Future Internet and Autonomic Networking:

Form Theory to Experimentation

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What is Future Internet?

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

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

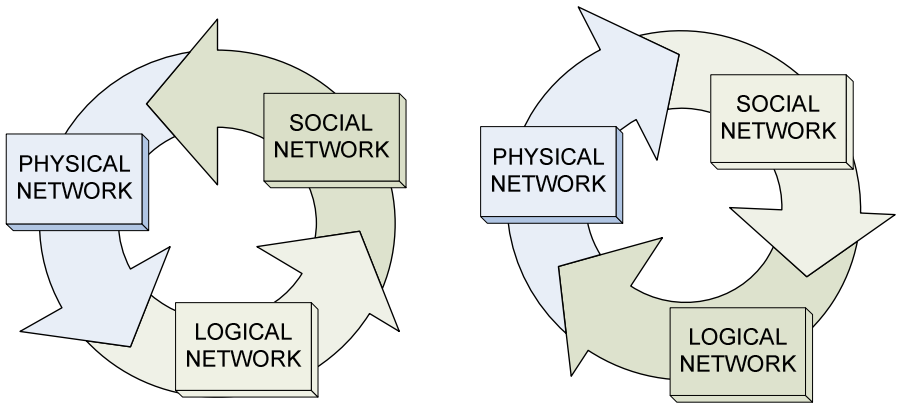
Networks: Different Views (1)

- 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

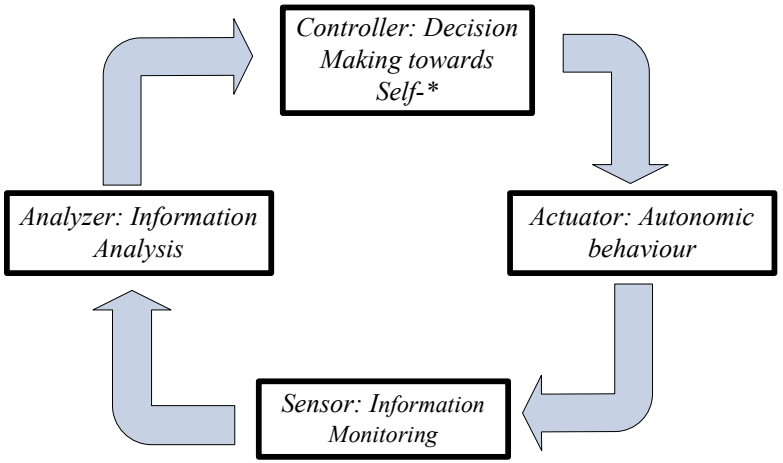
- A simple but fundamental observation is that the one element, besides an interface (e.g. radio), that all communicating objects will have in common is awareness
- In the future a plethora of enabled devices will act in an autonomic fashion with varying levels of intelligence and capabilities.
- Autonomic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

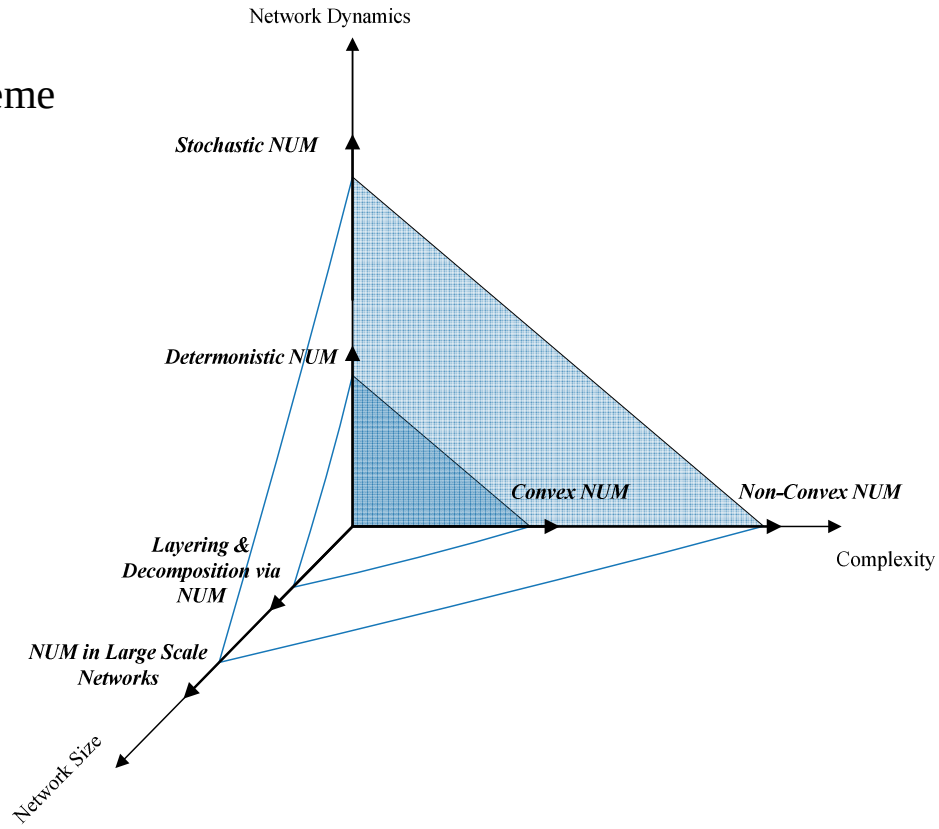
"Autonomic Future Internet Architecture"

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



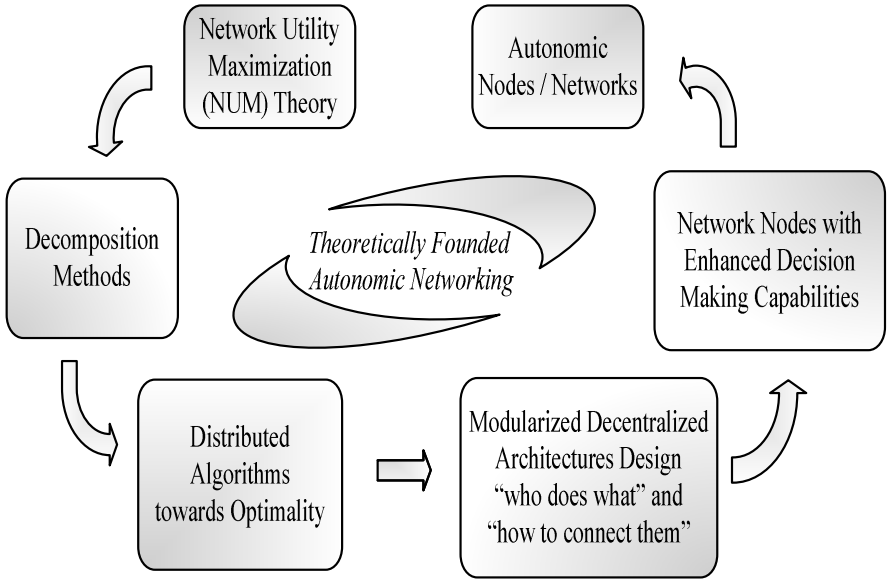
- Decomposition theory naturally provides the “mathematical language” to build an analytic foundation for the design of **modularized** and **distributed control** of networks.

NUM & Autonomic Architectures Design (ANUM)

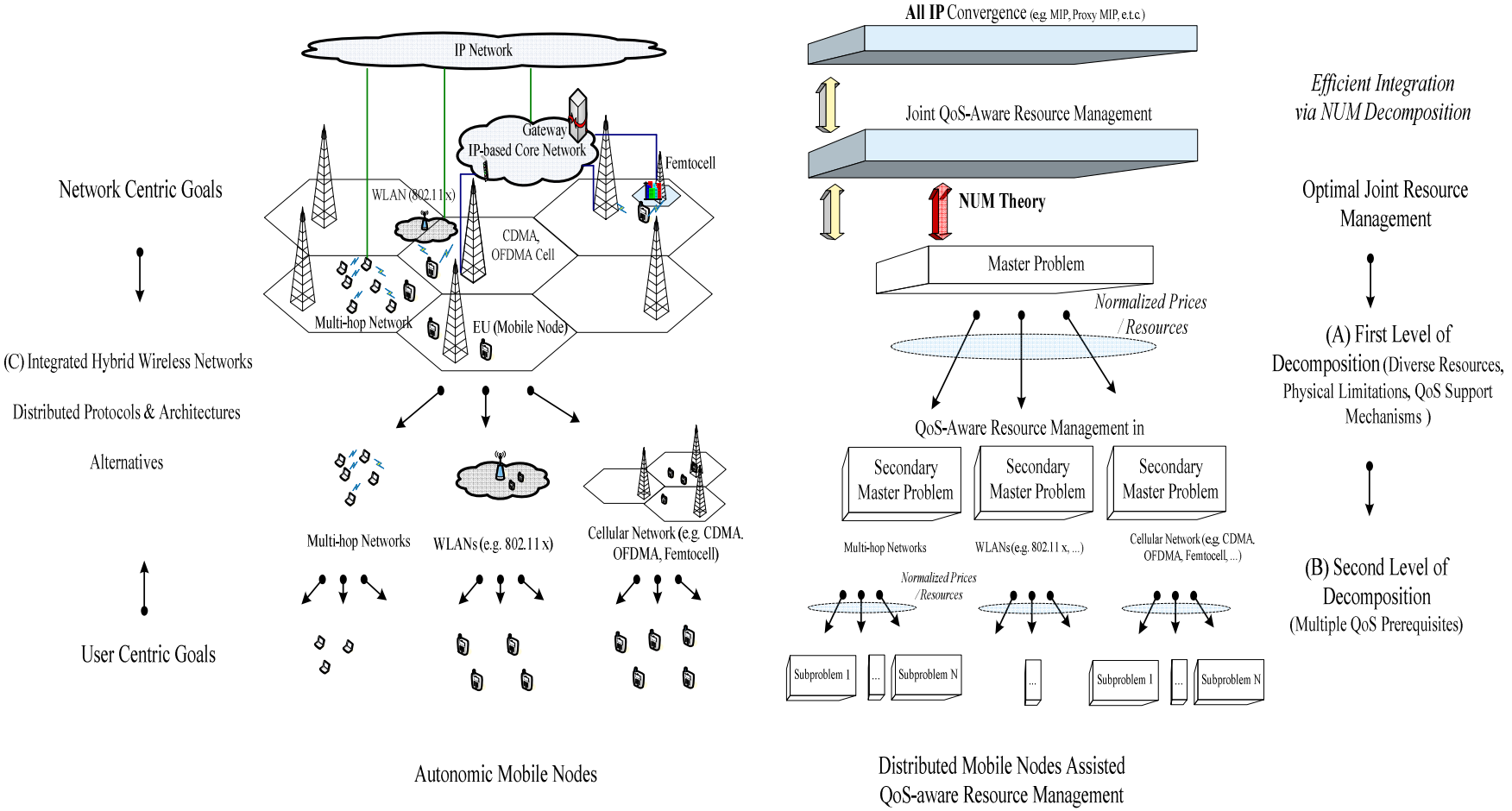
decentralized nature

- 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:

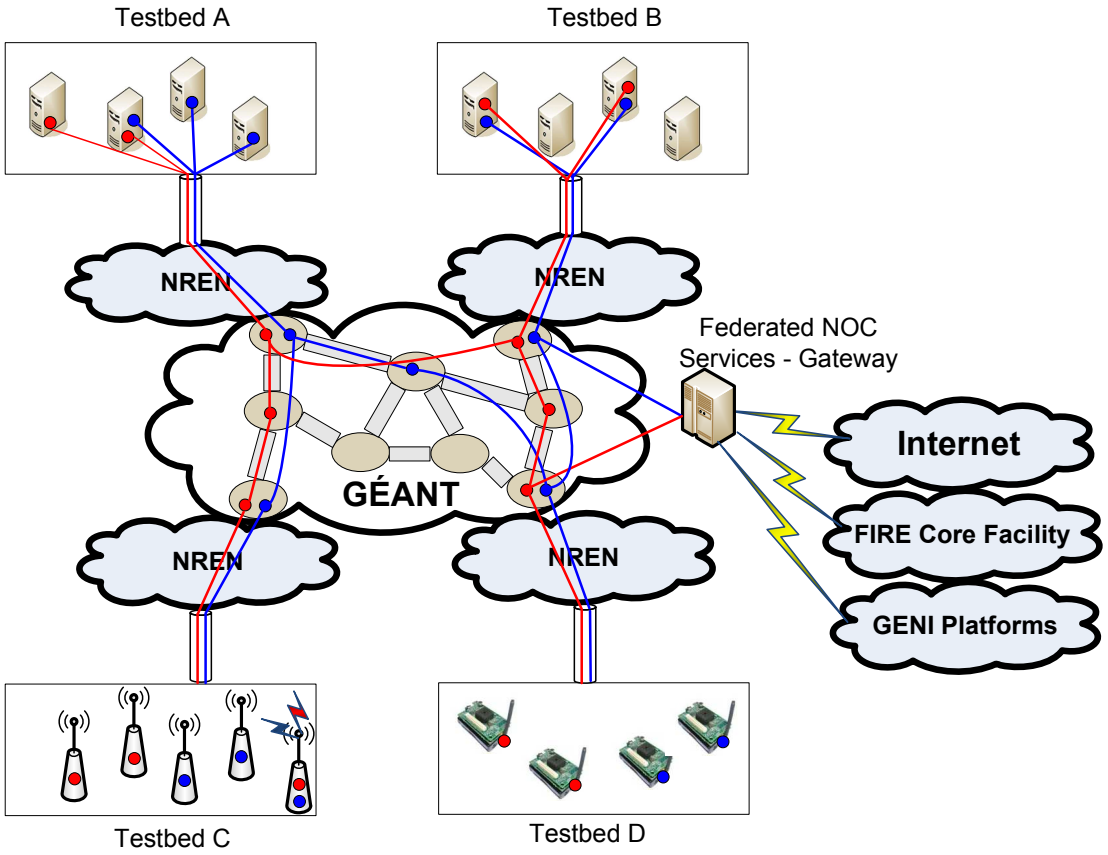
- Allows multiple heterogeneous network architectures to cohabit on a shared physical substrate
- Provides a powerful way to run multiple virtual networks, each customized to a specific purpose, simultaneously over a shared substrate
- Provides flexibility, promotes diversity, promises manageability

Testbed Federtation:

- 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…

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