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IEEE 5G Greece Summit

COOL: Common Optimization and Operation framework based on network utiLity theory for 5G technologies & IoT

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Future Wireless Networking Arena – 5G

- A heterogeneous environment
  - Different types of resources
  - Different QoS-provisioning and resource allocation mechanisms
- 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
- 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
- Act in an autonomic fashion with varying levels of intelligence and capabilities.

Utility Theory and Game Theory

Not centrally determined (uplink): The decision – optimization process lies at each user

Real Time Services

Multiple Services

Distributed Approach

Non Real Time Services

Resource Allocation

Transmission Technique

Optimally allocate Resources (Transmission Power and Rate) based on Utility Maximization

network utility maximization theory and game theory to address resource allocation and properly capture and reflect users' behavior within the competitive arena of system's resource allocation

Network Utility Maximization (NUM)

- Utility Function (concept adopted form the field of economics): reflects a user's degree of satisfaction with respect to his service performance.



- Objective Function $\sum_{i=1}^{N} U_i$

utility function that can depend on throughput, delay, jitter, energy

- Cost Function $\sum_{i=1}^{N} C_i$

cost function that can depend on several degrees of freedom, including power

- Utility-based frameworks for the QoS/QoE-driven power and rate control problem in wireless networks, due to the heterogeneity and diversity of the supported services and corresponding service requirements.

Service types in 5G networking era

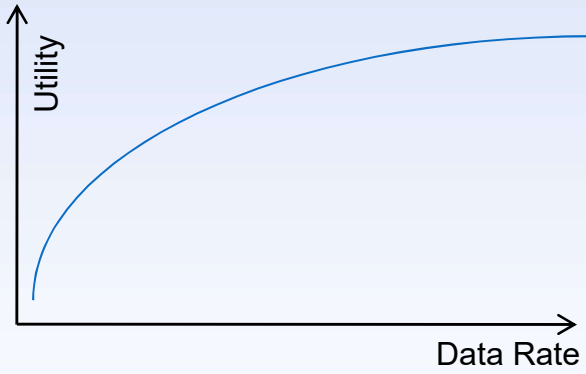
Elastic Services

or **Non Real Time** Services

- Shiftable in Time
- Delay tolerant

Examples include

- Data uploading
- E-mail



Log based concave utility where higher data rates drive higher user satisfaction levels

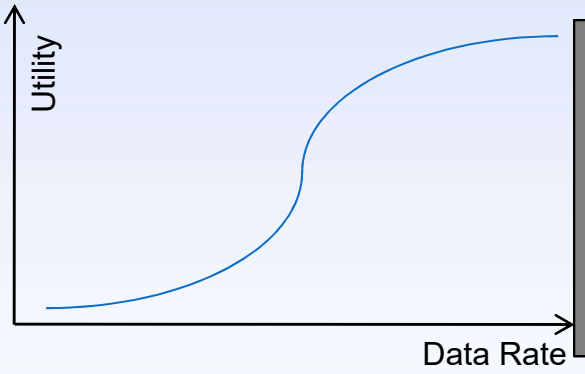
Inelastic Services

or **Real Time** Services

- Non shiftable in time
- Dependent on meeting specific QoS and data rate thresholds

Examples include

- Video streaming
- E-calls



Sigmoidal based utility where highest satisfaction is achieved when the minimum data rate thesholds are met

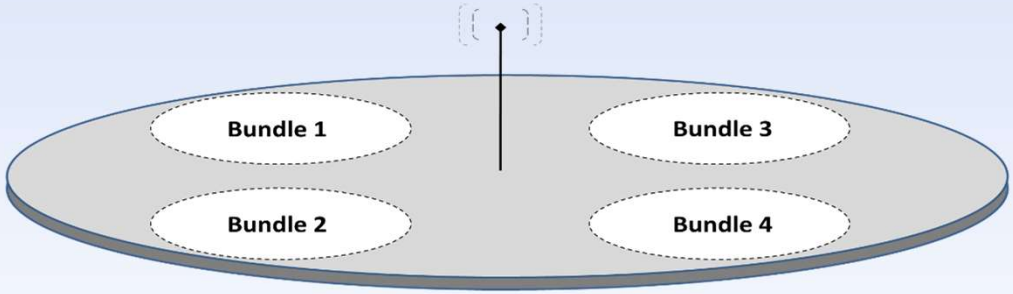
Scientific and Business Challenges in Resource Optimization in Wireless Networks

- Scientific Challenges – Multi-* 5G Wireless Networks: heterogeneity, diversity and multiplicity
  - Multi-Services in 5G Wireless Networks
    - reflecting different QoS/QoE requirements – real time vs. non-real time
  - Multi-Resources in 5G Wireless Networks
    - in nature (e.g., power and/or rate control)
    - in properties (e.g., continuous and/or discrete, depending on the wireless access technology, e.g., NOMA, SC-FDMA, etc.)
  - Multi-Tier Architectures in 5G Wireless Networks
    - e.g. cellular, femtocells, VLC
  - Multi-Providers Environment in 5G Wireless Networks

- From Business Service Bundling to Technical Service Bundling
  - Power, Rate, QoS, QoE, Price

Bundling and Pricing for Wireless Network Technical Services

Real Time Service Support					
	No Bundle				
	Bundle 1	Power Control			Price 1
	Bundle 2	Power Control	Rate Control		Price 2
	Bundle 3	Power Control	Rate Control	Additional support for Non Real Time Services	Price 3
	Bundle 4	Power Control	Rate Control	Additional support for Non Real Time Services	Femtocell Access	Price 4



Bundling refers to the integration and offering of two or more products for which different potentially markets exist into a unified package

Benefits:

- Adaptive utilization of resources among the different services
- Competitive advantage against competition
- Synergies from the concurrent support of the involved services leads to higher data rates in an energy efficient manner
- Address different user needs within the same offering
- Exploit bandwidth in a more efficient way
- Price advantages from the sale of different services in a single package

However there is a … Long Dialogue - Multidisciplinary

- Network scientists
  - "Give me data, w"ll model …"
    ["… and by the way, we are not interested in "details" like how the data was collected or if it can be used for our purpose …"]
- Mathematicians
  - "Give me (network) models, w"ll do (rigorous) proofs …"
- Internet researchers
  - "Give me network models (with or w/o proofs), w"ll use them."
    ["… and by the way, w"ll ignore all the domain knowledge that we have about the Network/Internet …"]

Need for Validation and Experimentation

Utility-based Networking experiments for Improving QUality of Experience in mobile broadband environments: The UNIQUE experiment of MONROE

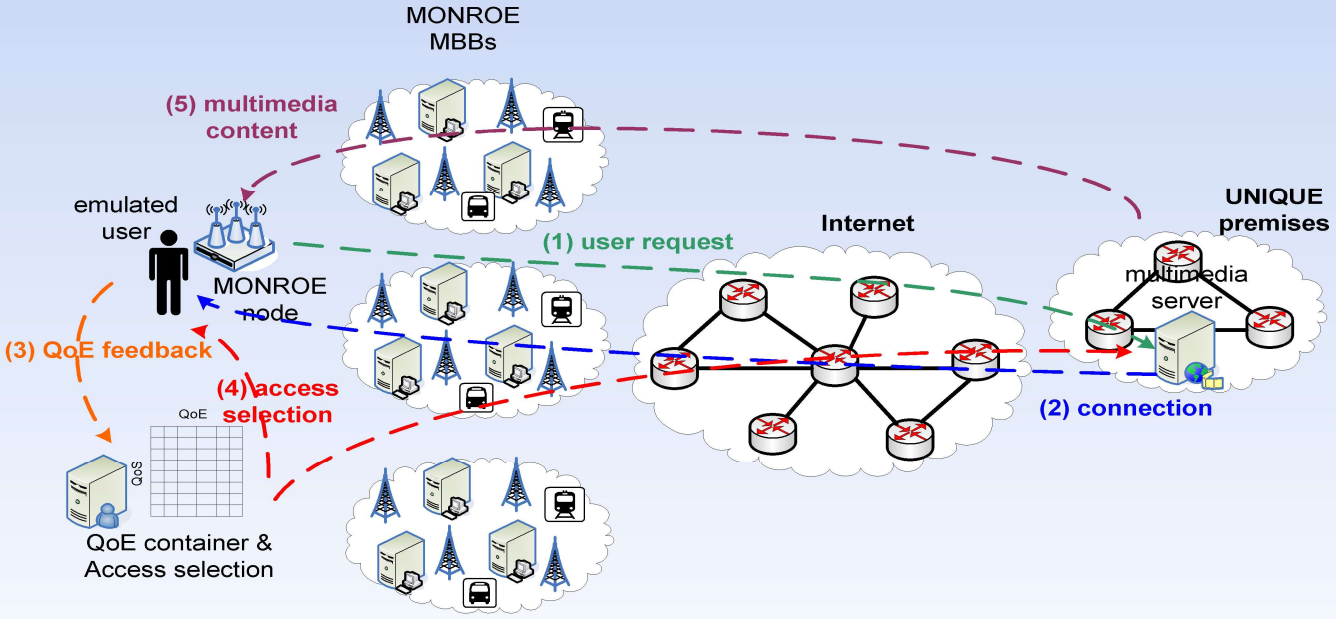
- Design a utility-based framework for wireless access network selection via utility functions
  - Take into account QoS parameters, e.g., throughput, delay, packet loss, etc.
  - Factor in QoE evaluations – quality of playback perceived by the users
- Use the framework to select among different (3) available wireless access networks
  - Devices are assumed to have available 3 interfaces to different mobile service providers
  - MONROE nodes provide such capabilities

General Design of Utility Function

$$U(i) = \underbrace{\sum_{d}\left[A(i,d)U_f(p_f,i,d) - B(p_f,i,d)\right]}_{\text{flow related part}} + \underbrace{\left[C(i)U_n(p_n,i) - D(p_n,i)\right]}_{\text{user related part}}$$

Utility-based Access Network Selection

- Use QoE-QoS mapping and properly designed utility functions to select the wireless access interface yielding better QoE-QoS combined outcome



Virtualization+Federation: viable path to large-scale 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

Thank you…

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