Data and Control Plane Solutions for an Optical 5G Transport

Paolo Monti

Optical Networks Lab (ONLab)
Communication Systems Department (COS)
KTH Royal Institute of Technology
Stockholm (Sweden)
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Outline

- Transport service evolution from 4G to 5G
- Transport challenges in the new 5G services paradigm
- Programmable and flexible transport infrastructure
- Use case: C-RAN architecture
  - Impact of different resource abstraction policies
  - Benefits of dynamic resource sharing
- Conclusions
What can we expect from a new generation of mobile networks?

5G vision:

- user- and machine-centric communications where access to information is available anywhere and anytime to anyone and anything, the so called **Networked Society**

*http://www.ericsson.com/thinkingahead/networked_society*
What is a transport networks?

- Transport network is the segment connecting the base stations (eNodeB) with their peering point in the Evolved Packet Core (EPC)
  - mobility management (MME), service gateway (SGW), packet data network gateway (PGW), home subscriber services (HSS)
- Transport technologies: copper, optical, and/or wireless technologies
- Research on 5G focused on new radio access networks (RAN): high peak-rates per subscriber; handle very large number of simultaneously connected devices; better coverage, outage probability, and latency
- So far less attention is put on defining the 5G transport network
Transport services in 4G

Before getting into the specifics of what should be the requirements of a 5G transport network it might be useful to understand how transport services look like in 4G networks.

With *current mobile networks* the transport should be able to accommodate:

- Backhaul services (distributed RAN)
- Fronthaul services (centralized RAN)

and support:

- Advanced radio coordination features
- (Massive) multi-input multiple-output (MIMO) antennas architectures

Idea: look at the current requirements and try to identify possible critical aspects when having to serve new 5G services.

Mobile backhaul:

- **Macro base station** composed of: (1) Antennas, (2) Remote Radio Units (RRUs), (3) Baseband Unit (BBU)
- **BBU** performs baseband signal processing and generates packet-based backhaul traffic. The backhaul traffic is composed of: data traffic (S1) + control traffic (X2)
- **Backhaul data traffic** is proportional to the data generated by the users
Backhaul: dimensioning

Transport dimensioning for backhaul*:

- For a single sector, peak bitrate corresponds to one user equipment (UE) with a good link served by the sector
- During busy hour, many UEs are served by each sector and the average bitrate is related to the average spectral efficiency over the coverage area

Provisioned capacity for a base station with N sectors typically obtained as maximum of:

- peak bitrate for single sector
- N x (busy hour average bitrate)

*Guidelines for LTE Backhaul Traffic Estimation", White Paper by NGMN Alliance
Peak rate and busy hour requirements

The peak bitrate of a sector depends on*:

- Radio access network (RAN) configuration
  - Channel bandwidth, MIMO (# of antennas/sector), peak spectral efficiency
- UE category (as specified by 3GPP) served by the sector

Average busy hour bitrate*: simulation for an urban macro cell environment

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Single Cell Mean</th>
<th>Single Cell Peak (95%ile)</th>
<th>Single base station Mean</th>
<th>Tri-cell Tput busy time mean</th>
<th>X2 Overhead over 4% peak busy time mean</th>
<th>Total U-plane + Transport overhead</th>
<th>No IPsec busy time mean</th>
<th>IPsec peak (95%ile)</th>
<th>No IPsec peak (95%ile)</th>
<th>IPsec busy time mean</th>
<th>IPsec peak (95%ile)</th>
<th>IPsec busy time mean</th>
<th>IPsec peak (95%ile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DL 1: 2x2, 10 MHz, cat2 (60 Mbps)</td>
<td>10.5</td>
<td>31.5</td>
<td>37.8</td>
<td>1.3</td>
<td>36.0</td>
<td>41.6</td>
<td>41.0</td>
<td>47.3</td>
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<tr>
<td>DL 2: 2x2, 10 MHz, cat3 (100 Mbps)</td>
<td>11.0</td>
<td>33.0</td>
<td>58.5</td>
<td>1.3</td>
<td>37.8</td>
<td>64.4</td>
<td>42.9</td>
<td>73.2</td>
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<tr>
<td>DL 3: 2x2, 20 MHz, cat3 (100 Mbps)</td>
<td>20.5</td>
<td>61.5</td>
<td>95.7</td>
<td>2.5</td>
<td>70.4</td>
<td>105.3</td>
<td>80.0</td>
<td>119.6</td>
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<tr>
<td>DL 4: 2x2, 20 MHz, cat4 (150 Mbps)</td>
<td>21.0</td>
<td>63.0</td>
<td>117.7</td>
<td>2.5</td>
<td>72.1</td>
<td>129.5</td>
<td>81.9</td>
<td>147.1</td>
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<tr>
<td>DL 5: 4x2, 20 MHz, cat4 (150 Mbps)</td>
<td>25.0</td>
<td>75.0</td>
<td>123.1</td>
<td>3.0</td>
<td>85.8</td>
<td>135.4</td>
<td>97.5</td>
<td>153.9</td>
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<td>UL 1: 1x2, 10 MHz, cat3 (50 Mbps)</td>
<td>8.0</td>
<td>24.0</td>
<td>28.8</td>
<td>1.0</td>
<td>27.5</td>
<td>22.8</td>
<td>31.2</td>
<td>26.0</td>
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<tr>
<td>UL 2: 1x2, 20 MHz, cat3 (60 Mbps)</td>
<td>15.0</td>
<td>45.0</td>
<td>38.2</td>
<td>1.8</td>
<td>51.5</td>
<td>42.0</td>
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<td>47.7</td>
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<tr>
<td>UL 3: 1x2, 20 MHz, cat5 (75 Mbps)</td>
<td>16.0</td>
<td>48.0</td>
<td>47.8</td>
<td>1.9</td>
<td>54.9</td>
<td>52.5</td>
<td>62.4</td>
<td>59.7</td>
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<tr>
<td>UL 4: 1x2, 20 MHz, cat3 (60 Mbps)*</td>
<td>14.0</td>
<td>42.0</td>
<td>46.9</td>
<td>1.7</td>
<td>48.0</td>
<td>51.6</td>
<td>54.6</td>
<td>58.6</td>
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<tr>
<td>UL 5: 1x4, 20 MHz, cat3 (60 Mbps)</td>
<td>26.0</td>
<td>78.0</td>
<td>46.2</td>
<td>3.1</td>
<td>89.2</td>
<td>50.8</td>
<td>101.4</td>
<td>57.8</td>
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</tbody>
</table>

*Guidelines for LTE Backhaul Traffic Estimation*, White Paper by NGMN Alliance
Backhaul: required bandwidth

Typical values for LTE-A base station (BS):

- **Macro BS**: 40 MHz with 4x4 MIMO = 830 Mbps per macro base station
- **Small cell Var.1**: 20 MHz with 2x2 MIMO = 245 Mbps per small cell
- **Small cell Var.2**: 40 MHz with 4x4 MIMO = 830 Mbps per small cell

MIMO and larger spectrum as well as additional X2 traffic drive the need for >1G backhaul links

Assumption on X2 traffic:
50 Mb/s base rate + 0.3 x S1 traffic

EU FP7 Project COMBO. http://www.ict-combo.eu/
Fronthaul services

- Centralized RAN (C-RAN):
  - The BBUs are decoupled from the base station and centralized in one or more pools (alternatively also BBU hotels or even BBU clouds)

- The transport network is divided in two parts:
  - **Fronthaul**: traffic between RRUs and BBU pool
    - Carries the sampled I/Q data generated at the RRU (C1 traffic)
    - Popular radio interface for D-RoF is Common Public Radio Interface (CPRI)
  - **Backhaul**: traffic between BBU pool and EPC (S1 + X2)
Motivation and challenges

Motivations for C-RAN:
- More efficient radio coordination
- Energy and cost savings (sharing infrastructure, BBU functionalities, reduced footprint outdoor equipment)
- Easy hardware/software upgrades, maintenance, and reparation

Challenges for C-RAN:
- Fronthaul latency requirements
  - LTE physical layer hybrid automated repeat request process (HARQ) requires maximum round-trip delay of 3ms, including both transport and BBU processing time
- Fronthaul traffic capacity requirements
  - Constant bit-rate → independent from traffic generated by the users equipment
  - Using CPRI*:

\[
B_{\text{CPRI}} = N_S \cdot N_{\text{Ant}} \cdot R_S \cdot 2N_{\text{Res}} \cdot O_{\text{CW}} \cdot O_{\text{LC}}
\]

Ns: # sector
N_ant: # ant. elements
R_s: sampling rate
N_res: bit/sample
O_CW: overhead
O_LC: line coding
Fronthaul: latency requirements

- LTE physical layer HARQ requires that eNodeB indicates within 4 ms to the user equipment (UE) to retransmit an erroneous packet.
- Gives a 3 ms budget including both transport and BBU processing time.
- Maximum theoretical RTT delay limit for the transport: 400 μs.
- A good practice is to limit the RoF transmission delay to around 100 μs.
- Maximum distance between a RRU and a BBU not to exceed 20 km.*

*C-RAN - The Road Towards Green RAN; China Mobile White Paper, Version 3.0 (Dec 2013)
Typical values for LTE-A base station (BS):

- **Macro BS**: 40 MHz with 4x4 MIMO = 10 Gbps per sector, 3 CPRI links per macro BS, total of 30 Gbps per macro BS
- **Small cell Var.1**: 20 MHz with 2x2 MIMO = 2.5 Gbps per sector
- **Small cell Var.2**: 40 MHz with 4x4 MIMO = 10 Gbps per sector
Advanced radio coordination

- Radio coordination improves transmission spectral efficiency, in particular at cell edges. Also used to mitigate interference in HetNet

- Different radio coordination schemes and algorithms:
  - Enhanced inter-cell interference coordination (eICIC)
  - Coordinated multi-point (CoMP)
    - Coordinated scheduling: interference management
    - Coordinated beamforming: interference management
    - Dynamic point selection: chose best signal
    - Joint tx and rx (JP-CoMP)
### Radio coordination benefits and requirements

<table>
<thead>
<tr>
<th>Coordination Classification</th>
<th>Coordination Feature</th>
<th>Max Throughput Gain</th>
<th>Max Capacity Gain</th>
<th>Delay Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Tight Coordination</td>
<td>Fast uplink CoMP (uplink joint reception/selection)</td>
<td>High</td>
<td>High</td>
<td>0.1-0.5 ms</td>
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<tr>
<td></td>
<td>Fast downlink CoMP (coordinated link adaptation, coordinated scheduling,</td>
<td>Medium</td>
<td>Medium</td>
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<tr>
<td></td>
<td>coordinated beamforming, dynamic point selection)</td>
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</tr>
<tr>
<td></td>
<td>Combined Cell</td>
<td>Medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tight Coordination</td>
<td>Slow uplink CoMP</td>
<td>Medium</td>
<td>Small</td>
<td>1-20 ms</td>
</tr>
<tr>
<td></td>
<td>Slow downlink CoMP (e.g., Postponed Dynamic Point Blanking)</td>
<td>Small</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate Coordination</td>
<td>eICIC</td>
<td>Medium</td>
<td>Small</td>
<td>20-50 ms</td>
</tr>
</tbody>
</table>

Small gain: <20% - Medium gain: 20-50% - High gain: >50%
Radio coordination with BH and FH

**Backhaul**
- An interconnection of X2 interface required, link distances between sites will cause delay
- To support JP-CoMP delay < 0.5 ms interconnection required

**Fronthaul**
- X2 interfaces are collocated, X2 delay close to zero
- Fulfils inherently X2 delay requirements for CoMP < 0.5 ms

Backhaul: X2 connection needs to support delay < 0.5 ms for JP-CoMP (difficult)
Fronthaul: fulfils inherently X2 delay requirements for JP-CoMP < 0.5 ms

*EU FP7 Project COMBO. http://www.ict-combo.eu/*/
Impact of MIMO

- Regular (i.e., a few elements) MIMO configurations already used in current LTE deployments
- m-MIMO: provide BS with *large spatial multiplexing gains* and *beamforming capabilities* thanks to hundreds of antenna elements
- It is expected new 5G radio access interfaces will include*: technology backward compatible with LTE and LTE-A, new technology (NX) based on m-MIMO
- Transport capacity requirement with m-MIMO:
  - Backhaul → rise to up to 10 Gbps (in LTE-A was ≈ 1 Gbps)
  - Fronthaul: may reach the Tbps per base station

\[
B_{CPRI} = N_S \cdot N_{Ant} \cdot R_S \cdot 2N_{Res} \cdot O_{CW} \cdot O_{LC}
\]

Midhaul with split processing

Splitting the wireless processing chain so that the capacity on interface is dependent on the amount of data to be transmitted over the air.

"PHY2" separates processing of user data from processing of cell signals with a bit rate in the range 0% - 20% of the CPRI bit rate.

Split points has impact on Radio coordination (PHY1 and PHY2 still OK) and energy savings (Layer 1 functions are the most consuming).

Further study on critical C-RAN technologies", White Paper by NGMN Alliance.
Evolution from 4G to 5G transport

- Backhaul services (user rate dependent) with increased capacity requirements (i.e., tens of Gbps or more)
- Centralized architectures will have to be revisited to consider the new requirements:
  - m-MIMO might create bottlenecks in the transport if not carefully addressed
  - Midhaul solutions can help but there is a tradeoff with
    - Achievable level of radio coordination
    - Benefits of C-RAN from the mobile network side are drastically reduced (some of the more energy consuming functionality are again distributed)
- No “one solution fits all” approach, but rather a solution with/without centralized processing depending on the requirements of on the specific 5G service(s)
- Need to map 5G service requirements into transport requirements
5G requirements

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- EU FP7 METIS 2020 project: laying the foundation of 5G
- 5G defined in terms of *scenarios* (S) supported
- Each scenario introduces a *challenge* (C)
- Each scenario multiple *test cases* (TC)

1. **METIS deliverable D1.1, “Scenarios, requirements and KPIs for 5G mobile and wireless system”, April, 2013.**
5G transport requirements

- **The 5G challenges → transport challenges:**
  - **Very high data rate** → huge aggregated traffic volumes
  - **Very dense crowds of users** → provide high capacity on-demand
  - **Best experience follows you** → fast reconfigurability of transport resources
  - **Super real time and reliable connections** → very low latency

- **The massive number of connected devices**
  - not a major issue: the traffic from a large number of machines over a geographical area will be aggregated

How to enable these functionalities?

- Two main directions for provisioning high capacity on-demand and in a flexible way
  - **Overprovisioning**: high capacity on-demand with (possibly) fast resource reconfiguration is satisfied thanks to the ubiquitous availability of ultra-high capacity transport
    - Pros: relatively low complexity at the control plane
    - Cons: potentially high cost because of inefficient use of network resources
  - **“Intelligence”** in the transport infrastructure
    - Dynamic resource sharing: re-configurable systems for dynamically sharing limited transport resources
    - Network functions virtualization (NFV): dynamically push network functions to different locations, e.g., closer to the users so that a portion of the traffic requests can be served locally

How to add intelligence to transport?

- Programmability/flexibility (resource sharing and/or NFV) puts requirements on the control plane
- A SDN-based control plane with end-to-end orchestration could provide a framework for such a scenario
- One possible control plane architecture might be:
Two interesting open questions

- If orchestration helps in using resources efficiently → what’s the best level of details to be used to advertise the availability of transport resources?
- With orchestration what are the advantages brought by dynamic resource sharing?

Diagram:

- SDN-based control
- Smart data plane
- Orchestration
- Radio controller
- Transport controller
- Small cells transport controller
- Small cells
- Dedicated small cells transport
- Technology Topology
- Access Ring
- Metro Ring
- Wireless small cells network
- Transport network
Orchestration implies knowledge of condition of the wireless and the transport network

Every time a new RRU needs to be turned on, a lightpath needs to be established between RRU and BBU hotel, as well as one between BBU and EPC.

Tradeoff between abstraction level (i.e., performance) and complexity (i.e., scalability, messaging overhead).

Abstraction policies

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- **Big Switch Basic**
  - Transport network presented to the orchestrator as a single node (switch)
  - No updates between transport controllers and orchestrator required

- **Virtual Link with Constant Weights**
  - Transport network presented to the orchestrator as a number of potential connections (virtual links) among switch ports
  - Each virtual link is assigned a constant weight
  - Whenever connectivity is lost between 2 switch ports corresponding virtual link is deleted
  - Updates between controller and orchestrator are required

- **Virtual Link with Variable Weights**
  - Transport network presented to the orchestrator as a number of potential connections (virtual links) switch ports
  - Each virtual link is assigned a variable weight, i.e., # of wavelength between 2 switch ports
  - Updates between controller and orchestrator are required
Resources abstraction: results

- 38 nodes, 2 BBU Hotels, EPC accessible via two node

η = ration of amount of radio resources vs. transport resources

η = \frac{[1 + b] \cdot \sum_{i=1}^{N_H} N_i^{BBU}}{W \cdot \sum_{i=1}^{N_H} D_i^{BBU}}
Advantages of dynamic resource sharing

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- 7 access rings with 5 access edge (AE) nodes per ring
- 1 metro ring with 3 metro nodes (MNs) and 1 ME connected with BBU pools
- 1 macro base station (MBS) and N small cells (SCs) per AE
- Daily traffic variations over the ARs (residential vs. office areas vs. city center)
Daily traffic variations over the ARs

- Traffic profile over 24h for each ring, shifted by 3 hours
Simulation results

- No. of experiments = 100, Available lambdas per pool = 96; N=2

<table>
<thead>
<tr>
<th></th>
<th>No. of transponders for $N=2$</th>
<th>No. of transponders for $N=5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Dimensioning</td>
<td>$35 \text{ (for MBS)} + 70 \text{ (for SCs)} = 105$</td>
<td>$35 \text{ (for MBS)} + 175 \text{ (for SCs)} = 210$</td>
</tr>
<tr>
<td>Dynamic Resource Sharing</td>
<td>77</td>
<td>144</td>
</tr>
</tbody>
</table>

↓ Saving = 26.7%               ↓ Saving = 31.4%
Focus of new 5G radio technologies: high peak-rates per subscriber; handle large number of simultaneously connected devices; better coverage, outage probability, and latency

Will not have a “one solution fits all” approach, but a solution with/without centralized processing depending on the requirements of on the specific 5G service(s)

Transport will evolve towards a programmable infrastructure able to flexibly adapt to the various 5G service needs

Highlighted a few directions on how programmability and flexibility can be achieved (joint orchestration with dynamic resources sharing) and demonstrated some of benefits that can be obtained

Development and deployment of new radio and transport networks need to go hand in hand in order to be able to get the best of out the new 5G communication paradigm
References

ONLab


- METIS deliverable D1.1, “Scenarios, requirements and KPIs for 5G mobile and wireless system”, April 2013
We recently opened a CSC (China Scholarship Council) for a PhD position at our Lab on Optical Transport Networks.

For more info, pls. feel free to get in touch with me at:
- pmonti@kth.se
- Talk to me after the talk.
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Paolo Monti

pmonti@kth.se
http://web.it.kth.se/~pmonti/