



# Future Internet and Autonomic Networking: Form Theory to Experimentation

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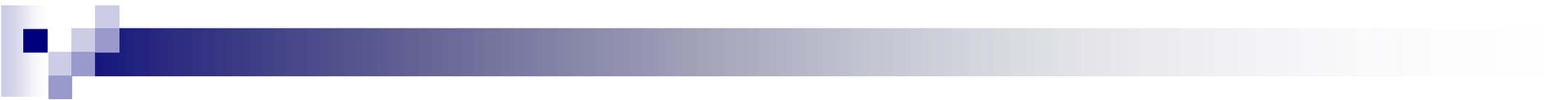
# What is Future Internet?

- 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 with feedback (many loops) → **dynamic systems**

**Trade-off:** gain from collaboration vs. cost of collaboration



# The Grand Challenges in Future Networking

- A **heterogeneous** environment
  - 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**
- **Measurement**-driven activities, **Validation**, data **hygiene**



# Autonomic Networking

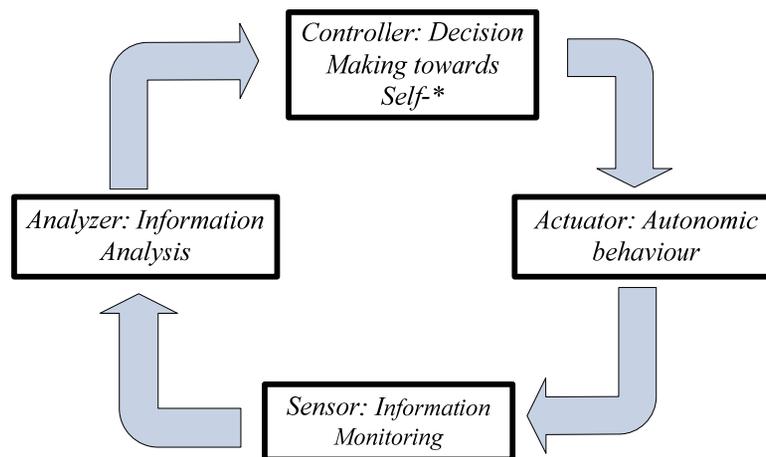
- A simple but fundamental observation is that the one element, besides an interface (e.g. radio), that all communicating objects will have in common is **awareness**
- In the future a plethora of enabled devices will act in an **autonomic** fashion with varying levels of intelligence and capabilities.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

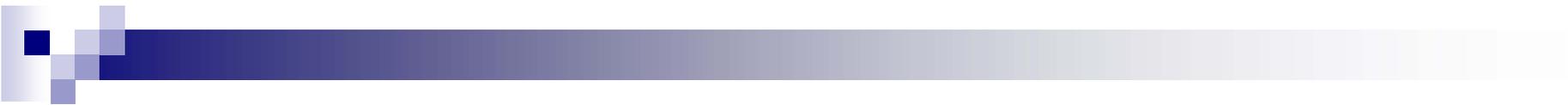


But who does what and how can be connected towards enabling an overall optimization goal?



## 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:

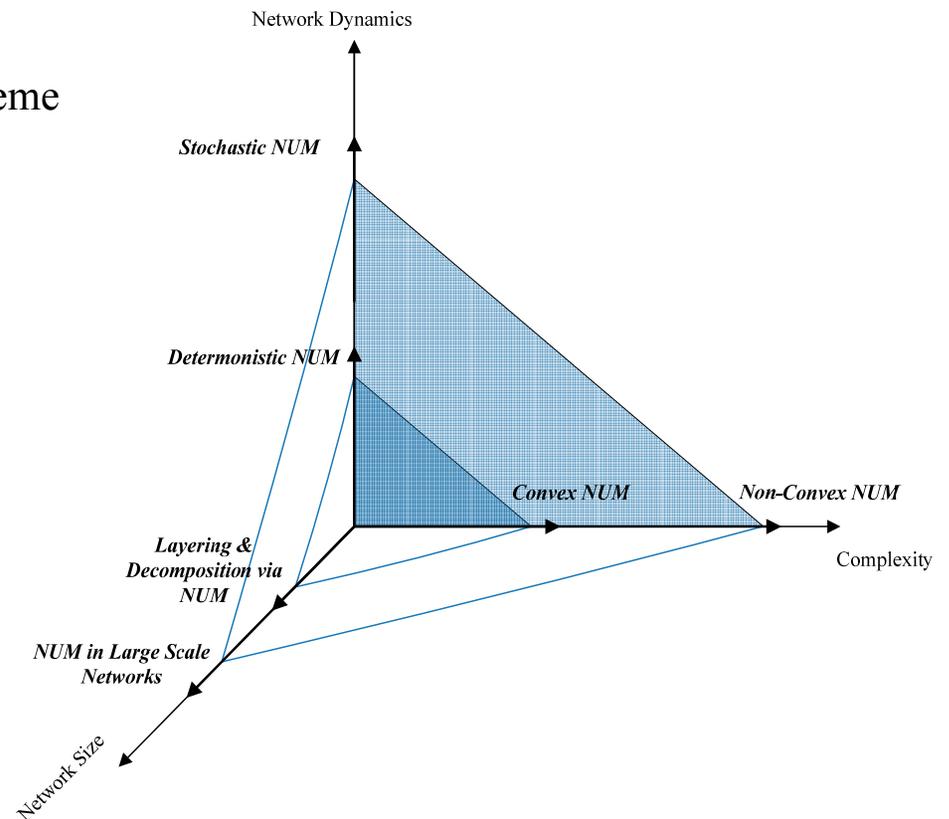
“Autonomic Future Internet Architecture”

B. Large scale realistic assessment/validation

*“Don’t Optimize Current Networking Functionalities via Autonomics,  
Design Theoretically-Sound Autonomic Mechanisms”*

# Network Utility Maximization (NUM theory)

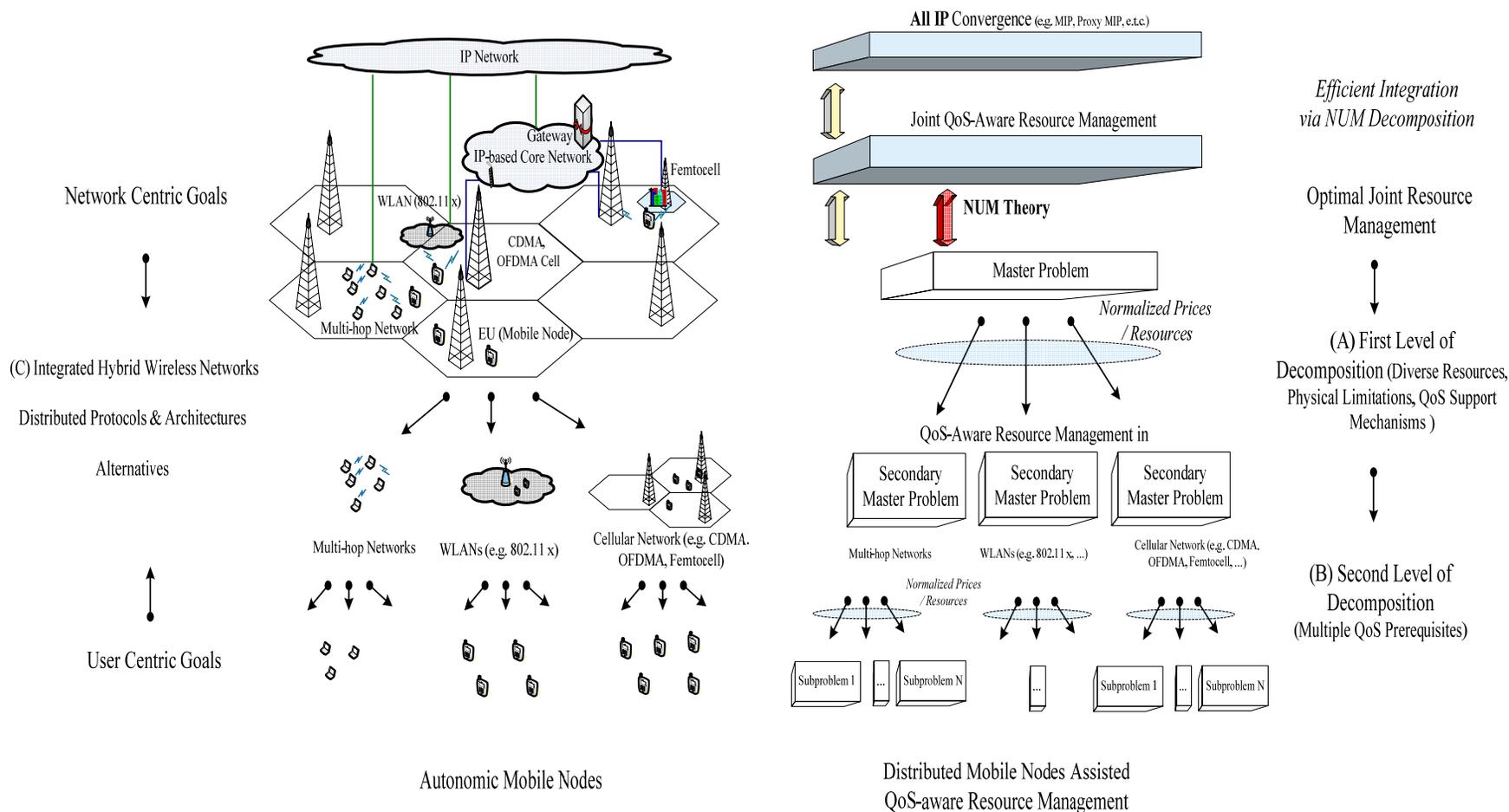
- Math foundation for network architecture:
  - Network: Generalized NUM
  - Layering architecture: Decomposition scheme
  - Layers: Decomposed subproblems



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



# 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.
- Validation
- Experimentation
  - **Testbed as a Service**



# Validation

- Measurement-driven activity
  - In the Internet, what we want to measure is often not what we can measure
  - Critical role of “**data hygiene**” as a scientific pre-requisite
    - The example of traceroute measurements
- “**Details matter**”
  - Domain knowledge is critical
  - “Hub-like Internet core” –a myth
- Model validation
  - Matching certain statistics of the data is insufficient
  - Clean separation between data used for **model selection** vs data used for **model validation**



# Virtualization+Federation: viable path to experimentation

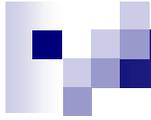
## Network Virtualization:

- 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



*Thank you...*

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