

# Engineering control levels in an Autonomic Network

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## Abstract

*The following paper contains problem statements about Autonomic Networking intended to contribute to the position paper to be submitted to ICT Mobile Summit 2009.*

## Introduction

According to the convergence of different network services and networks, the Internet is expected to become the communication substrate over which the majority of the voice, data and multimedia traffic between people will be conveyed. The clearly observable trend that communication networks are becoming increasingly complex is going to continue well into the future. System complexity, obviously, escalates with the number and functional complexity of the elements that make up the system and the level of interactions between them [1]. In the case of communication networks, the dramatic increase of complexity what we witness today originates from the boost in the number of components, the widespread use of small and portable devices, MEMS, sensors, RFIDs, etc. The heterogeneity of the network also stems from the wide variety of standards and vendors that in some way or another contribute to the network infrastructure. Since manually engineering this ever-growing complexity does not seem viable in the future, an important challenge is to automate the process of network management as much as possible. State-of-the-art communication systems perform several management tasks (e.g. addressing, scheduling, routing etc.) in an autonomic manner, however complexity enforces autonomicity to become a dominant and ubiquitous feature in future networks. Autonomic Networking is an emerging paradigm to make this happen. The idea is to organize much of the network functionality into a hierarchy of so called control loops: the system constantly monitors for misbehavior or a change in the operational environment, then, after thorough analysis, a management decision is made in order to respond to the shift in network state based on aggregated system information, and finally the adjustment of the system is performed accordingly. This endues the network with certain self-management capabilities, like self-adaptation, self-healing, self-protection, or self-optimization, etc.

*For a feasible operation, an important requirement is that the management decision is made much faster than the operational environment actually changes, which in many cases naturally limits the tolerable complexity and dynamics of the controlled system, the management process and the hierarchy of decision making elements.* In order to speed up the control process, management decisions should be made as close to the bare metal as possible. *On the other hand, deliberate management decisions are impossible to make without proper and up-to-date knowledge on the system under control, on the operational environment it is embedded in, etc., but this aggregated knowledge and state information is, usually, only available at higher levels of the control loop hierarchy.* This pushes control decisions upwards in the hierarchy of decision making elements. It is, therefore, a fundamental task to determine the optimal level at which control decisions should be made, depending on the specifics of the actual aspect of the Autonomic Network being under control. This can be done at the node itself, e.g., in the case of bus allocation in local area Ethernet, buffer management, or packet scheduling, or has to

be done at higher levels where the decision is of global interest and is made based upon aggregated state information, like in IP address allocation, QoS routing, etc.

In this sense, different problems require control loops of different “extent”. On one hand, a certain amount of information is needed to make a decision, which pushed decision making upwards in the hierarchy. On the other hand, resource efficiency or timeliness require to make decision making as fast as possible, which requires quick, low level decisions. Also, for specific management tasks it is acceptable to make decision with incomplete information at low levels, which can be refined globally if necessary.

The hierarchy of the autonomic managers is clearly affected by the facts mentioned above, therefore the analysis of management tasks with respect to the properties of the system under control, is crucial in autonomic networking.

## **Open problems**

### 1. Control loop levels

The most important question is to stipulate what levels of control loops are required to make a management decision. This question can be answered by in-depth analysis of the management task and the properties of the system. The following factors should be considered:

#### a) Management side

- Operational considerations: constraints imposed on the system that should be respected by the autonomic decision making process, management goals and objective, state information to be monitored, parameters needed be controlled, etc.
- Convergence speed: Time interval within which the management constraints should be fulfilled.
- Robustness: Toleration to uncertainty in the input data.
- Scalability: The computational complexity, memory footprint, etc., should be kept under reasonable limits.
- Flexibility: How adaptive the system should be against new challenges.

#### b) System side

- Size of the system
- Complexity of the elements: This can be architectural as well as computational like amount of memory, processing capacity etc.

Besides identifying the necessary control loop levels another interesting issue within this topic is to propose the appropriate algorithms to specific management tasks.

### 2. Tradeoffs

The final solution of a management task has to take under consideration some trade-offs between the factors mentioned above. From the management side, the optimal solution would be the global control of the system properties by gathering an arbitrary amount of relevant information. However, this solution may conflict with the speed, scalability and flexibility requirements. On the other hand, if we give up the idea of global control and push the managerial decision making downwards, the system may exhibit autonomous aspects when viewed from outside (e.g. in a non-global addressing scheme, duplicate labels may appear).

The in depth investigation of these managerial and system trade-offs are desirable when planning Autonomic Networks.

### 3. Areas of interest

The above mentioned control loop and trade-offs are to be investigated in numerous areas of autonomic networking:

- In case of addressing, the structure and distribution of the address space is a major issue.
- The routing and searching tasks on large scale networks may call for unstructured addressing like in social networking [2].
- Scheduling of different time scales (packet, connection, process etc.) on a decentralized basis is an open issue.
- Trust-based data forwarding inspired by human acquaintance networks is an interesting future challenge [3].
- High performance autodefense and security mechanisms can have strict timing constraints, which imply reduced control loops.
- Finally, fault tolerance and self-healing with respect to system performance is an interesting point.

## **References**

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