Editorial
Cognitive and Smart Adaptation in Computer-Communication Networks

THE WORLD of telecommunication has experienced a rapid transformation in the last decade, and this transformation is still accelerating. On the one hand, new communication technologies bring high bandwidth and affordable communication channels to the millions. The public has quickly embraced wired technologies such as the cable and asymmetric digital subscriber line (ADSL), which were once thought to provide very large bandwidth. With the auctioning of the Universal Mobile Telecommunications System (UMTS) frequencies in many European countries, a similar growth is also taking place for the wireless technologies. On the other hand, new applications and new services are being developed, which make use of the bandwidth and the connectivity provided by the communication networks and which increase the requirements put on these networks manyfold. In addition to that, users increasingly expect that their networking and communication needs should be handled ubiquitously and pervasively, without limitations related to their location or geographical constraints. Many telecommunication services are transitioning to the Internet, and this is bound to be a dominant trend. However, the Internet is not only a source of information, but it has become a medium through which businesses reach their customers and organize themselves internally. New applications corresponding to the new ways of working, enabled by ready access to computer networks, means that the computer-communication networks must be able to accommodate the increased expectations and the requirements put on them. These expectations and requirements will increase geometrically with the advent of technologies such as ambient intelligence [1], [2].

With this transformation at hand, the area of computer-communication networks is reaching a major crossroads. The industry and major actors state that the current networks in general, and the Internet protocol (IP) in particular, with its various extensions and modifications, are unable to provide the quality of service (QoS) that many of these applications need and expect. To deliver the QoS needed by these applications, networks must be responsive to the heterogeneity in the demands and goals of the users, and they must be self-aware [3], [8] in the sense that they have means to observe and measure their own environment and the performance that they are experiencing, and that they make configuration decisions depending on the dynamic conditions and the different requirements of the applications. Furthermore, they must be able to respond quickly to various kinds of technical and nontechnical changes, and they must maintain a certain level of self-sufficiency. Computer-communication networks currently do not possess these characteristics.

What is required from modern computer-communication networks is that they possess more intelligence [4]. This intelligence is required for two major reasons. The first reason is to provide scalability. As the networks become ubiquitous, network maintenance and management requirements grow exponentially, making it too expensive to perform manually. Hence, the networks must have sufficient intelligence to take over most of these tasks. This provides scalability comparable to the scalability obtained for the telephone networks, when the telephone operators were replaced by automated "switch boxes." The second reason is to make networks adaptive and responsive to different circumstances, such that the high demands on the QoS [5] can quickly and optimally be met. This requires smart adaptation from the networks and implies more cognitive capabilities.

The architecture of intelligent networks can be viewed as an overlay network, where the network provides functionality for finding services and users, routing through the network, and self-observation and network monitoring to obtain the best QoS and performance. For this, it makes use of the available distributed machine learning and reasoning techniques. The infrastructure of the intelligent networks must also be smart adaptive. One such infrastructure that has been proposed is the cognitive packet network (CPN) [6], [7]. In this network, the packets that the network sends may be smart, and the network tries to learn optimal policies through machine learning techniques such as reinforcement learning to provide the requested or agreed QoS. The CPN algorithm, which runs at the packet transport level and finds destination nodes, can be also abstracted to higher levels where it can search for users and/or services.

The search for such intelligent networks such as the CPN has motivated research into "control plane"-based techniques that can provide some level of QoS with the help of adaptive control and "cognitive network" approaches that exploit smart online algorithms and use computational intelligence techniques. This special issue collects recent contributions in this rapidly progressing field.

The paper by Sabella considers the subject of self-adapting networks and discusses the key issues that need to be solved to realize future infrastructures. An example system is described that could be regarded as a concrete step toward realization of self-adapting networks. The characteristics of such a system

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are discussed, and the feasibility of the concept is assessed, whereas some hot issues that need to be addressed are also discussed.

In the paper by Ghanea-Hercock *et al.*, the authors propose an algorithm for forming a dynamic and self-organizing network, where each network node tries to maintain a minimum number of connections proactively. The network parameters are updated using Hebbian-style learning, such that the network as a whole exhibits adaptive self-organizing behavior. This is an example of the work where techniques from computational intelligence are applied to design robust networks resilient to targeted attacks.

Saffre *et al.* study the emergence of cooperation in a network of autonomic devices. In this example of an interdisciplinary approach to intelligent networks, they make use of approaches developed to study complex adaptive systems in biology, and the authors demonstrate how these approaches can be a powerful tool when planning the deployment of large ensembles of interacting autonomic devices.

Gelenbe *et al.* conduct an experimental investigation of path discovery using genetic algorithms (GAs) in CPNs. The GA combines paths that were previously discovered to create new untested but valid source-to-destination paths, which are then selected on the basis of for their "fitness." The authors present an implementation of this approach, where the GAs run in background mode. The experimental results that they report show that the GA can result in improved QoS when it is able to be responsive to dynamic network changes. They also show that a more dynamic approach, based on CPN's reinforcement learning algorithm, is more effective when the system is undergoing heavy load.

Finally, Lent considers scalability problems in ad hoc CPNs. He proposes a couple of solutions to these problems to effectively balance the traffic of multiple flows, without the large overhead that would be needed if round-trip delay were used.

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