Next generation access network planning

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Outline

- Evolution
- Issues for operators
Fixed access networks

Evolution

40 years ago
One phone per home

today
Several devices per home

near future
Much more devices per home and user

Devices

40 years ago
One phone per home

today
Several devices per home

near future
Much more devices per home and user

Technology

40 years ago
Copper

today
Wireless

near future
Mobile

Operator

40 years ago
One per country

Services

40 years ago
Voice [kbps]

today
Voice, Data, Video... [Mbps]

near future
Real time services [+Gbps]

Voice [kbps]

Voice, Data, Video...

Real time services

Source: Needham ARRIS

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SP: Service provider
NP: Network provider
PIP: Physical Infrastructure provider
Fixed access networks

Evolution

xDSL technology is distance sensitive

How far are you from central office

Optical fiber (also) in access networks!

- Huge bandwidth (over 50 Tbps): 3-4 orders of magnitude higher than copper
- Low signal attenuation → less repeaters required, longer distances
- Immunity to electromagnetic interference → difficult eavesdropping → security
- No crosstalk between fibers of the same cable
- Low space requirement

Source: http://www.unitrek.com.au
Fixed access networks

Issues for the operators

**Infrastructure**
- Huge investment → use it as long as possible
- Seamless upgrade/migration
Fixed access networks

Issues for the operators

- Diverse user requirements
- Competitive telecom area
- Investments required
- Network upgrade
- Limited/Conditioned ARPU
- Objective: Maximize Profits

*ARPU: Average Revenue per User*
Outline

- Evolution and terminology
- Example of FTTB in Munich
- NGOA Architectures
- Converged access networks
Each cable is laid on demand:
• inefficient,
• time and cost consuming
• no flexibility

Use of flexibility/distribution points → Tree topology
Optical Access Networks

Topology

Feeder Cable

Distribution Cable

Easier, faster and less costly to connect new users
Optical Access Networks

Terminology

DSLAM: Digital Subscriber Line Access Multiplexer
MDU: Multi-Dwelling Unit
ONU/ONT: Optical Network Unit/Terminal
OLT: Optical Line Terminal
FTTx: Fiber to the x
Optical Access Networks

FTTB project in Munich

Use GPON to connect the powermeters of each building → FTTB

How to achieve

Source: SWIM

HH: Household
MDU: Multi-Dwelling Unit
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ONU/ONT: Optical Network Unit/Terminal
OLT: Optical Line Terminal
FTTx: Fiber to the x

~7%
4T buildings
55T HH

~35%
25T buildings
260T HH

~50%
44T buildings
380T HH

~73%
90T buildings
550T HH

1st Phase

2nd Phase
Optical Access Networks

FTTB project in Munich

1st Phase
- 2009-2013
- 160 Mio. €
- 32,000 buildings
- 350,000 HH

2nd Phase
- 2016-2021
- 170 Mio. €
- 35,000 buildings
- 230,000 HH

70% of HH in Munich

Source: SWM

HH: Household
MDU: Multi-Dwelling Unit
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ONU/ONT: Optical Network Unit/Terminal
OLT: Optical Line Terminal
FTTx: Fiber to the x
Optical Access Networks

FTTB project in Munich

1st Phase
2009-2013
32,000 buildings
350,000 HH

Required cable?
~7,000 km (from Munich to Sydney)

Required fiber?
~260,000 km (6.5 x round-the-globe)

2nd Phase
2016-2021
35,000 buildings
230,000 HH

ONU/ONT: Optical Network Unit/Terminal
OLT: Optical Line Terminal
FTTx: Fiber to the x

Source:
SDLAM: Digital Subscriber Line Access Multiplexer
MDU: Multi-Dwelling Unit
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Next Generation Optical Access (NGOA) Networks

Towards NGOA

Today

- **FTT LEx**: Modem → DSLAM
- **FTT Cab**: Modem → DSLAM
- **FTT B**: Modem → MDU/ONU → OLT
- **FTT H**: ONT → OLT

Access bit rate

**DSLAM**: Digital Subscriber Line Access Multiplexer

**MDU**: Multi-Dwelling Unit

**ONU/ONT**: Optical Network Unit/Terminal

**OLT**: Optical Line Terminal

**FTTx**: Fiber to the x
Next Generation Optical Access (NGOA) Networks

Towards NGOA

- Home/Building
- Cabinet
- Central office/Local Exchange (LEX)
- Metro access node

NGOA

ONT

OLT

Aggregation network

No Consolidation

Aggressive Consolidation

CO less than 20 km away from user

In Germany, ~8000 COs

CO less than 60 km away from user

In Germany, ~800 COs
Next Generation Optical Access (NGOA) Networks

NGOA architectures

TDM solution

WDM solution

WDM solution

How to increase BW with limited investments? \(\rightarrow\) Hybrid PON

AWG: Array Waveguide

ONU/ONT: Optical Network Unit/Terminal

OLT: Optical Line Terminal

ONU/ONT: Optical Network Unit/Terminal

OLT: Optical Line Terminal

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Achieved goals:
- Sustained bit rate per ONU: 150-500 Mbps
- Peak bitrate per ONU: 1-10 Gbps
- Reduction of central offices → node consolidation
- Maximum reuse of existing optical infrastructure → low cost migration
Towards Converged Access Networks

Nowadays

Home/Building

Cabinet

Central office/Local Exchange (LEx)

Metro access node

ONU

Power Splitter

Aggregation networks

OLT

CAN

Fiber to the Base Station (FTTBS)

Fiber to the Antenna (FTTA)

AWG: Array Waveguide

ONU/ONT: Optical Network Unit/Terminal

OLT: Optical Line Terminal

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Towards Converged Access Networks

Nowadays
Towards Converged Access Networks

5G and later

Aggregation networks

CAN

OLT

ONU

ONU

ONU
Towards Converged Access Networks

5G and later

Aggregation networks

CAN

OLT

ONU

ONU

ONU

ONU

ONU

ONU

ONU

ONU

ONU

ONU

ONU
Towards Converged Access Networks

Converged access networks

A single converged NGOA can interconnect different users:
• Residential users
• Business users
• Base Stations
• Small cells
Each user gets the required bandwidth

AWG: Array Waveguide
ONU/ONT: Optical Network Unit/Terminal
OLT: Optical Line Terminal

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Towards Converged Access Networks

Converged access networks

Disjoint:
- GPON 1:32 for fixed users,
- P2P for BS

Joint HPON:
- HPON 40λ 1:32 for all users and BS

Joint NG-PON2:
- 1:16 (RN1) and 1:32 (RN2)

Case Study: Darmstadt (Germany)
- 9.63 km2
- 6056 buildings
- 32000 households
- Number of base stations: 5 (UMTS) and 37 (LTE)
Towards Converged Access Networks

Converged access networks

Disjoint: GPON 1:32 for fixed users, P2P for BS

Joint HPON: HPON 40λ 1:32 for all users and BS

Joint NG-PON2: 1:16 (RN1) and 1:32 (RN2)
Towards Converged Access Networks

Converged access networks

**Disjoint:**
GPON 1:32 for fixed users, P2P for BS

**Joint HPON:**
HPON 40\(\lambda\) 1:32 for all users and BS

**Joint NG-PON2:**
1:16 (RN1) and 1:32 (RN2)

---

Disjoint: GPON 1:32 for fixed users, P2P for BS

Joint HPON: HPON 40\(\lambda\) 1:32 for all users and BS

Joint NG-PON2: 1:16 (RN1) and 1:32 (RN2)
Towards Converged Access Networks

Converged access networks

Important aspects to be taken into account:

• Existing infrastructure?

• Locations availability?

• Planning time span (5 years? 10 years?)

• Demands: type, distribution, etc.

• Costs (and time) factors
  • Techniques/expertise/availability/wages/permits...

• Protection?

• Flexibility
Outline

- Fixed Access Networks
- Optical Access Networks
- Access Network Planning methodology
- Case Studies
Converged access network planning

Objectives

- Deliver services requested by users
- Deliver acceptable throughput and response times
- Be within budget and maximize cost efficiencies
- Be reliable
- Be expandable without major redesign
- Be manageable by maintenance and support staff
- Be well documented
Converged access network planning

Methodology

Scenario → Models → Planning → Evaluation
Converged access network planning

Methodology

- Area
  - Dense Urban? Urban? Rural?
  - Size?
Converged access network planning

Methodology

- Scenario
- Models
- Planning
- Evaluation

Area

- Dense Urban? Urban? Rural?
- Size?
- Available data?

<table>
<thead>
<tr>
<th>Raster maps</th>
<th>Vector maps</th>
</tr>
</thead>
<tbody>
<tr>
<td>based on conventional images files</td>
<td>based on text files with coordinates describing the various points and curves on a map. The data can be used to generate a map image</td>
</tr>
<tr>
<td>• From .gif, .jpg, other image files</td>
<td>• Maps scale very well and is relatively small</td>
</tr>
<tr>
<td>• Details can be observed, low time&amp;money for map acquisition</td>
<td>• Map information can be structured in layers</td>
</tr>
<tr>
<td>• Maps don’t scale well, too big files for high resolution</td>
<td>• Costly from raster map to vector map</td>
</tr>
<tr>
<td></td>
<td>• Only details that have vectorized can be shown</td>
</tr>
</tbody>
</table>

Raster maps

![Raster map image](image1)

Vector maps

![Vector map image](image2)
Converged access network planning

Methodology

- Area
  - Dense Urban? Urban? Rural?
  - Size?
  - Available data?
    - Information?
      - For fixed access: Street type/size, public transport lines, bridges, etc.
      - For mobile access: Area topography, building high, building access, etc.
Converged access network planning

Methodology

- Scenario
  - Area
  - GF/BF

Existing ducts?  
Can be resused?
Converged access network planning

Methodology

- Area
- GF/BF
- Technology
- Architecture

Examples of some solutions without protection
Converged access network planning

Methodology

- Area
- GF/BF
- Technology
- Architecture

Examples of some solutions without protection
Converged access network planning

Methodology

- Area
- GF/BF
- Technology
- Architecture

Examples of some solutions without protection
Converged access network planning

Methodology

- Area
- GF/BF
- Technology
- Architecture
- End users different from requirements: BW, availability, max. delay, etc.
  - Residential
  - Business
  - MBS
  - SC
  - RSU
  - Others...

The location is crucial to be known....
Converged access network planning

Methodology

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Models</th>
<th>Planning</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>Based on maps.</td>
<td>Based on building size and area</td>
<td>Number of HH/Building</td>
</tr>
<tr>
<td>Business</td>
<td>If no real data available → some models: e.g., based on building size and area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MBS</td>
<td>If no real data available → some models: e.g., grid. Realignment is required.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SC</td>
<td>If no real data available → some models: e.g., based on building type (hospital, shopping mall, etc.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RSU</td>
<td>Distributed along streets/roads.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Converged access network planning

Methodology

- Area
- GF/BF
- Technology
- Architecture
- End users
- Penetration curves

Impact of the location of new customers
Converged access network planning

Methodology

- Cost models

**CAPEX**
- Infrastructure
  - On site
  - In field
- Equipment
  - On site
  - In field
- Customer premises

**OPEX**
- Maintenance
- Failure Management
- Energy consumption
- Service Management
- ...

**Depreciation**
- Straight line
- Declining method
- Double declining method
Converged access network planning

Methodology

- Cost models
- Architecture model
  - Splitting points
    - Single
    - Multiple
  - BW

Scenario -> Models -> Planning -> Evaluation

---

| ONU: Optical Network Unit |
| MBS: Macro Base Station |
| AWG: Array Waveguide |
| BBU: Base Band Unit |
| RRU: Radio Remote Unit |

Diagram:

- 5 λ's/MBS (3x10G and 2x3G)
- 1 λ's/Cabinet (10G)
- 1 λ's/SC (10G)

Fronthaul of MBS and SC (FH WR WDM-PON)
Converged access network planning

Methodology

- Cost models
- Architecture model
  - Splitting points
    - Single
    - Multiple
  - BW

Scenario → Models → Planning → Evaluation

- Cost models
- Architecture model
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    - Multiple
  - BW

ONU: Optical Network Unit
MBS: Macro Base Station
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BBU: Base Band Unit
RRU: Radio Remote Unit

SC fronthauled to MBS and MBS backhauled to OLT (FBH WR WDM-PON)
Converged access network planning

Methodology

- Cost models
- Architecture model
  - Splitting points
    - Single
    - Multiple
  - BW
  - Protection
    - Disjoint fibers:
      - FF
      - FF and DF

OU: Optical Network Unit
MBS: Macro Base Station
AWG: Array Waveguide
BBU: Base Band Unit
RRU: Radio Remote Unit
Converged access network planning

Methodology

- Cost models
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    - Disjoint fibers:
      - FF
      - FF and DF
      - Inter DF
Converged access network planning

Methodology

- Cost models
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  - BW
  - Protection
    - Disjoint fibers:
      - FF
      - FF and DF
      - Inter DF
    - FF Ring

---

ONU: Optical Network Unit
MBS: Macro Base Station
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Converged access network planning

Methodology

- Cost models
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    - Single
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  - BW
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    - Disjoint fibers:
      - FF
      - FF and DF
      - Inter DF
    - FF Ring
    - μwave links

ONU: Optical Network Unit
MBS: Macro Base Station
AWG: Array Waveguide
BBU: Base Band Unit
RRU: Radio Remote Unit
Converged access network planning

Methodology

- Scenario
- Models
- Planning
- Evaluation

- Cost models
- Architecture model
- Component model
Converged access network planning

Methodology

- Scenario
- Models
- Planning
- Evaluation

- Cost models
- Architecture model
- Component model
- Area models
Converged access network planning

Methodology

- Cost models
- Architecture model
- Component model
- Area models (*no available maps*)
- Geometric models

Scenario → Models → Planning → Evaluation

- Random geometric model
- Tree street model
- Parallel street model
- Gabriel graph model
- Procedurally Generated Topologies
Converged access network planning

Methodology

- Scenario
- Models
- Planning
- Evaluation

- Cost models
- Architecture model

ArcGIS
Converged access network planning

Methodology

Heuristics

- Clustering
  - K-means clustering: Set of $N$ nodes, group them in $k$ clusters
    - Partition of $N$ nodes into $k$ subsets
    - Compute seed points as the clusters centroids
    - Assign nodes to closest seed point

Scenario Models Planning Evaluation

$N=10$ $k=2$
Converged access network planning

Methodology

Heuristics

- Clustering
  - K-means clustering: Set of $N$ nodes, group them in $k$ clusters
    - Partition of $N$ nodes into $k$ subsets
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Converged access network planning

Methodology

Scenario → Models → Planning → Evaluation

Heuristics

- Clustering
  - K-means clustering: Set of $N$ nodes, group them in $k$ clusters
    - Partition of $N$ nodes into $k$ subsets
    - Compute seed points as the clusters centroids
    - Assign nodes to closest seed point
    - Repeat until no new assignment is done

Converges fast but usually in a local optimum.

Global optimum $\rightarrow$ deterministic annealing and genetic algorithms

How to determine best $k$ in advance?
Converged access network planning

Methodology

Heuristics
- Clustering

- Given splitting ratio of RN
- Allowing some spare ports → resilience, new ONUs, etc.
- Minimizing distance to each cluster centroid
Converged access network planning

Methodology

Heuristics
- Fiber layout:
  Duct is the cost driver compared to fiber

Minimum Spanning tree: Very long paths
Converged access network planning

Methodology

Heuristics
- Fiber layout:
  Duct is the cost driver compared to fiber

Shortest path tree: High costs
Converged access network planning

Methodology

Scenario ➔ Models ➔ Planning ➔ Evaluation

Heuristics

- **Fiber layout:**
  - Duct is the cost driver compared to fiber
  - Bounded Radius Minimum Spanning Tree ➔ Trade off between radius and cost
  - Steiner Tree ➔ finds a tree of minimum weight that contains all end nodes (but may include additional vertices).
  - Modified Dijkstra (reducing weights –e.g., to 1- when a street segment has a duct)

Kruskal’s algorithm

Prim’s algorithm

Modified Dijkstra
Converged access network planning

Methodology

Scenario  →  Models  →  Planning  →  Evaluation

ILP

MBS and SC fronthauled to CO

MBS backhauling to CO
SC fronthauled to MBS
Converged access network planning

Methodology

- **Scenario**
- **Models**

**ILP**

- **Objective Function to minimize the total equipment and infrastructure cost**

\[
Z = \sum_{i=0}^{n \times m} C_{AWG2} \times AWG2_i + \sum_{i=0}^{n \times m} (C_{AWG1} + C_{OLT/FF}) \times AWG1_i + C_f \times \sum_{i=0}^{n \times m} (\sum_{i=0}^{n \times m} d_{ij} \times D_{MCO-AWG1j}) + C_f \times \sum_{i=0}^{n \times m} (\sum_{i=0}^{n \times m} e_{12ij} \times D_{AWG1i-AWG2j}) + C_f \times \sum_{i=0}^{n \times m} (\sum_{i=0}^{n \times m} e_{ij} \times D_{AWG2i-Cabj}) + C_f \times \sum_{i=0}^{n \times m} (\sum_{i=0}^{n \times m} SC_{ij} \times D_{AWG2i-SCj}) + C_f \times \sum_{i=0}^{n \times m} (\sum_{i=0}^{n \times m} BS_{ij} \times D_{AWG2i-BSj}) + C_t \times \sum_{i=0}^{n \times m} (D_{tj})
\]

- **AWG costs at RN2 locations**
- **AWG and CO costs based on number of RN1**
- **FF cost**
- **DF cost**
- **LMF cost**
- **Duct cost**
Converged access network planning

Methodology

Scenario → Models → Planning → Evaluation

ILP

- **Objective Function** to minimize the total infrastructure cost

- **Constraints:**
  - Every cabinet, SC and BS must be connected to a unique AWG2:
    - For every j, \( \sum_{i=0}^{n \times m} e_{ij} = 1 \)
    - For every j, \( \sum_{i=0}^{n \times m} SC_{ij} = 1 \)
    - For every j, \( \sum_{i=0}^{n \times m} BS_{ij} = 1 \)
  - Every AWG1 must be connected to the MCO:
    - For every j, \( \sum_{i=0}^{n \times m} d_{ij} = 1 \)
  - The sum of the connections between one RN and its connected Cabinets, SC and BS must be smaller than the AWG2 capacity (\( k_2 \))
    - For every i, \( \sum_{j=0}^{n \times m} (e_{ij} + \text{Number\_per\_SC}_{j} \times SC_{ij} + \text{Number\_per\_BS} \times BS_{ij}) \leq k_2 \)
Converged access network planning

Methodology

- Scenario
- Models
- Planning
- Evaluation

ILP

- **Objective Function to minimize the total infrastructure cost**

- **Constraints:**
  - The distances between the MCO and the cabinets must be smaller than the maximal reach:
    - For every \(i, j, l, v\):

\[
d_{ij} \cdot D_{\text{MCO}i-\text{AWG}1j} + e_{12l} \cdot D_{\text{AWG}1j-\text{AWG}2l} + e_{lv} \cdot D_{\text{AWG}2l-\text{Cab}v} \leq D_{\text{max}}
\]
Converged access network planning

Methodology

Evaluation metrics
- TCO = CAPEX + OPEX(T)
- Yearly Cash Flow
- Payback period
- Net Present Value (NPV)
- Discounted Payback period (DPB)
- Internal Rate of Return (IRR)

TCO: Total Cost of Ownership
NPV: Net Present Value

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Outline

Fixed Access Networks

Optical Access Networks

Access Network Planning methodology

Case Studies
Converged access network planning

Goal:
- Different areas (DU,U,R),
- Different penetration curves,
- Different ARPUs
- Greenfield/Brownfield
Converged access network planning

Hybrid PON Analysis

Scenario ➔ Models ➔ Planning ➔ Evaluation

Market penetration models:
- Random
- Bass model
- BS distribution
- Grid with different interBS distances depending on the area

Geographic topology

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Area</th>
<th>Total Buildings</th>
<th>Building Density</th>
<th>Total MBS</th>
<th>MBS Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Munich</td>
<td>DU</td>
<td>4km²</td>
<td>2042</td>
<td>510/km²</td>
<td>12</td>
<td>3/km²</td>
</tr>
<tr>
<td>Miesbach</td>
<td>U</td>
<td>28km²</td>
<td>2730</td>
<td>98/km²</td>
<td>9</td>
<td>0.3/km²</td>
</tr>
<tr>
<td>Höhndorf</td>
<td>R</td>
<td>150km²</td>
<td>1163</td>
<td>8/km²</td>
<td>4</td>
<td>0.02/km²</td>
</tr>
</tbody>
</table>
Converged access network planning

Hybrid PON Analysis

Scenario → Models → Planning → Evaluation

Heuristics
https://github.com/EGrigoreva/FixedNetworkPlanningTool
Converged access network planning

Hybrid PON Analysis

Greenfield - pure FTTB network – 20 year NPV – optimal cluster – homogeneous distribution

\[ NPV = \sum_{n=0}^{N} \frac{(R - C)^n}{(1 + r)^n} \]

- R: Revenue of Buildings
- C: TCO
- r: Discount Rate (8%)
- n: time frame (20 years)

Unprofitable
Converged access network planning

Hybrid PON Analysis

- Scenario
- Models
- Planning
- Evaluation

Greenfield - pure FTTB network – Payback period – optimal cluster – homogeneous distribution

- DU
- Urban
- Rural

Unprofitable

0.4

0.6

0.8

1

1.2

0

2

4

6

8

10

12

14

16

18

YEAR

ARPU [CU]

Aggressive
Likely
Conservative

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Converged access network planning

Hybrid PON Analysis

- Scenario
- Models
- Planning
- Evaluation

Greenfield - pure FTTB network – Payback period – optimal cluster – Bass distribution

- First year users, then spread outwards following the adoption curves

Which is the impact of planning according to Bass??
Converged access network planning

Hybrid PON Analysis

Scenario | Models | Planning | Evaluation

Greenfield - pure FTTB network – Payback period – optimal cluster – Bass distribution

TCO

Rural

Aggressive | Likely | Conservative

Random | Bass Optimal | Bass Yearly
Tutorial Take away

- Strategic planning required by operators but also for manufacturers, regulators and governments.
- Planning depends significantly on the considered models and approaches.
- These studies are useful but …other aspects must also be considered.
- Cost is important:
  - Specially infrastructure!
  - How to take advantage:
    - Converged Networks → More and diverse users sharing same ODN
    - Reuse ducts and fibers for protection
- Do not underestimate OPEX!!!

More information on our tools at:
https://www.ei.tum.de/lkn/research/dfg-converged-access/
https://github.com/EGrigoreva/FixedNetworkPlanningTool
Questions?