Overview

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Introduction

Man-made self-organizing systems date back to antiquity; for example, elaborate water clocks found from Alexandria (Ctesibius’s clepsydra) to Seoul (King Sejong’s Chagyongnu) were designed to keep constant rates or strike at regular time intervals without human adjustment. More modern examples include Watt’s centrifugal governor, Black’s negative feedback amplifier, and Nyquist’s stability test, which enabled engineered systems to stabilize themselves. These and numerous innovations in control theory and engineering optimization have contributed much to modern communications technology. But there is a need for advances in both methods and applications beyond what has been achieved in the precise settings of mechanical, electronic, and optical switching and transmission towards the self-management and control of large-scale systems with many interacting and semi-autonomous components. Natural phenomena may be a guide for us, a model for self-organized decentralized systems. Spontaneous magnetization, crystallization, lasers, and superconductivity are examples of structural self-organization in physics where cohesive behavior emerges from initial disorder. In self-assembly and auto-catalytic networks in chemistry, molecules organize themselves in well-ordered arrangements without external action, and in biology, we observe highly complex coordinated action as in the folding of proteins, homeostasis, and flocking.

The scale and complexity of modern communication systems and networks, and the progressively decentralized nature of their ownership, are strong reasons to look at self-organization and self-optimization as possible models for management and control of these highly complex systems, ultimately with no direct involvement of the human operator. Complexity here is not merely a computational and transport challenge that could be overcome through acquisition of vast amounts of computational, switching, and transmission resources; it is the diversity of applications, volume of connections, geographic spread of users, localized ownership of the network, and “connectivity, anytime, anywhere” with ever-increasing bandwidth that make the underlying systems challenging to manage in traditional ways. Resource management for best-effort data services in the Internet in the form of Transmission Control Protocol (TCP) is perhaps an early successful example of a distributed solution that not only addresses the problem of dynamic resource allocation with negligible overhead, but also self-optimizes network capacity. With the heterogeneity of new applications, real time and non-real time services, the requirement of being connected (wireline or wireless) all the time, the challenge is to develop and implement appropriate generalizations of effective and low-overhead mechanisms not only in the “control plane” which is rather well mechanized but also in the “management plane” where much of the complexity of modern day communication systems has shifted.

The need for large-scale automation is felt even more strongly as the management of each piece of the global network continues to demand more effort. As the cost of hardware has declined, the cost of operating the network has risen, outpacing hardware costs many times over for the majority of operators. Of course not all operations expenses are related to the efficient and intelligent management of the network; there are also fixed charges, marketing and sales costs,
and costs of goods that together typically exceed 70 percent of the network-related costs, as illustrated in Figure 1. But the remaining 20 percent of costs for network operations fall within the addressable space of large-scale automation or “self-x.” Considering that the total worldwide service provider operations expenses range in the multiple hundreds of billions of dollars annually, the absolute size of the potential cost savings due to network operation comes sharply into focus.

**Issue Content**

In this volume we aim to provide a snapshot, from the research and development (R&D) perspective, of where we stand with respect to the goal of making communication networks and systems self-organizing and self-optimizing. Figure 2 provides an outline of a possible roadmap of “self-x” functionality, illustrating just how far research has progressed and how far it still has to go. For example, there is much we can still learn and discover about self-recovery in networks, but in comparison with self-adaptation and learning, we have come a long way. As witness, consider Bidirectional Line-Switched Ring (BLSR) and Unidirectional Path-Switched Ring (UPSR) for self-recovery in optical ring architectures, Optimized Link State Routing (OLSR) and Open Shortest Path First (OSPF) as self-healing protocols for Internet Protocol (IP) layer link restoration, and numerous other techniques both proposed and implemented across the layers of the communication systems. Similarly, there is much progress in auto-configuration and “zero touch” systems for initializing and starting-up network elements. Still, adapting these static parameters as a function of load and scale continues to be a considerable and worthy challenge. We still have some way to go to enable “machine reasoning” so that automated action can be correlated, articulated, and explained.

The 14 papers in this issue focus on three main topics: 1) self-organization in Long Term Evolution (LTE), a high performance air interface standard for cellular mobile communication systems; 2) Self-managed wireline broadband access via copper (DSL) and fiber-like Gigabit passive optical networks (GPON); and 3) self-organization and self-optimization techniques in general.

LTE is a prime target for self-x enablement since much has been done in the standardization of key parameters and measurements under the 3rd Generation Partnership Project Self-Optimized Network (3GPP SON) initiative. Service provider interest and enthusiasm around SON in conjunction with the deployment of LTE have stimulated much research and development in this area, and six papers in this issue address a variety of solutions proposed for deployment in the next one to three years. In “The Evolution of SON to Extended SON,” the authors provide a vision of self-organization in LTE networks mapped to the goals and aspirations for fourth generation (4G) wireless systems. Next, “Self-Organizing
Interference Management for LTE” and “ICIC in DL and UL With Network Distributed and Self-Organized Resource Assignment Algorithms in LTE” discuss a key differentiator for LTE: the elimination of time-consuming and inefficient frequency planning through semi-static and dynamic sharing of the entire spectrum between all LTE base stations known as eNodeBs (representative of bullet 4 and bullet 5 in Figure 2). In “Autonomous Neighbor Relation Detection and Handover Optimization in LTE,” the authors discuss a critical problem in the automation of wireless cellular networks so that geographic proximity can be learned and used through indirect feedback from mobile terminals (bullet 4). “Autonomous Spectrum Sharing for Unstructured Cellular Networks With Femtocells” presents a case for highly distributed resource allocation techniques when base stations have been shrunk to cover a household (bullet 5). Here there is no state to communicate—all action is unilateral, and the challenge is effective use of the same spectrum between these tiny cells and across to the macro cells that cover much larger areas. The final paper in this set is “Self-Optimization of LTE Networks Utilizing Celnet Xplorer,” which provides a highly granular data acquisition, summarization, and anomaly detection framework underpinning LTE SON and xSON (bullets 3 and 4).

Two papers, “Autonomous Dynamic Optimization for Digital Subscriber Line Networks” and “Self-Adaptive Dynamic Bandwidth Allocation for GPON,” respectively, consider self-learning schemes for increasing bandwidth in DSL lines and effective bandwidth allocation in GPON without feedback (bullets 4 and 5). Both papers introduce novel yet simple tools to achieve considerable efficiency through automated learning.

Reconfiguration,” which presents a quick overview of self-x work under the support of European Union (EU) Framework initiatives.

The ultimate judge of our innovations for making communication networks and systems self-organizing and self-optimizing are the networks and systems themselves, which will accept or reject our solutions almost in the Darwinian sense of the “survival of the fittest.” In *Cybernetics: Or Control and Communication in the Animal and the Machine* [1], Norbert Wiener, an inventor of the science of cybernetics, and arguably a father of our modern efforts in the analysis and design of self-organizing systems, had the following to say as early as 1948: “Historically it is interesting that in the early days of alternating-current engineering, attempts were made to connect generators of the same constant voltage type used in modern generating systems in series rather than in parallel. It was found that the interaction of the individual generators in frequency was a repulsion rather than an attraction. The result was that such systems were impossibly unstable unless the rotating parts of the individual generators were connected rigidly by a common shaft or by gearing. On the other hand, the parallel busbar connection of the generators proved to have an intrinsic stability which made it possible to unite generators at different stations into a single self-containing system. To use a biological analogy, the parallel system had a better homeostasis than the series system and therefore survived, while the series system eliminated itself by natural selection.”

Reference

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