New scenarios for resource slicing and sharing in beyond 5G networks

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Joint work with

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Why do we slice a wireless network?
Multiple working points for 5G networks

• For the first time 5G allows to optimize
  – not only rate performance
  – but also: energy consumption, reliability, number of users, …

• Obviously not all at a time

• Managing multiple working points depending on applications is easier done on somehow separated network portions

(Source: ETR graphic, from ITU-R INT 2020 requirements)
Specialized network functions and edge computing

- The **virtualization** approaches of new network architecture
- **Specialized service chains** depending on applications
- Easy integration with **edge computing** modules in application domain
- Selling network and computing resources to vertical applications is easier done in separated and optimized chunks
A sliced network is more easily shared

• Network slicing potentially allows an easier sharing of the infrastructure and its resources

• A reshaping of mobile market can modify the value chain that over the years has increasingly favored OTTs

• New regulatory trends (in some regions like Europe) are pushing for wholesale approaches for telco services

• Trying to allow the entrance in the market of strong players of vertical domains with local roots
Is infrastructure and resource sharing convenient?
To share or not to share, this is the question

**Question:** What will be the most common industry structure for infrastructure ownership in 5G era?

<table>
<thead>
<tr>
<th>Industry structure for infrastructure ownership</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Widespread network sharing (both passive and active sharing)</td>
<td>40%</td>
</tr>
<tr>
<td>Each operator owns and operates its own network</td>
<td>40%</td>
</tr>
<tr>
<td>Hybrid network models (e.g. public funding for rural areas)</td>
<td>11%</td>
</tr>
<tr>
<td>Single/dual wholesale shared networks per country (both private &amp; public owned)</td>
<td>3%</td>
</tr>
<tr>
<td>Single shared network per city/region</td>
<td>3%</td>
</tr>
<tr>
<td>Others</td>
<td>3%</td>
</tr>
</tbody>
</table>

Source: GSMA, “The 5G Era”, survey on 750 operators’ CEO survey, 2017
State-of-the-Art

• **Technical approaches**
  – How to virtualize service and network portions
  – How to manage resources in shared environment
  – How to save energy

• **Economic approaches**
  – Strategic planning for operators
  – Asset management and market strategy
  – Economic models of sharing
The missing link: perceived user quality and willingness to pay

- We have developed a model for mobile operators to estimate user perceived quality based on network statistical counters.
- We have defined a simplified simulation model for associating quality indicators to sharing scenarios.
- We have used a common model for associating quality perceived and willingness to pay.
Modeling convenience to share

- **Objective**: provide a techno-economic framework which evaluates the viability and profitability of infrastructure sharing under different technical, economical and regulatory settings.

- **Methodology**: mathematical programming and game theory

- **Focus**: Small cells deployment
Scenario

- A set of MNOs with given market shares coexist in a given geographical area.
- MNOs plan to upgrade their network by deploying a layer of small cell Base Stations (BS)s.
- Problem: Will MNOs invest? If so, which coalitions will be created and how many BSs will they deploy?
Approach

MNOs WITH GIVEN MARKET & SPECTRUM SHARES

PRICING MODEL
REVENUES=$\mathcal{F}(\delta q)$

Model

COALITIONAL STRUCTURE

# SMALL CELL BSs

STABLE COST DIVISION

SIMULATION
USER RATE $q=\mathcal{F}(\#BSs, \text{coalition type})$


Model and key findings

- **MNOs are profit-maximizing entities** (regulator does not intervene) modeled as a non-cooperative and as a cooperative game – w/o & w/ transferable utility

- **Stable network sharing configuration**: Nash Equilibria (NE) of the non-cooperative game / core of cooperative game

- **Key Findings**:
  - Decreasing \( \delta \) makes **sharing more convenient** since MNOs cannot afford individual more congested networks
  - **Grand coalition fast becomes stable for vast majority of instances** (spectrum pooling gain > quality degradation due to sharing)
  - **Stable cost divisions** reflect the MNOs individual market and spectrum share e.g. an MNO with a large spectrum holding & few users can be exempted from the infrastructure cost
How can we move from sharing to market layering?
• Assuming no-competition among infrastructure providers (InP)
A market? ... similarities

Energy market
Time granularity from days to minutes

Ads market
Time granularity from minutes to seconds
Assumptions

• The InP behave fairly in the resource allocation phase

• Virtual Operators trade the amount of resources according to their users’ needs (estimation/prediction of traffic load, type, distribution, channel qualities, etc.)

• Pricing model ensures that the InP has enough money to cover recurrent costs and expand capacity


Resource allocation problem

- Given traffic estimation, virtual operators can set a quality target $Q_i$ depending on their business model.
- InP resource allocation problem (RAP):
  - Assign resources to virtual operators
  - so as to maximize overall quality
  - Subject to fairness constraints
Changing the quality targets (and traffic estimations), operators can influence the resource allocation.

How to differentiate strategies?

Costs and revenues !!!
Costs and revenues

Revenues based on acceptance probability based on price and quality [BLZZ03]

\[ A(p, U) = 1 - e^{-Cp - \varepsilon U^\mu} \]

Market competition

Strategy 1
Q_1, Q_2, Q_3, ... → RAP
Payoff = revenues
Nash Equilibrium
Non-cooperative game with complete information
Solve K instances of the optimization model

Strategy 2
Q_1, Q_2, Q_3, ... → RAP

... ...

Strategy K
Q_1, Q_2, Q_3, ... → RAP

Game

Single game with given payoff matrix for all the strategies
Example results

Work in progress:
- Modelling competition among infrastructure providers
- Fundamental to show that the approach is feasible also during transition from traditional market to the new one
Can trading become automated?
How to make trading more dynamic?

- The idea is that we can automate the **pricing model** and combine it with real-time **resource scheduling**
- We add **flexibility** since scheduler is able to exploit **variations in traffic** (volume and mix)
- The business **strategy** remains **under control of virtual operators**
- Diversity in **traffic mix** can be accounted for (**tenants of specialized slices**)
An automated market

Single Infrastructure provider

Resource Sharing

Set of Tenants

Physical resources

Resource Allocation

Set of services


Two Step Solution Framework: Anticipatory networking

For every time instance, $n$

Initial $S_m$ and $\Delta_m$

Resource Allocation

$\xi_m$ $r[n]$

Resource Sharing

$S_m^{new}$ and $\Delta_m^{new}$

At the end of a time window, $W$

$r[i], \forall i \in [n - W, n]$
Example results

Work in progress:
- Defining an interface between automated trading and resource scheduling
- Modelling long term SLAs into trading strategies in multi-cell scenarios
• **Sharing is a need** for the evolution of mobile networks
• Like in different sectors, the creation of a:
  – **layered market**
  – with **automated trading**
  appears a natural evolution
• **Technical solutions for making resource allocation algorithms suitable for being exposed on a market like this are still to be defined**
Thanks!

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