Off-line optimization of energy efficient mobile metro-core network based on predictable aggregated traffic patterns

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Mobile Cloud Workshop 2015
San Candido, January 13th
Outline

- Introduction
- Mobile Metro-Core Network: traffic model and topology
- Optical Routing optimization
- Conclusions
Introduction

Framework
- MobileCloud IRSES European Project
- Ongoing cooperation between BUPT (user-mobility patterns) and PoliMi (network optimization)

Aim
- Exploit the predictability of user mobility in a MobileCloud network to:
  - Improve network adaptability to predictable traffic variations
  - Increase network efficiency: avoid current overprovisioning of network capacity
  - Reduction of OpEx (energy) and CapEx by avoiding the static nature of today’s optical network
Mobile network: user mobility patterns

From the Group of Prof. Jajing Xu – BUPT:

- Real Data from a Mobile network of a Middle size city of China
- Per-cell user mobility patterns in an LTE urban-area network

![Graph showing daily pattern of # users in a mobile network Cell](image)
Mobile network: Bandwidth demand estimation of cells

- Daily pattern of the number of users in a mobile network cell
- Normalized user traffic
- Bandwidth demand of the cell
- Maximum capacity of the base-station (packet layer)
- Saturation
Network architecture

- Metro-Core Network that adapts to traffic variations

Offered traffic
- $< 1$ Gbit/s with traditional eNodeB
- $\approx 25$ Gbit/s with optical front-haul

Clustering is performed by an heuristic algorithm based on Real cell locations
Effect of user mobility on aggregated traffic

Social function vectors of aggregation rings

- C0 residential area
- C1 education and science area
- C2 hospital and clinic
- C3 office building
- C4 commercial / entertainment district
- C5 scenic / historic spot
- C6 nature and parks
- C7 hotels and motels
- C8 governmental agencies and public organizations
- C9 sparse

Average bandwidth demand of aggregation rings
As future development, we will also consider a 5G use case, with direct access to datacenters and ISPs, without passing through a PGW.
ROADMs can avoid OE conversion and routing at intermediate-point transponders with optical bypasses → decrease power consumption

Very effective in a metro network with relatively short distances
Mobile-core fiber-network Topology

- Mobile network of a middle-size city of China
  - Real geographical position of 4645 cell sites
- The network topology has been synthetized from cell sites locations
  - LTE cells: 1 Gbps
  - Last mile: Star
  - Aggregation network: Ring
  - Metro-core: Mesh (planar)
- Peak dimensioning
- Objective: CapEx minimization

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Network dimensioning at the peak

- Serving Gateway (SGW)
- Two OXCs that interface with the same Aggregation Ring (grey circle)

Number of Active Wavelengths (under the peak demand)
Optical Routing Optimization

Given a network graph $G$

Phase 1: Offline planning
Given predicted demands (traffic values averaged over the whole 2-month historical observation window).
For each hour $t$ and all predicted demands:
- Wavelength path (WP): Find optimal Routing and wavelength assignment (RWA) *minimizing power consumption* (ILP)
  - Optical bypass.
- Virtual wavelength path (VWP): Find the routing assignment (RA) *minimizing power consumption* (ILP)
  - Traffic grooming

Variation: complexity can be reduced by reducing the number of off-line optimizations and weight computations to less than one per hour
Power-consumption model

- Model of power consumption of the optical equipment

<table>
<thead>
<tr>
<th>Component</th>
<th>Power Consumption (Watt)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transponder/muxponder, 10 G</td>
<td>50 W</td>
<td>Per channel pair</td>
</tr>
<tr>
<td>OLA, short span 2 km</td>
<td>65 W</td>
<td>Per fiber pair, includes overhead</td>
</tr>
<tr>
<td>WDM terminal, 80 channels</td>
<td>240 W</td>
<td>Per fiber pair</td>
</tr>
<tr>
<td>ROADM, 80 channels, 100%</td>
<td>600 W</td>
<td>Per node</td>
</tr>
<tr>
<td>OXC, 80 channels</td>
<td>$f \times 85 \text{ W} + a \times 100 \text{ W} + 150 \text{ W}$</td>
<td>Per node. Node degree $f$, add/drop degree $a$</td>
</tr>
</tbody>
</table>


- To achieve minimization of Opex, you have to lit-up as fewer transponders and optical amplifiers as possible
Results - Reconfiguration time-point optimization

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<table>
<thead>
<tr>
<th>Power Consumption (KW)</th>
<th>Time of the day (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VWP</strong></td>
<td><strong>WP</strong></td>
</tr>
<tr>
<td><strong>Static</strong></td>
<td><strong>Hourly</strong></td>
</tr>
<tr>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>40</td>
<td>5</td>
</tr>
<tr>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td>60</td>
<td>15</td>
</tr>
<tr>
<td>70</td>
<td>20</td>
</tr>
<tr>
<td>80</td>
<td>25</td>
</tr>
<tr>
<td>90</td>
<td>30</td>
</tr>
<tr>
<td>100</td>
<td>35</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>VWP</th>
<th>WP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average non-disruption rate</strong></td>
<td>hourly</td>
<td>optimized</td>
</tr>
<tr>
<td>51%</td>
<td>88%</td>
<td>4.2%</td>
</tr>
<tr>
<td><strong>Energy saving</strong></td>
<td>29.6%</td>
<td>26%</td>
</tr>
</tbody>
</table>
Optical Routing Optimization

Given a network graph $G$

Phase 1: Offline planning
Find optimal RWA (or RA) planning based on predicted demands.

Phase 2: Online weight computation and routing
Set up connections on demand performing RWA (or RA) with greedy heuristics using the weights computed upon results of Phase 1 to favor RWA (or RA) optimal planning.

At an specific hour $t$ of a specific day $D$: For each actual demand $d$:
  - Calculate for $d$ the optimal weights of the wavelengths of $G$
  - Use the optimal weights to run a heuristic greedy routing algorithm (real time) and to route $d$
    - e.g., $k$-shortest edge disjoint paths

A discrete-event simulator has been coded and will be used to assess the performance of the routing optimization.
Offline planning and weight computation

• **OFFLINE: ILP**
  - Objectives:
    - Minimization of power consumption for the specific hour $t$
    - Minimize service disruption, i.e. change of routed compare to the previous hour $t - 1$
  - WP: Protected demands, optical bypass, ROADMs
  - VWP: Protected demands, wavelegnths conversion, traffic grooming.

• **ONLINE: weight computation**
  - General criteria:
    - Try to force an actual demand $d$ to follow the path of a corresponding predicted demand $d'$ (the path computed by the ILP)
    - If deviation is unavoidable: use *first* (lower cost) unassigned resources and *then* (higher cost) resources assigned to other demands
Results - VWP

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Time of the day (h)

Power Consumption (KW)

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<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Daily energy consumption</td>
<td>2503.2 kWh</td>
<td>1760 kWh</td>
<td>1917.16 kWh</td>
<td>1787.67 kWh</td>
</tr>
<tr>
<td>Energy saving</td>
<td>-</td>
<td>29.7%</td>
<td>23.4%</td>
<td>28.6%</td>
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</table>
Results - WP

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</thead>
<tbody>
<tr>
<td>Daily energy consumption</td>
<td>1699.5 kWh</td>
<td>1314 kWh</td>
<td>1441.47 kWh</td>
<td>1331 kWh</td>
</tr>
<tr>
<td>Energy saving</td>
<td>-</td>
<td>23%</td>
<td>15.2%</td>
<td>21.7%</td>
</tr>
</tbody>
</table>
Conclusions and outlook

- Optical-technology and control-plane evolution allows energy and traffic-load-aware dynamic operation of optical networks

- In a metro-core mobile network mobility of users is predictable and relevant

- Predictability allows to precompute the set of optimal routing solutions for each hour to minimize energy consumption

- The weight optimizations based on the off-line planning give an on-line solution with a very small optimality gap
Outline of the work

- Starting point: collection of user-mobility data in a mid-size Chinese city provided by BUPT
  - Based on the number of active calls in each cell of the metro cellular network
  - 2-month measurements of the 24 hours
  - The geographical position of the cells is known
- Elaboration of a hypothetical network infrastructure interconnecting cells
  - Estimation of traffic generated by a single user
  - 2 different levels of traffic aggregation
  - Clustering algorithms to aggregate cells
- Design of the optimal core fiber infrastructure (peak dimensioning)
- Resource assignment techniques minimizing power consumption
  - Offline periodic optimization
  - Online predictive technique
- Testing
  - Discrete event simulator
- SDN implementation

Future work
THANKS - GRAZIE!

QUESTION-TIME...

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