive Networks," in 1st Intl. Conf. on Cognitive Radio Oriented Wireless Networks and Communications (CROWNCOM), pp. 1-5, 2006.
- [5] N. Baldo and M. Zorzi, "Learning and adaptation in cognitive radios using neural networks," in 5th IEEE Consumer Communications and Networking Conference (CCNC), 2008, pp. 998-1003.
- [6] C. Facchini and F. Granelli, "Towards a model for quantitative reasoning in cognitive nodes," in 3rd IEEE Workshop on Enabling the Future Service-Oriented Internet - Towards Socially-Aware Networks (GLOBECOM '09), Dec. 2009, pp. 1-6.
- [7] C. Facchini, F. Granelli, and N. L. S. da Fonseca, "Cognitive Service-Oriented Infrastructures," Journal of Internet Engineering Special Issue on Service-Oriented Infrastructures, Klidarithmos Press, 2010.
- [8] C. Facchini, F. Granelli, and N. L. S. da Fonseca, "Identifying Relevant Cross-Layer Interactions in Cognitive Processes," in GLOBECOM '10, Dec 2010.
- [9] M. G. Kallitsis, G. Michailidis, and M. Devetsikiotis, "Measurement-based optimal resource allocation for network services with pricing differentiation," Performance Evaluation, vol. 66, no. 9-10, Sept. 2009, pp. 505-523.
- [10] B. Kosko, "Neural Networks and Fuzzy Systems: A Dynamical Systems Approach to Machine Intelligence", Prentice-Hall, 1992.