



Internet Factories

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Summary

We live in an information-centric society kept together by the Internet. From its humble beginnings as a scientific experiment, the Internet is becoming an immense data processing infrastructure in which people and manmade objects exchange information. However, the incredible pace at which the Internet is developing is a problem. The telecom industry can hardly catch up with the speed of technological developments. Think of the difference between the first mobile phones and today's smart phones. My current smart phone on Swisscom's 4G network offers almost 7000 times more bandwidth to the Internet than my first 14k4 modem connection around twenty years ago. Also for the realization of smart cities, connected cars, and other cyber-physical systems the Internet plays a crucial role, as these developments will interconnect everyone and everything.

The consequence is that computer networks are becoming increasingly complex and difficult to innovate. With each new technology and development the number of combinations and interactions with existing technologies and devices only increases. This is unsustainable in the long run. It is inefficient and expensive to introduce technology as a package of hardware and software, which have to be embedded in existing systems often in an application-specific manner. A new innovation model is required in which hardware, software, and services are decoupled.

This thesis presents the concepts for a sustainable innovation model for computer networks based on software. Instead of introducing devices implementing new network technologies, network technologies are implemented in application software. Consequently, telecommunication networks and services are simply applications running on a networked infrastructure of servers and a new network technology is simply the creation of an application program. This is a new avenue of research for computer science that has not been given attention yet: how to create a methodical process for programming computer networks from application programs?

This thesis contributes a novel concept for solving the presented research problem, which is named *Internet factories*. The Internet factories concept describes the steps to create *Netapps* and the software platform, the Internet factory, to allow its execution. A Netapp is a description of the behavior of a network in all its aspects in the form of a computer program. An Internet factory uses the Netapp and additional input parameters to manufacture and

deploy application-specific Internets including the mechanisms for its operation. A major advantage of this approach is that developers of Netapps can use standardized components, common patterns, and software libraries for the creation of Netapps and profit of higher reliability and faster development times for new network technologies. Experiments with a proof of concept, called Sarastro, show that in essence the network is just a manifestation of the Netapp. Therefore, the contribution of Internet Factories can also be summarized as: *the Netapp is the network*.

The Internet Factories concept comes just in time while the telecommunication industry is becoming aware of the emerging need for mass customization and complete unbundling of network services. In my thesis, I have created a structural basis for the development of computer networks in application software. Upcoming technologies, such as Network Function Virtualization (NFV), Software Defined Networks (SDN), and Openflow, show that the vision of this thesis is becoming reality. My work also shows that the research focus in network research will shift to the development of Netapps, as Netapps are at the basis for articulating a new computer science problem: can we create computer programs that scale to the size of the Internet? In other words, what are the controllability and programmability limits of Netapps?