Future Internet and Autonomic Networking:
Form Theory to Experimentation

Symeon Papavassiliou

Institute of Communications and Computer Systems (ICCS)
School of Electrical and Computer Engineering
National Technical University of Athens (NTUA), Greece

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What is Future Internet?

- Collection of nodes?
- Internet as a Service?
- Internet as Cloud?
- Content distribution framework?
- Internet of Things?

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A collection of (nodes, agents, components, objects, services …) that **collaborate** to accomplish actions, gains, …that cannot be accomplished with out such collaboration

It is all about **Interactions** that keep increasing and become more complex

Trade-off: gain from collaboration vs. cost of collaboration
Networks: Different Views (1)

- Today: Host centric abstraction
- Future: Information centric abstraction – primary object is not the host but the content – information object is conceptually detached from original host
- Network of Information vs. Network of nodes
- Networks:
  - as distributed, asynchronous, feedback (many loops), dynamic systems
  - as distributed asynchronous active databases and knowledge bases
  - as distributed asynchronous computers
Networks: Different Views (2)

Network Science employs a three level consideration:

- **Physical** networks, in which node associations correspond one-to-one in actual interactions among the entities and physical connectivity.

- **Logical** networks, involve logical associations and connectivity among peers. Such networks include, overlay and peer-to-peer (p2p) networks.

- **Social** networks, involves more complex interactions, that take into account mainly unpredictable/hidden social associations (activities).
Control vs. Communications

- Many graphs as abstractions
- Collaboration graph – or a model of what the system does (behavior)
- Communication graph – or a model of what the system consist of (structure)
- Challenge 1: Given behavior, what structure (subject to constraints) gives best performance?
- Challenge 2: Given structure (and constraints) how well behavior can be executed?
- Topology modification – topology formation/Transformation
The Grand Challenges in Future Networking

- A heterogeneous environment (virtualization, federation)
  - Different types of resources
  - Different QoS-provisioning and resource allocation mechanisms.
  - Various services with various and often diverse QoS prerequisites.

- New types of networks and roles
  - Dynamic environment (Manual management is difficult)
  - Large scale deployment
  - New roles in network components (e.g. mobile phones as routers)

- Broadband mobile is a key element for sustainable and inclusive quality of life in Europe
  - Year 2020 (estimation): 5 billion broadband mobile subscribers, 50 billion wireless devices

- Complexity, Stability, Scalability
Autonomic Networking

- A simple but fundamental observation is that the one element, besides an interface (e.g. radio), that all communicating objects will have in common is **awareness**.
- In the future a plethora of enabled devices will act in an **autonomic** fashion with varying levels of intelligence and capabilities.
- Autonomic Network Management in terms of
  - Self-configuration
  - Self-optimization
  - Self-healing
  - Self-protection
  - .....

Autonomic networks depend on **collaboration** between their nodes for all their functions

- The nodes gain from collaboration: e.g. multihop routing
- Collaboration introduces cost: e.g. energy consumption for packet forwarding
Designing Autonomics….

A well established architecture

But who does what and how can be connected towards enabling an overall optimization goal?
Traditional approaches…

- Autonomicity via heuristics – ad hoc environment-specific solutions
  - What about optimality?

- Autonomicity via “control” theory
  - What about robustness to network dynamics & network’s stochastic nature?

- Autonomic architectures via design
  - What about stability, scalability and optimization?
What is missing.....?

A. A common “mathematical language” as a theoretic foundation towards designing:
   “Autonomic Future Internet Architecture”

B. Large scale realistic assessment/validation

“Don’t Optimize Current Networking Functionalities via Autonomics,
Design Theoretically-Sound Autonomic Mechanisms”
Network Utility Maximization (NUM theory)

- Math foundation for network architecture:
  - Network: Generalized NUM
  - Layering architecture: Decomposition scheme
  - Layers: Decomposed subproblems

- Decomposition theory naturally provides the “mathematical language” to build an analytic foundation for the design of **modularized** and **distributed control** of networks.
NUM & Autonomic Architectures Design (ANUM)

**decentralized nature**

- necessitates the collaboration of various network components to achieve different layering objectives
- implies the distribution of the decision making procedures of the network among its components, instead of traditional centralized approaches.

- Such alternatives favor the development of nodes’/networks’ self-optimization and self-manageability functionalities, that are founded on theoretical frameworks towards enabling future networking vision of autonomicity.
An Example: Towards an Autonomic Integrated Wireless Paradigm
Validation and Experimentation

- Designing Autonomic Future Internet architecture is a complex task involving:
  - various end-user communities; various functionalities; network components; various technologies; heterogeneity; signalling; synchronization; communication; collaboration; orchestration; distributed operation; optimality; decision making; etc.
  - Various self-* functionalities (i.e. control loops) at node or network level with inherent issues of stability, scalability, complexity and optimality.

- Testbed and Experimentation
  - Testbed as a Facility
  - Testbed as a Service
Virtualization+Federation: viable path to experimentation

Network Virtualization:
- Allows multiple heterogeneous network architectures to cohabit on a shared physical substrate
- Provides a powerful way to run multiple virtual networks, each customized to a specific purpose, simultaneously over a shared substrate
- Provides flexibility, promotes diversity, promises manageability

Testbed Federation:
- Interconnection of independent testbeds/environments for enhanced experimentation under common management framework – “being part” of single resource/environment
- Positive externality (benefits of both the users and providers of the individual testbeds)
- Heterogeneity and diversity (geographical, technological)

Hybrid Testing: Large scale experimentation in combination with emulations
Towards Virtualization over the NREN/GÉANT Federation
Advanced federated services required

- Common tools to create, monitor and control virtual resources allocated to Future Internet user communities, enabling the “network on demand” service
- Common, context aware descriptions of heterogeneous virtual networking elements, enabling resource discovery and provisioning of composite services
- End-to-end virtualization across a heterogeneous substrate that extends from core optical networking to end-user testbeds
- Virtual resource allocation algorithms, scheduling and federated admission control mechanisms leading to the concept of “infrastructure as a service”
Thank you…

papavass@mail.ntua.gr
http://www.netmode.ntua.gr/papavass/