Mathematical Modeling of Self-Organizing Systems*

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Extended Abstract

The evolution of the Internet reveals surprising turns and obstacles. Centralized approaches of introducing new services and architectures consistently failed to materialize at large scale. Quality of Service, group communication, and mobility support are only some examples for the difficulty with orchestrated approaches. The success story of the Internet, on the other hand, is strongly linked to decentralization.

Robustness to failures or flexibility in introducing new applications such as the World Wide Web or Peer-to-Peer systems has been key momentum to technological advances and economics. Future networks are envisioned to be highly complex and difficult to manage due to heterogeneity of networks, spontaneous set-up of networks, and the envisioned number of interconnected devices, appliances, and artifacts.

The concept of self-organization is widely spread in science among various disciplines. It has been applied successfully already in engineering and for describing the behavior of specific technical systems. Thus, self-organization is foreseen to play a major role in future communication systems.

The question that poses itself is whether self-organization can be generally exploited to a larger scale for solving some of the previously mentioned pending problems for future networks. This question leads to a variety of open research challenges. Solutions to these challenges are pivotal in either leveraging the possible advantages of self-organizing systems, but could also turn out to be a heavy burden for both operators and users. The goal is clearly set: after purposefully introducing (artificial) means of self-organization, the beneficial features – often identified as the so-called self-* properties – should clearly outnumber the critical ones, like un-controllability, undesired instability and criticality, or unpredictability. Thus, it is essential for the community to learn how to design, engineer, optimize, and control complex, almost chaotic systems in a structured, purposeful way. One tool that provides means for this demand is the concept of mathematical modeling.

The particular challenge in building mathematical models for self-organizing systems lies in their complexity. Driven by randomness and feedback, the relation between cause and effect of these systems may appear chaotic: minor causes may have severe impact, whereas seemingly major causes may only have a small effect. Traditional mathematical models tend to be unsuitable to model self-organizing systems. Models to be developed should be simple to remain scalable to the huge number of entities in the systems under investigation and to be generally applicable.

Moreover, the non-centralized nature of self-organizing networks makes them sensitive to non-cooperative behavior of users since in such networks users are expected to be able to take their proper decisions on issues such as forwarding packets for other users (in Peer-to-Peer networks or in access to wireless networks). Game theoretic models are then appropriate for modeling the decision making. Although a major research effort has been devoted to game theory in this context, there is little that includes randomness and feedback in the modeling.

In this talk, we propose a survey on the concept and impact of self-organization, on already existing but application-specific approaches for self-organizing system models, and our first steps towards a generally applicable model to be developed in a joint EuroFGI research project on "Mathematical Modeling of Self-Organizing Systems".

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