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Next generation access network planning

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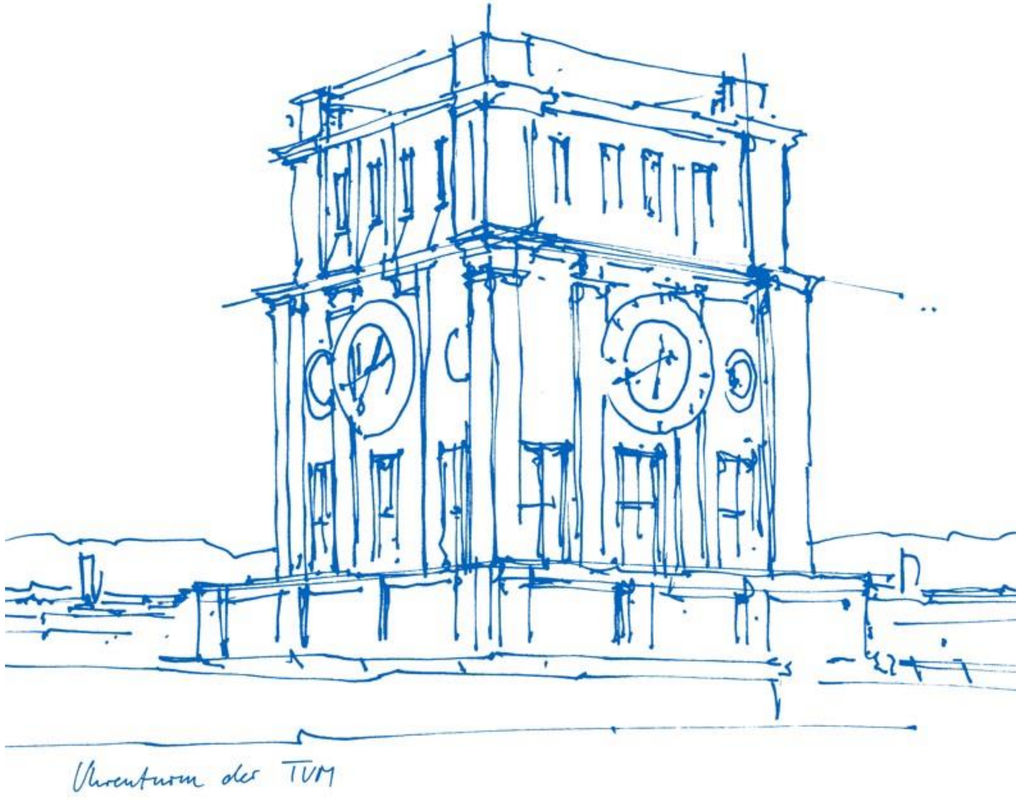


Outline

Fixed Access Networks → Optical Access Networks → Access Network Planning Methodology → Case Studies

- Evolution
- Issues for operators

Fixed access networks

Evolution

	40 years ago	today	near future
Devices	One phone per home	Several devices per home	Much more devices per home and user
Technology	Copper		MCF,...))cols
Operator	One per country		
Services	Voice [kbps]	Voice, Data, Video... [Mbps]	Real time services [+Gbps]

Source: Needham ARRIS

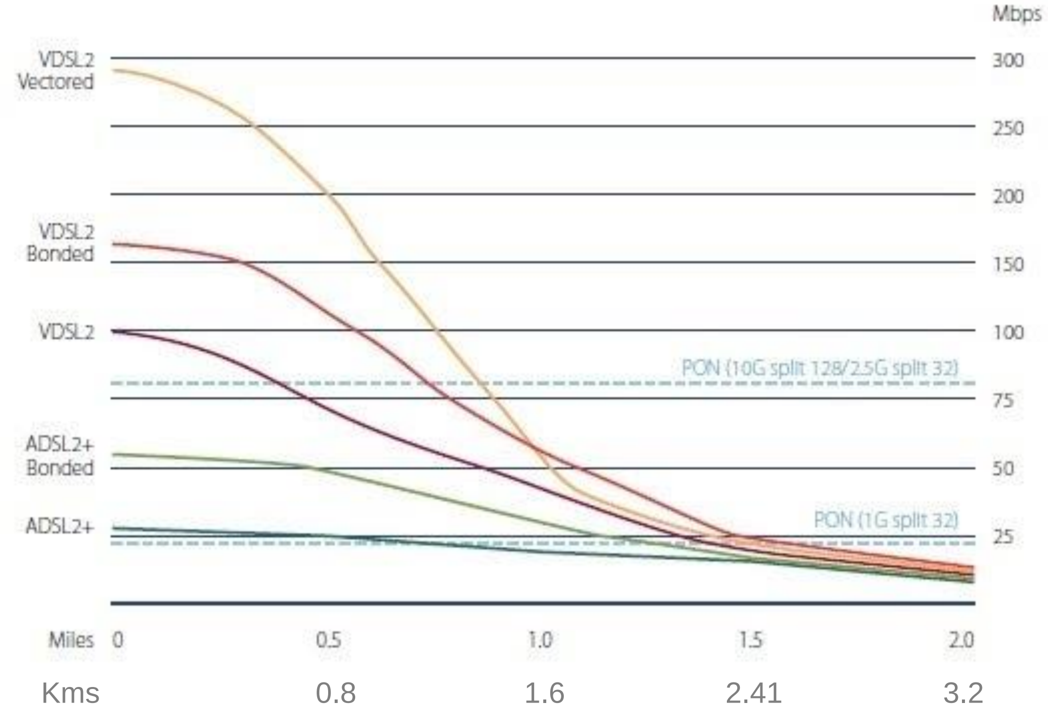
SP: Service provider
NP: Network provider
PIP: Physical Infrustucture provider

Fixed access networks

Evolution

xDSL technology is distance sensitive

How far are you from central office



Source: http://www.unitrek.com.au

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

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

Investments required
Network upgrade

Competitive telecom area

Limited/Conditioned ARPU

Objective: Maximize Profits

ARPU: Average Revenue per User

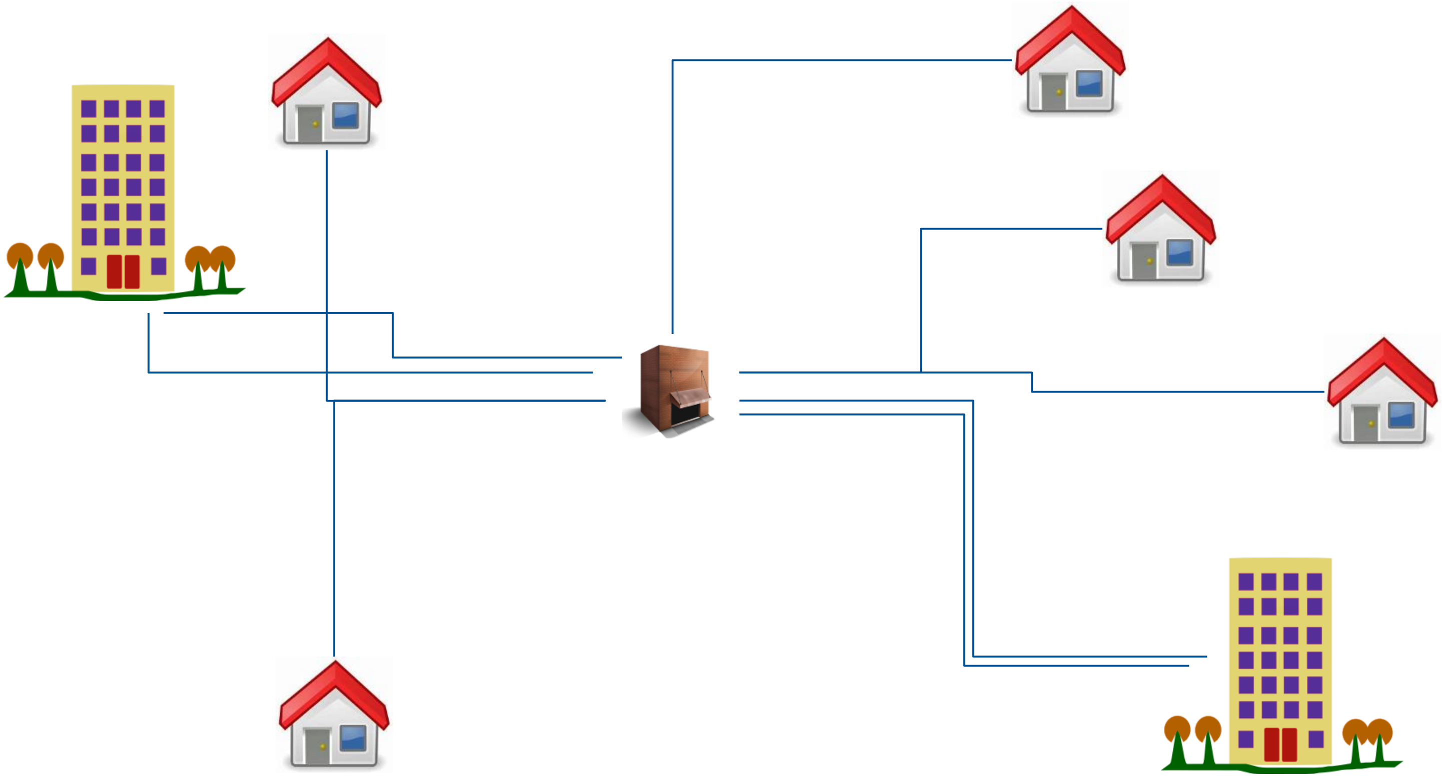
Outline

Fixed Access Networks → Optical Access Networks → Access Network Planning Methodology → Case Studies

- Evolution and terminology
- Example of FTTB in Munich
- NGOA Architectures
- Converged access networks

Optical Access Networks

Topology

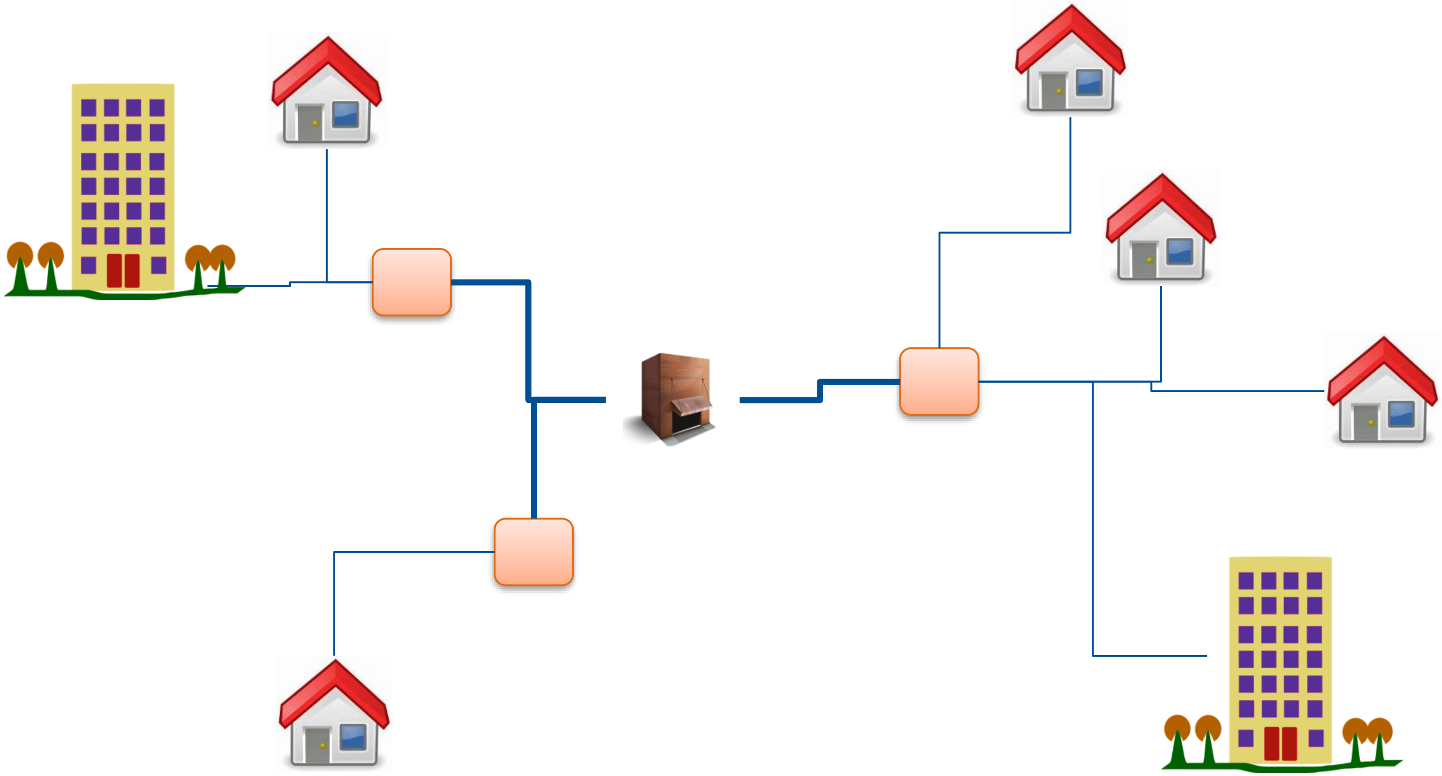


Each cable is laid on demand:
- unefficient,
- time and cost consuming
- no flexibility

Use of flexibility/distribution points→ Tree topology

Optical Access Networks

Topology



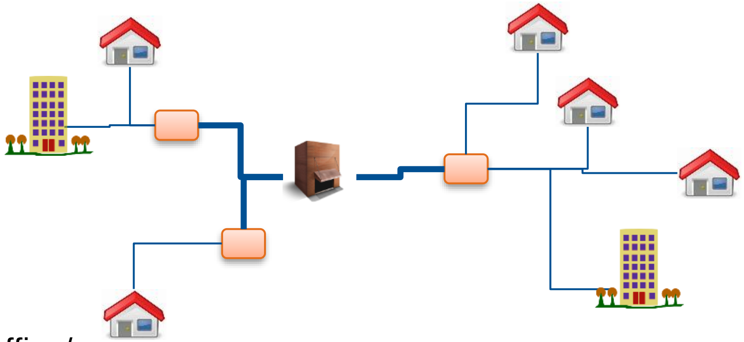
Feeder Cable

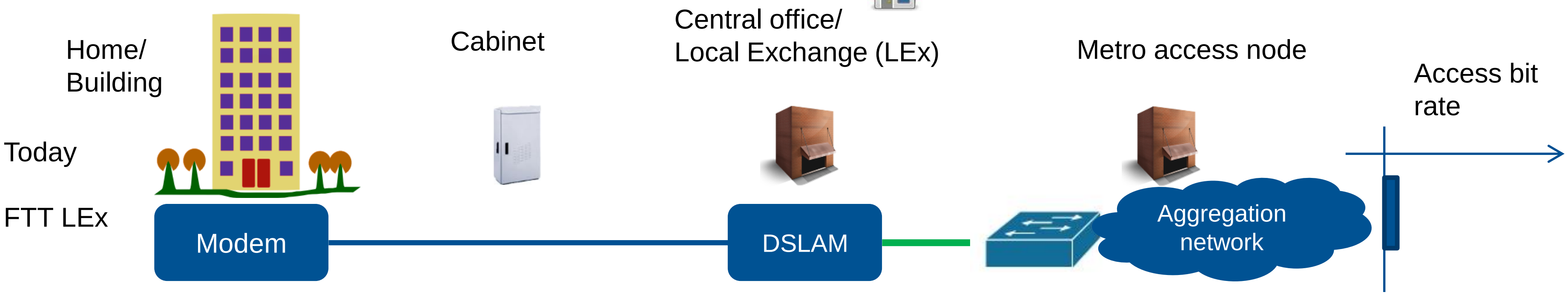
Distribution Cable

Easier, faster and less costly to connect new users

Optical Access Networks

Terminology

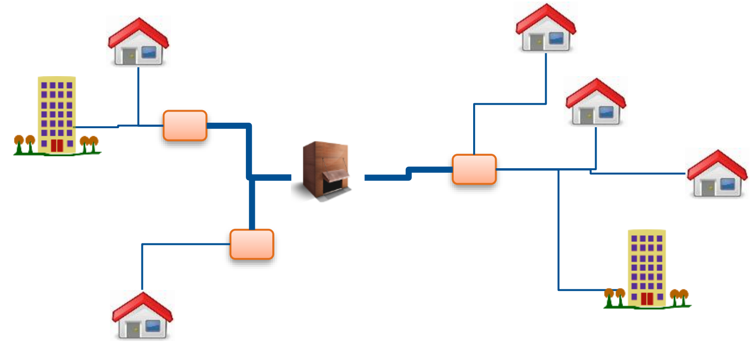




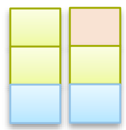
DSLAM: Digital Subscriber Line Access Multiplexer
MDU: Multi-Dwelling Unit

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

Optical Access Networks

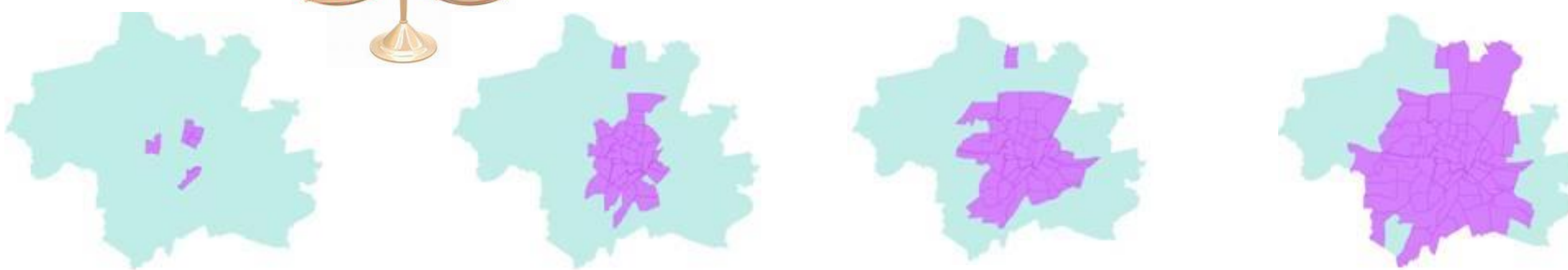


FTTB project in Munich



Use GPON to connect the powermeters of each building→ FTTB

How to achieve



~7% 4T buildings 55T HH	**~35% 25T buildings 260T HH**	**~50% 44T buildings 380T HH**	**~73% 90T buildings 550T HH**
		1st Phase	2nd Phase

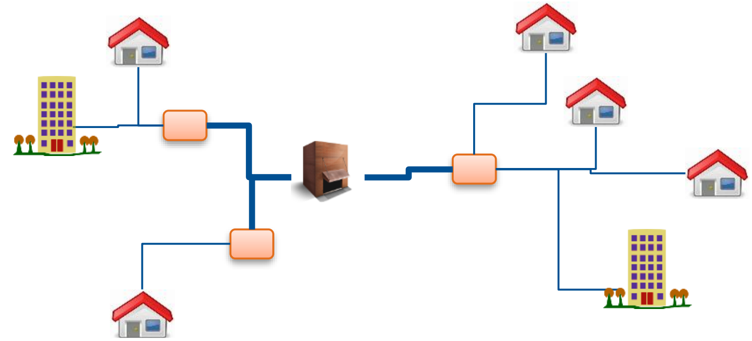
Source: SWM

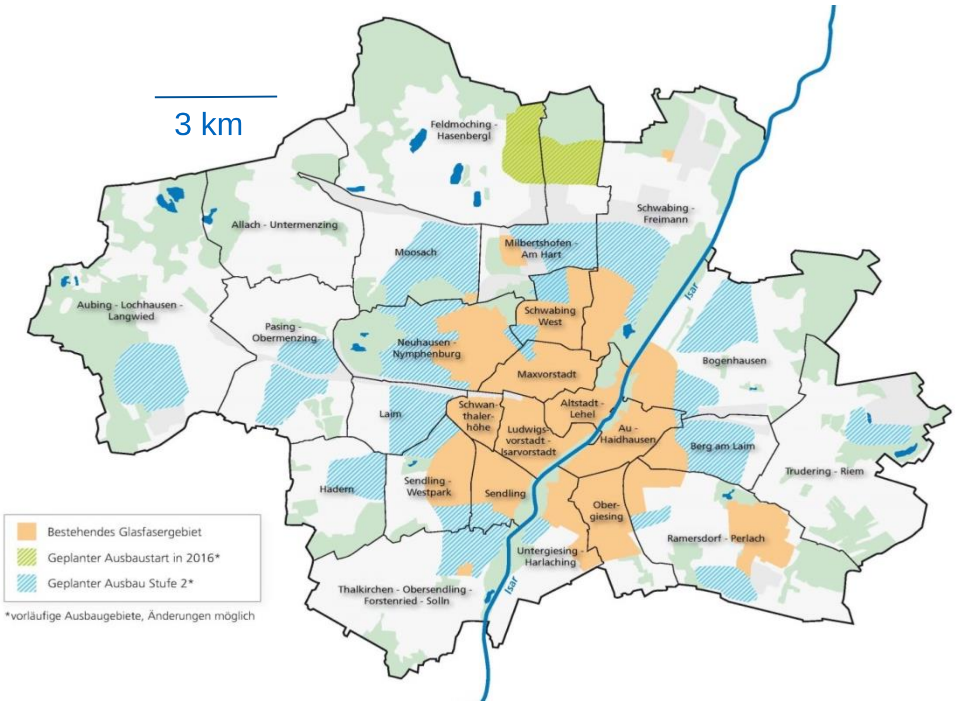
HH: Household
MDU: Multi-Dwelling Unit

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

Optical Access Networks

FTTB project in Munich





1st Phase	2nd Phase
2009-2013	2016-2021
160 Mio. €	170 Mio. €
32.000 buildings	35.000 buildings
350.000 HH	230.000HH

70% of HH in Munich

Source: SWM

HH: Household
MDU: Multi-Dwelling Unit

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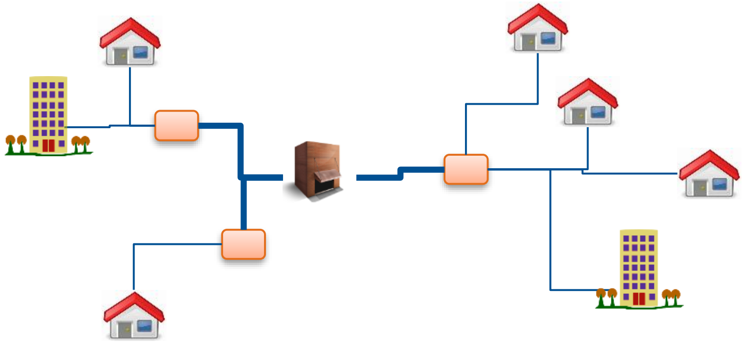
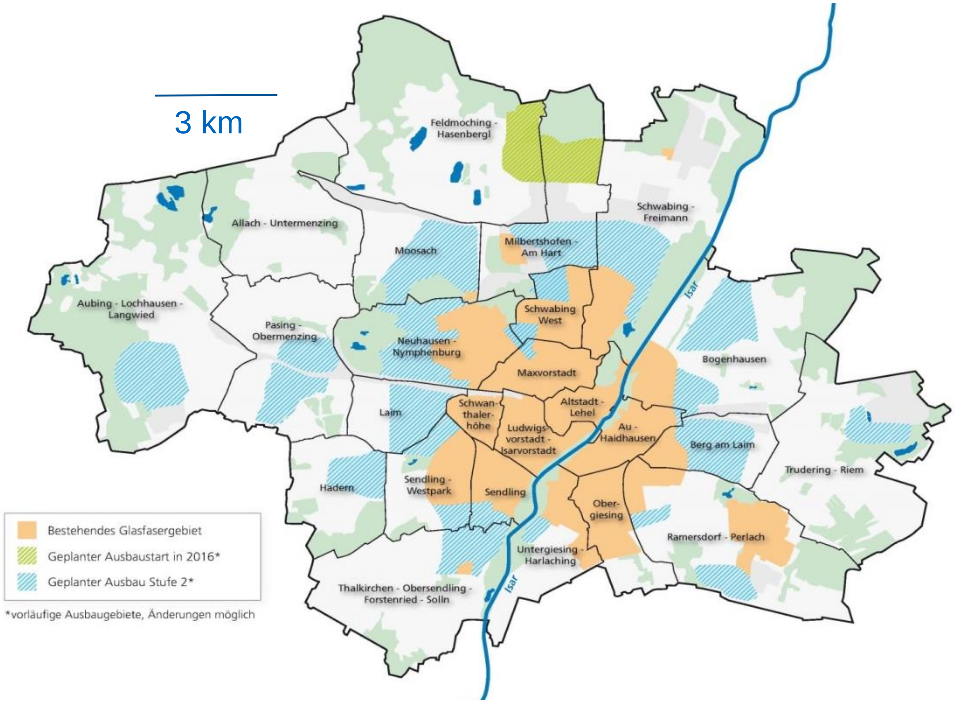
Optical Access Networks

FTTB project in Munich





1st Phase

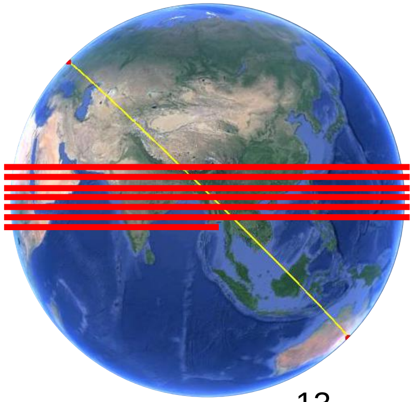
2009-2013

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)



Source: SW//M

DSLAM: Digital Subscriber Line Access Multiplexer
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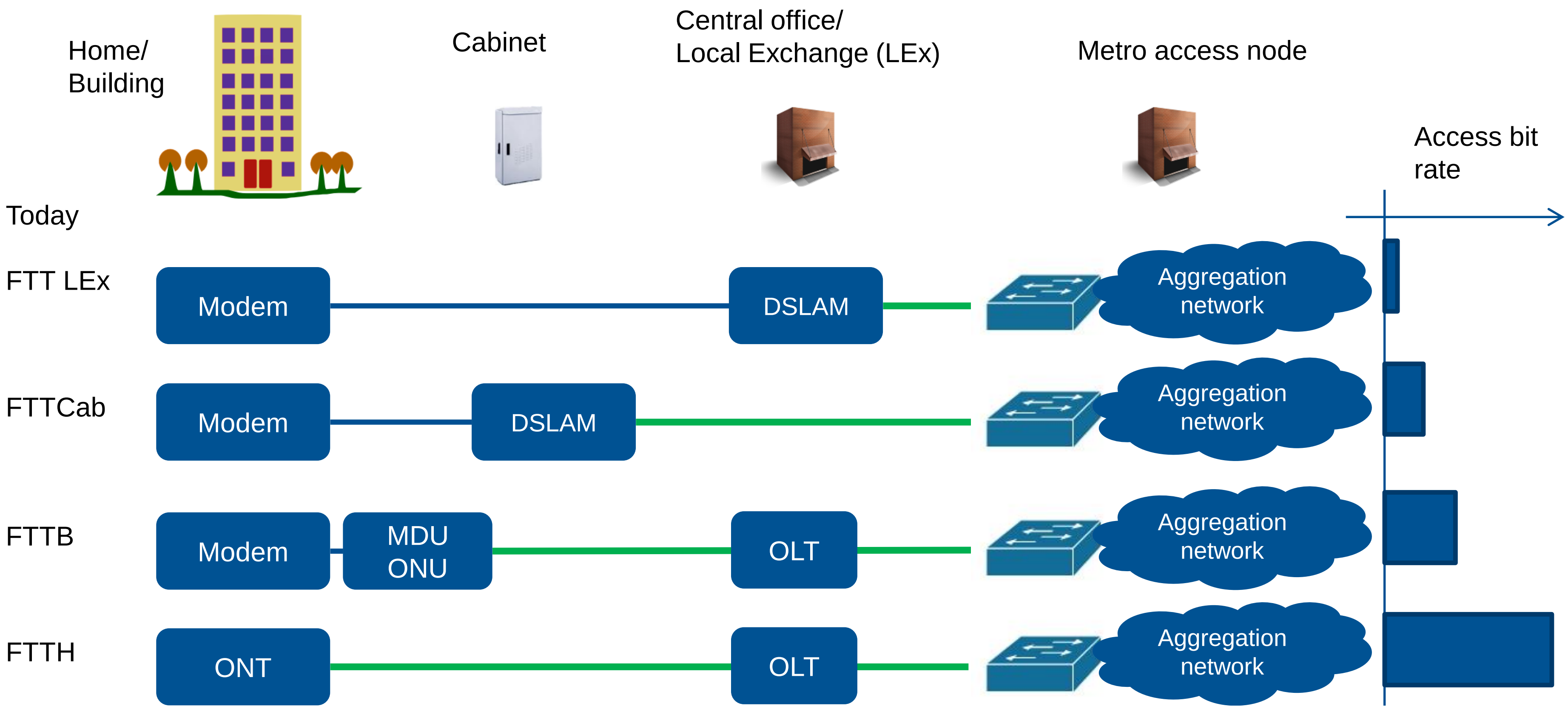
Next Generation Optical Access (NGOA) Networks

Towards NGOA



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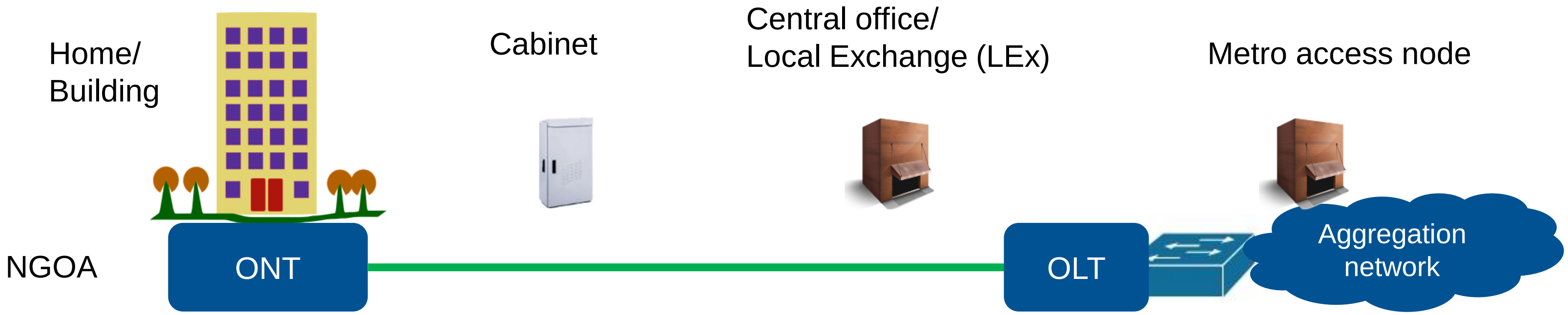
Next Generation Optical Access (NGOA) Networks

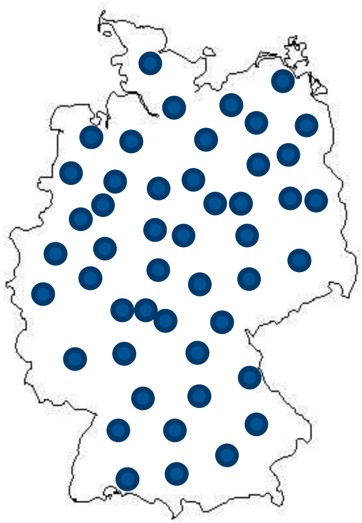
Towards NGOA



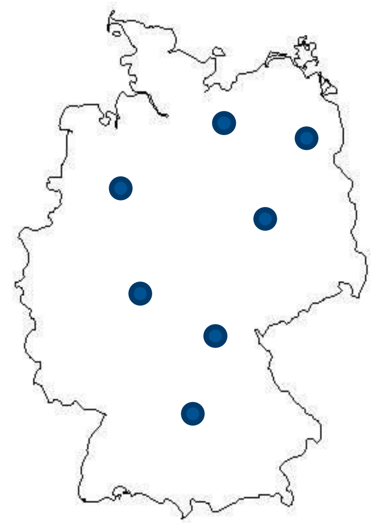
CO less than 20 km away from user

In Germany, ~8000 COs

No Consolidation



Aggressive Consolidation

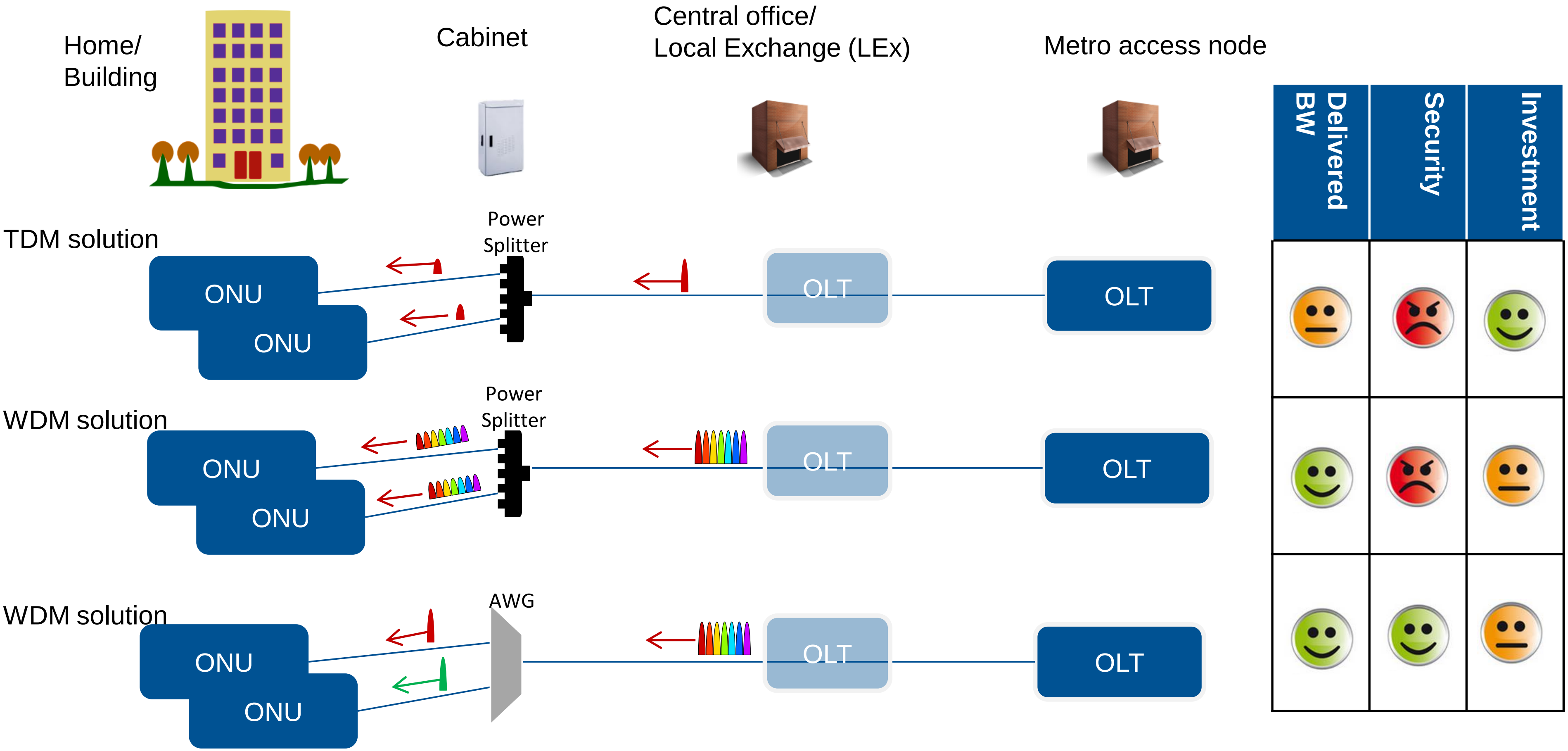


CO less than 60 km away from user

In Germany, ~800 COs

Next Generation Optical Access (NGOA) Networks

NGOA architectures



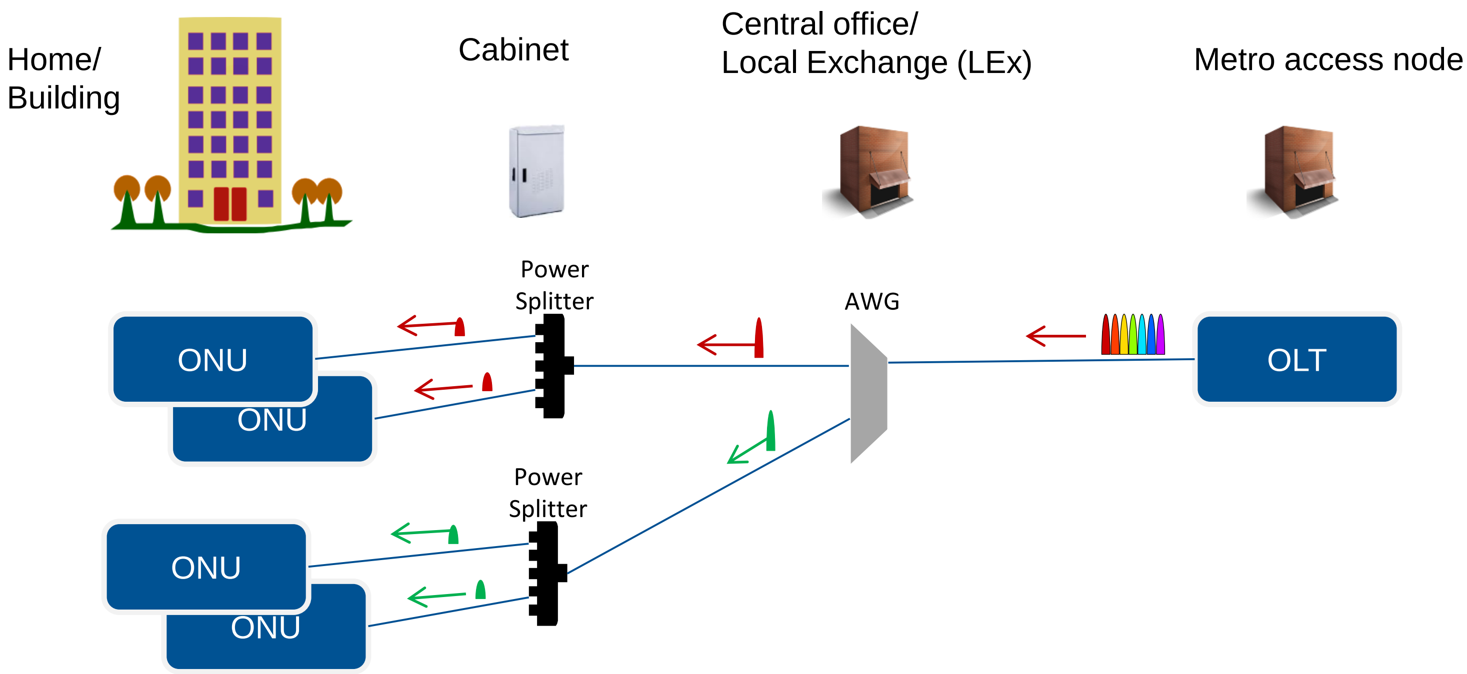
How to increase BW with limited investments?→ Hybrid PON

AWG: Array Waveguide

ONU/ ONT: Optical Network Unit/Terminal
OLT: Optical Line Terminal

Next Generation Optical Access (NGOA) Networks

NGOA architectures



Delivered BW	Security	Investment
😐	😐	🙂

Achieved goals:

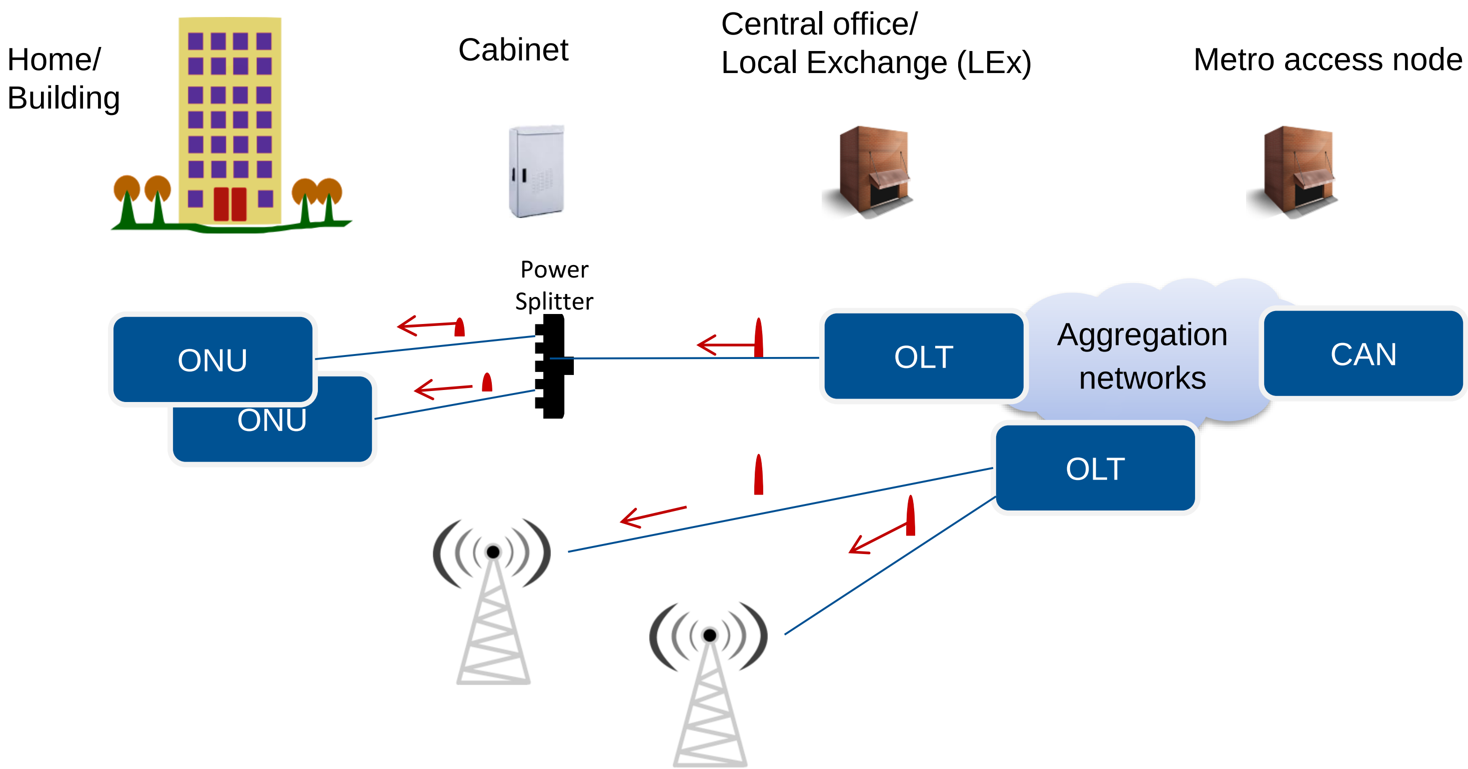
- Sustained bit rate per ONU: 150-500 Mbps
- Peak bitrate per ONU: 1-10 Gbps
- Reduction of central offices→ node consolidation
- Maximum reuse of existing optical infrastructure → low cost migration

AWG: Array Waveguide

ONU/ ONT: Optical Network Unit/Terminal
OLT: Optical Line Terminal

Towards Converged Access Networks

Nowadays



Fiber to the Base Station (FTTBS)

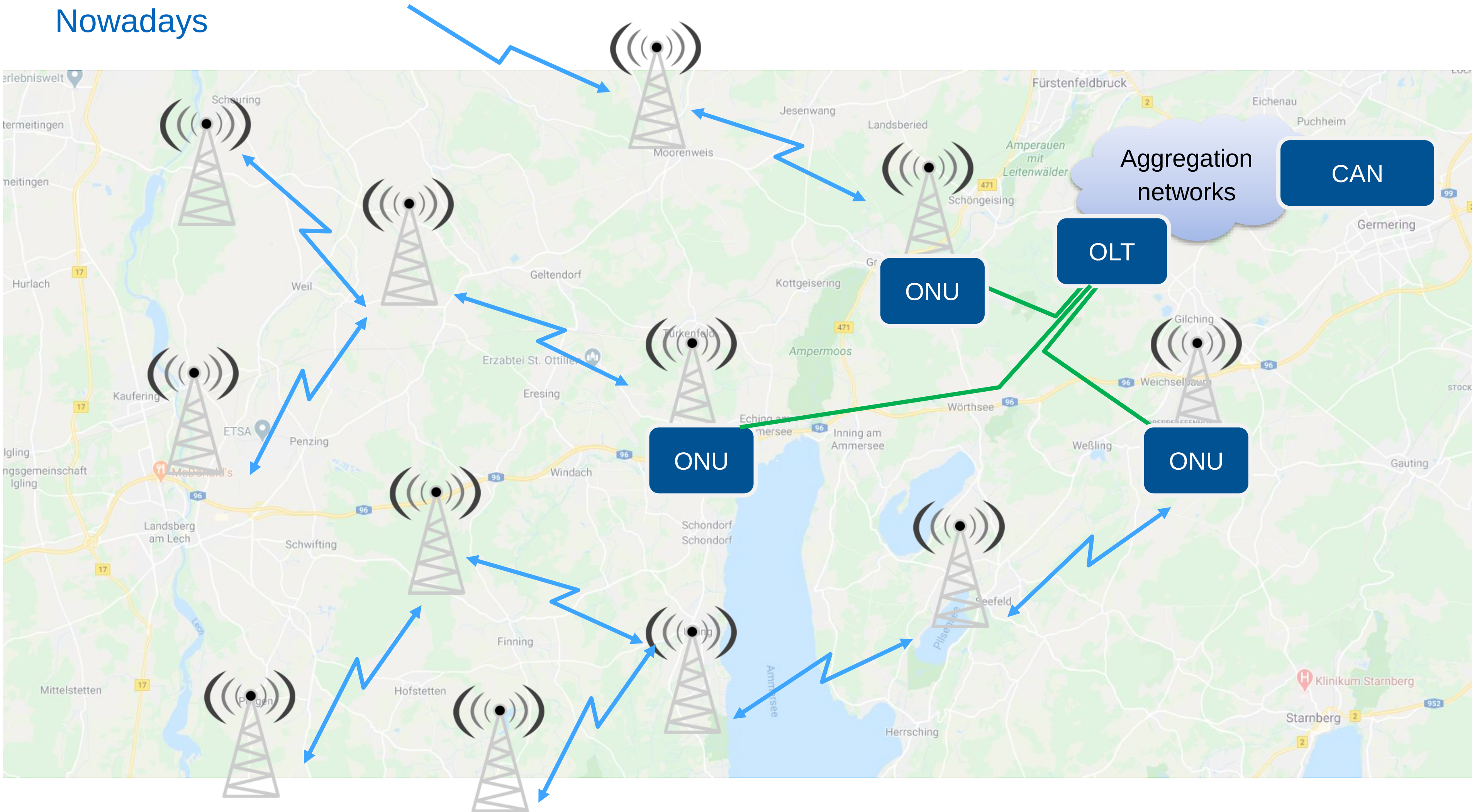
Fiber to the Antenna (FTTA)

AWG: Array Waveguide

ONU/ ONT: Optical Network Unit/Terminal
OLT: Optical Line Terminal

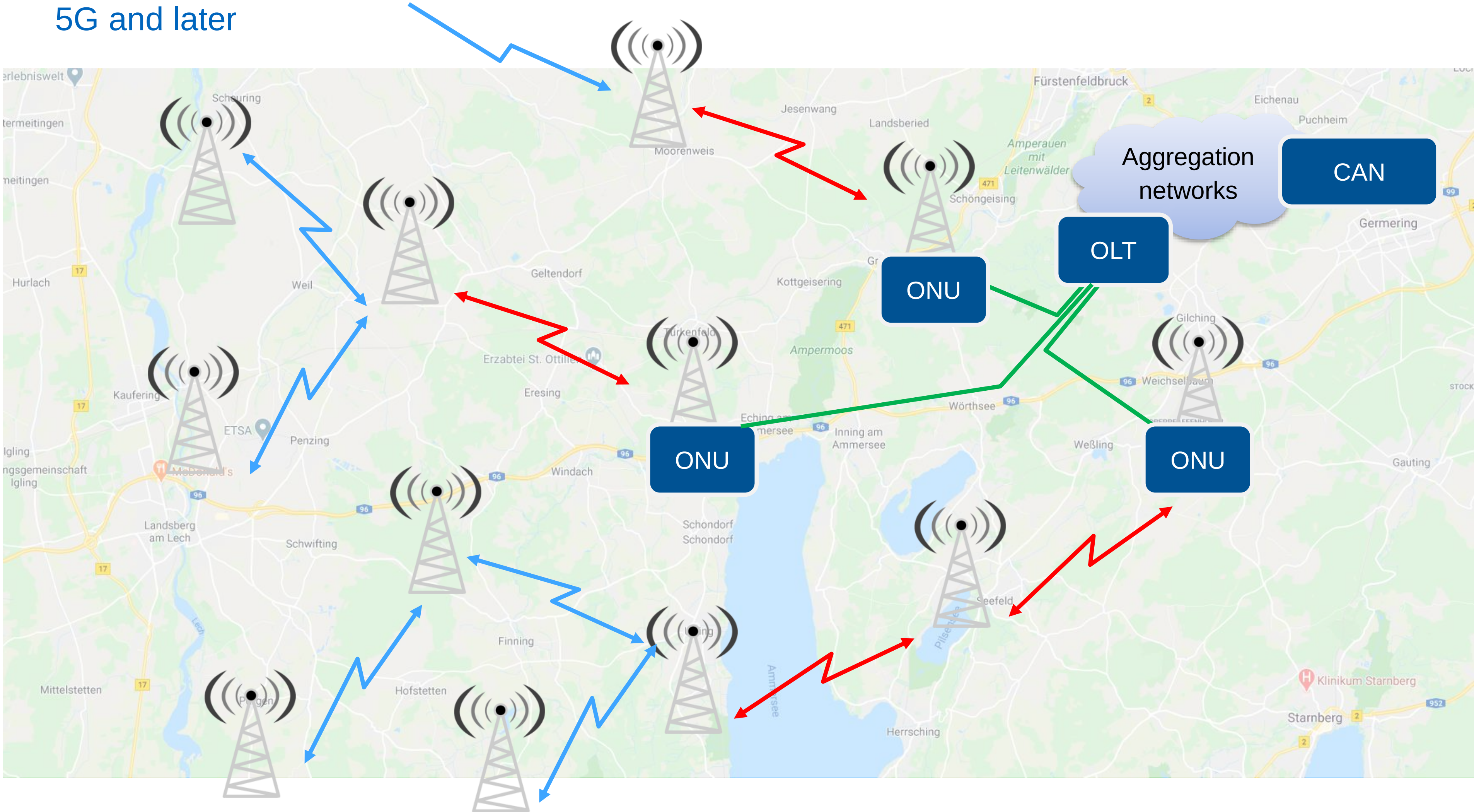
Towards Converged Access Networks

Nowadays



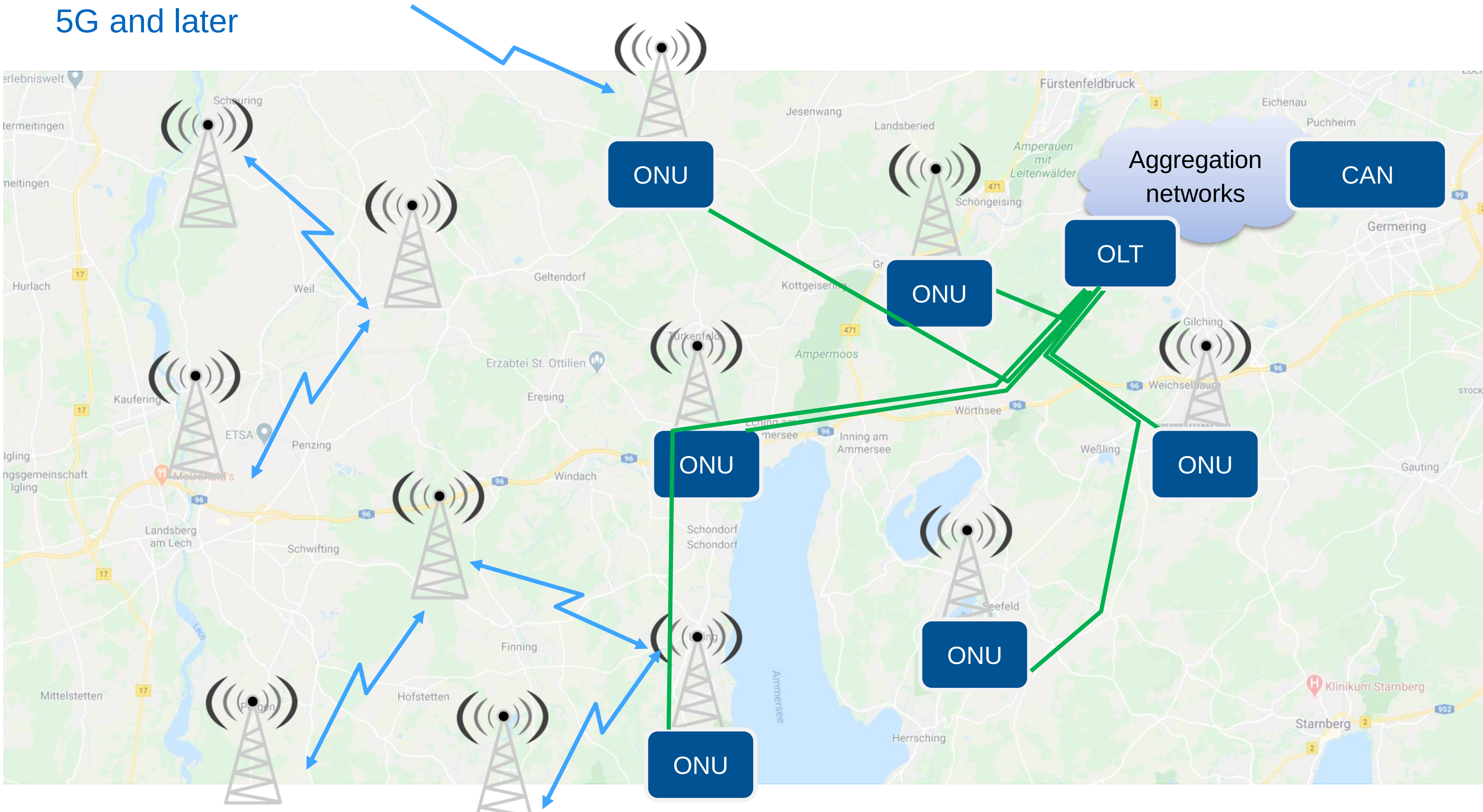
Towards Converged Access Networks

5G and later



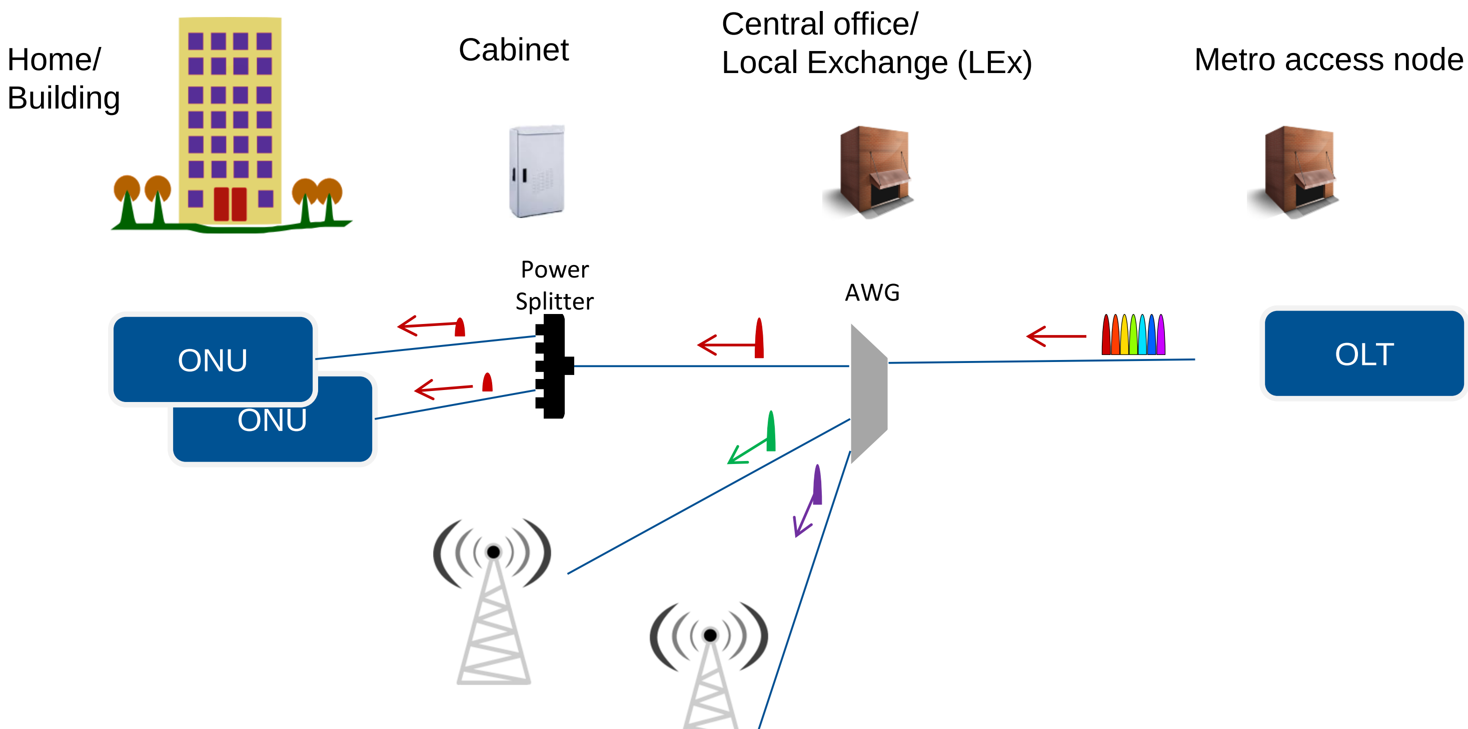
Towards Converged Access Networks

5G and later



Towards Converged Access Networks

Converged access networks



A single converged NGOA can interconnect different users:

- Residential users
- Business users
- Base Stations
- Small cells

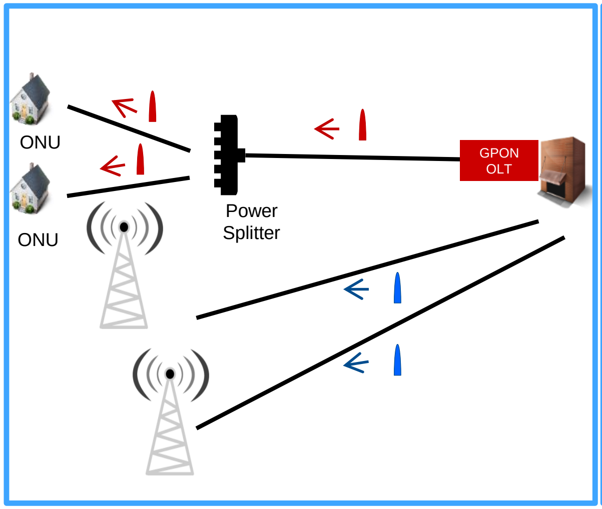
Each user gets the required bandwidth

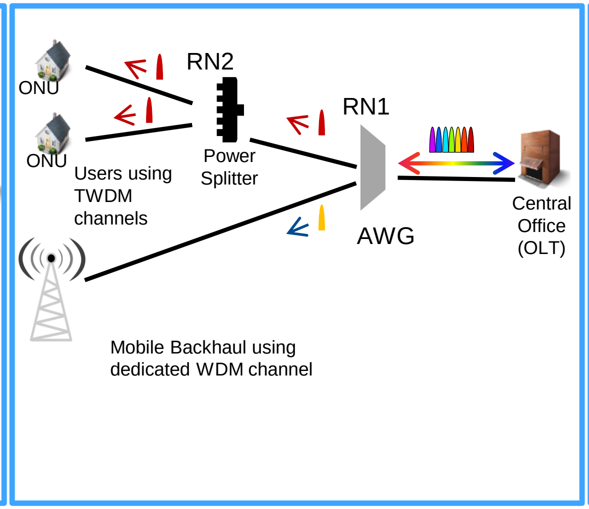
AWG: Array Waveguide

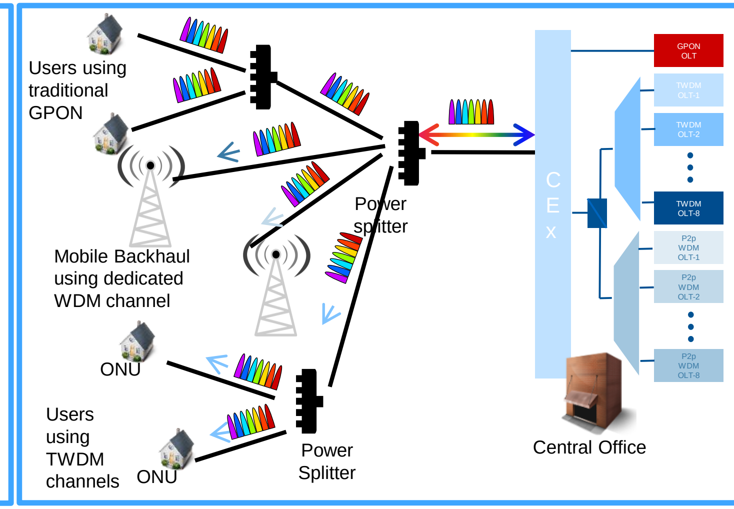
ONU/ ONT: Optical Network Unit/Terminal
OLT: Optical Line Terminal

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

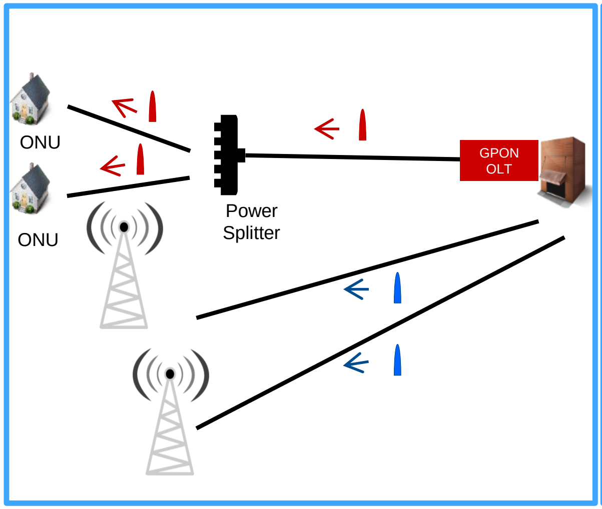
Joint NG-PON2:
1:16 (RN1) and 1:32 (RN2)

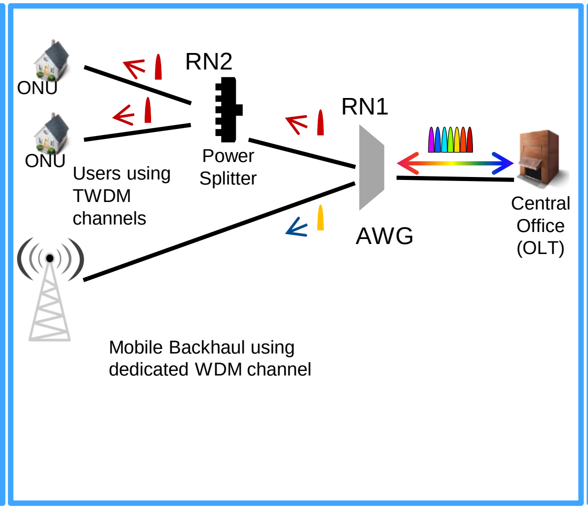
Case Study: Darmstadt (Germany)

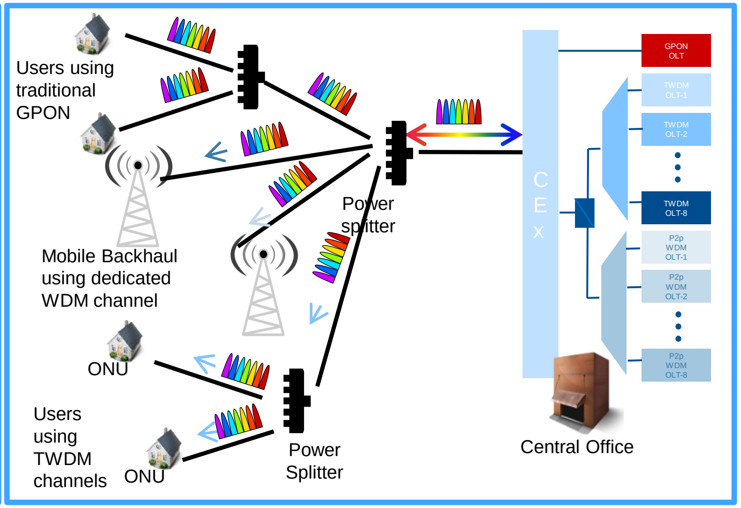
- 9.63 km2
- 6056 buildings
- 32000 households
- Number of base stations: 5 (UMTS) and 37(LTE)

Towards Converged Access Networks

Converged access networks







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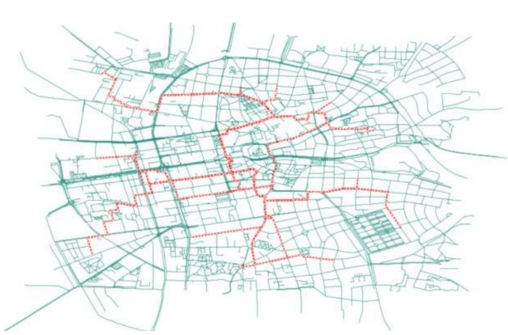
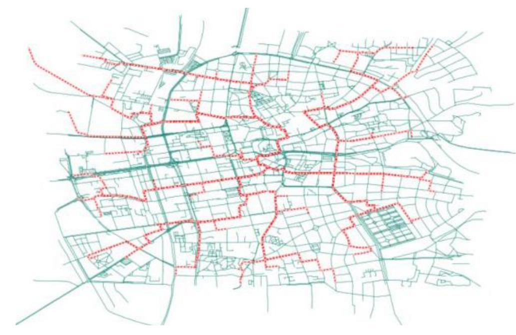
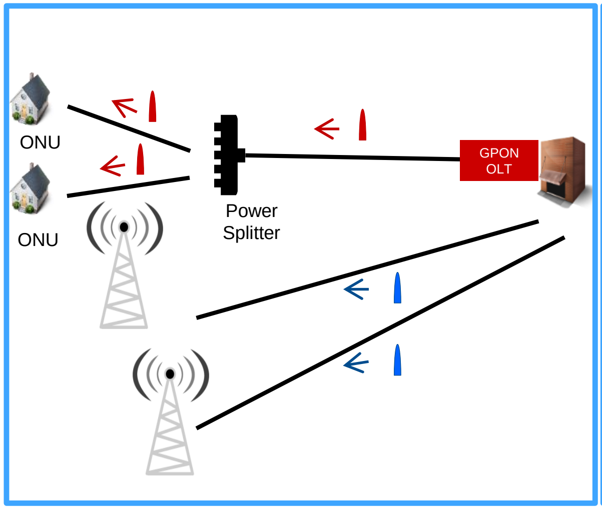
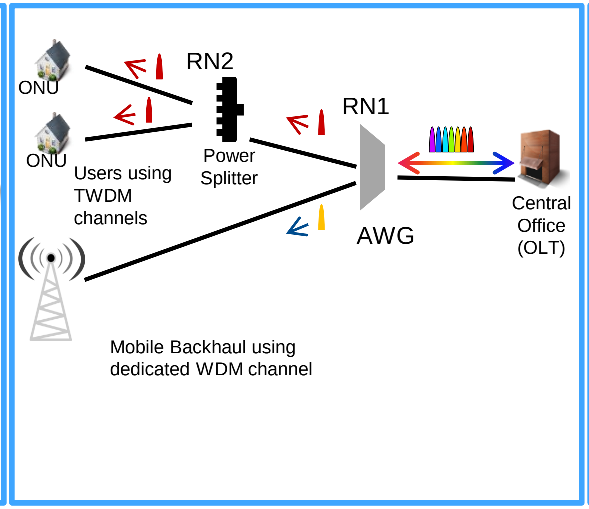


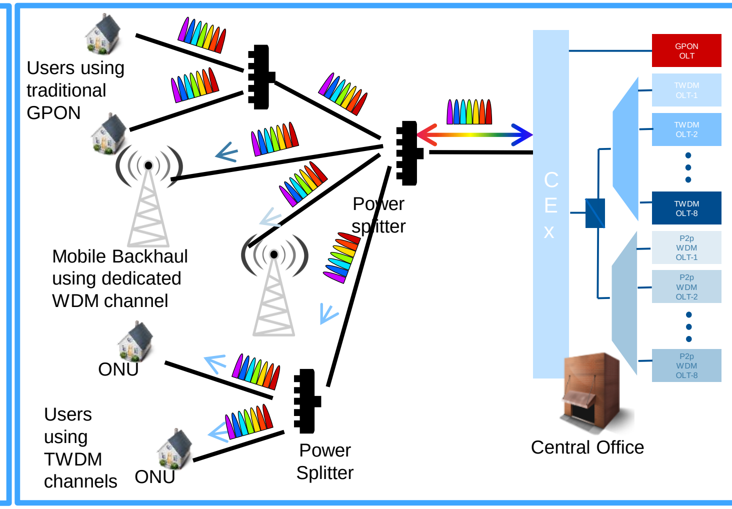


Towards Converged Access Networks

Converged access networks







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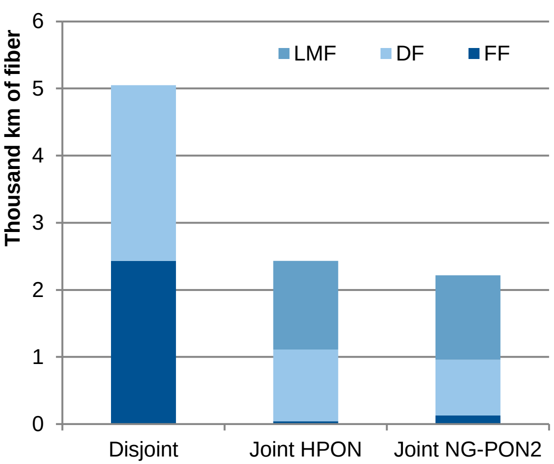
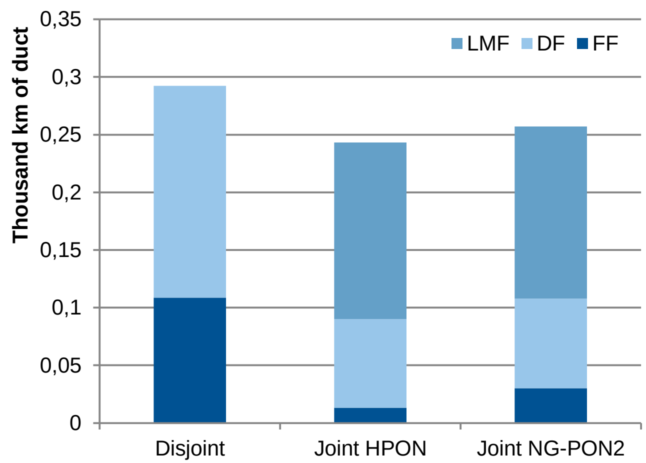
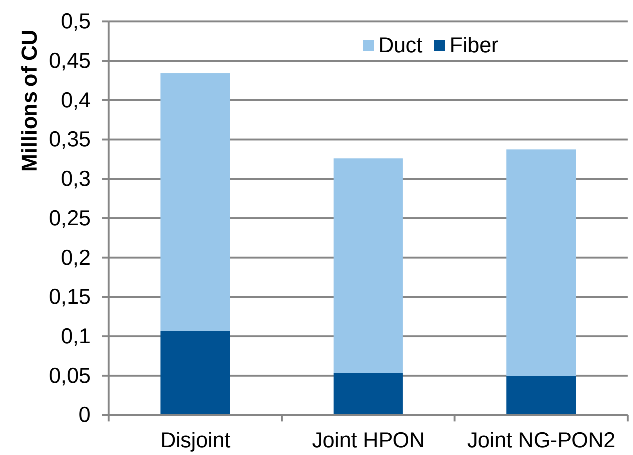






Towards Converged Access Networks

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

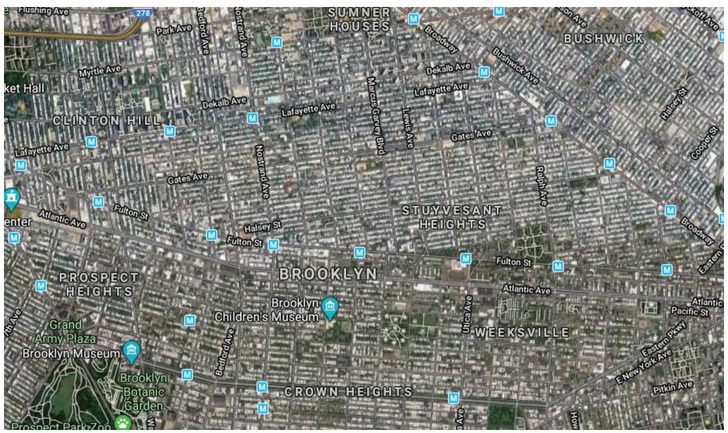
Scenario → Models → Planning → Evaluation

Converged access network planning

Methodology

Scenario → Models → Planning → Evaluation

- Area
  - Dense Urban? Urban? Rural?
  - Size?



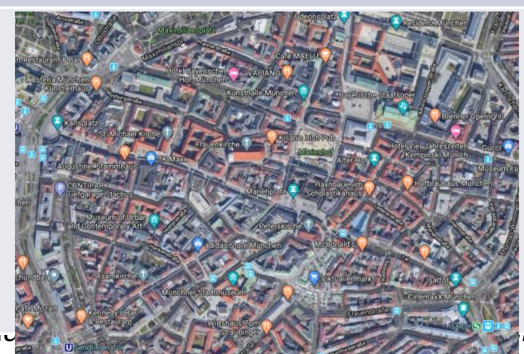
Converged access network planning

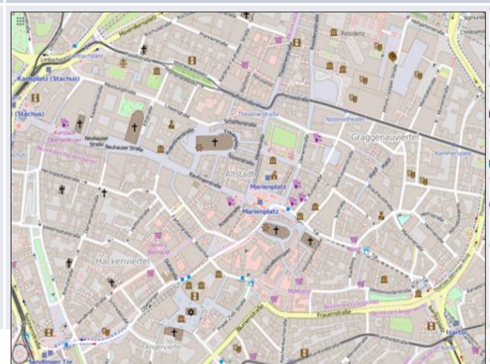
Methodology

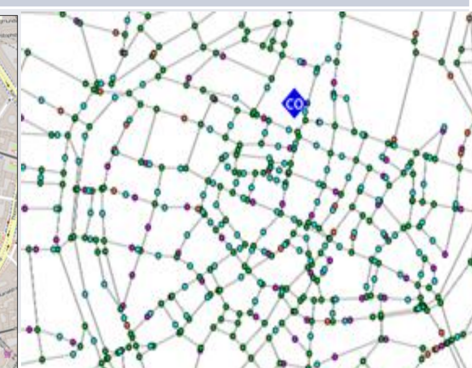
Scenario → Models → Planning → Evaluation

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

Raster maps	Vector maps
based on conventional images files • From .gif, .jpg, other image files • Details can be observed, low time&money for map acquisition • Maps don’t scale well, too big files for high resolution	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 • Maps scale very well and is relatively small • Map information can be structured in layers • Costly from raster map to vector map • Only details that have vectorized can be shown







Converged access network planning

Methodology

Scenario → Models → Planning → Evaluation

- 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 → Models → Planning → Evaluation

- Area
- GF/BF

Existing ducts?
Can be resused?

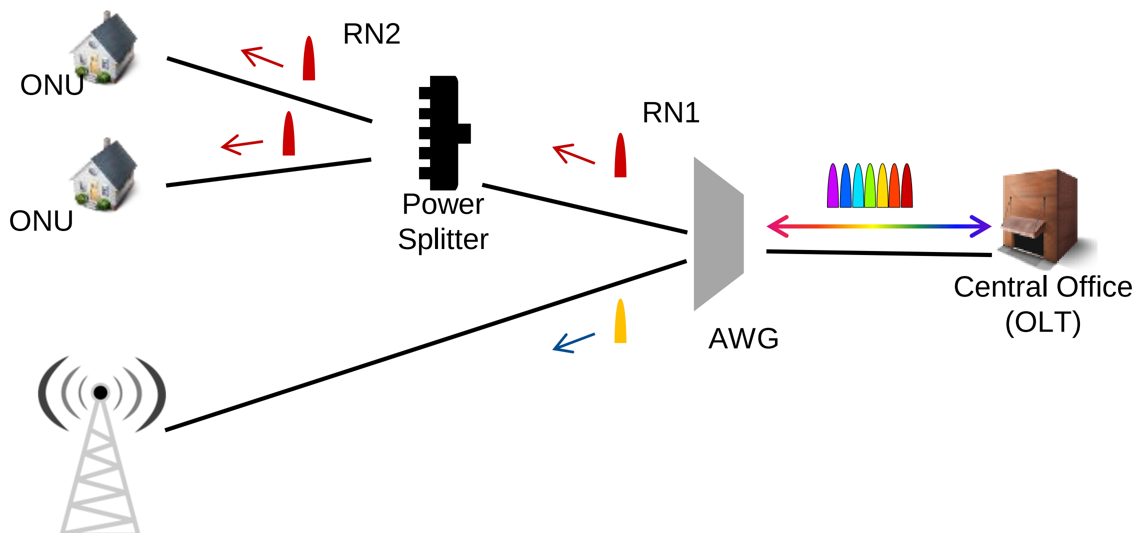



Converged access network planning

Methodology

Scenario → Models → Planning → Evaluation

- Area
- GF/BF
- Technology
- Architecture



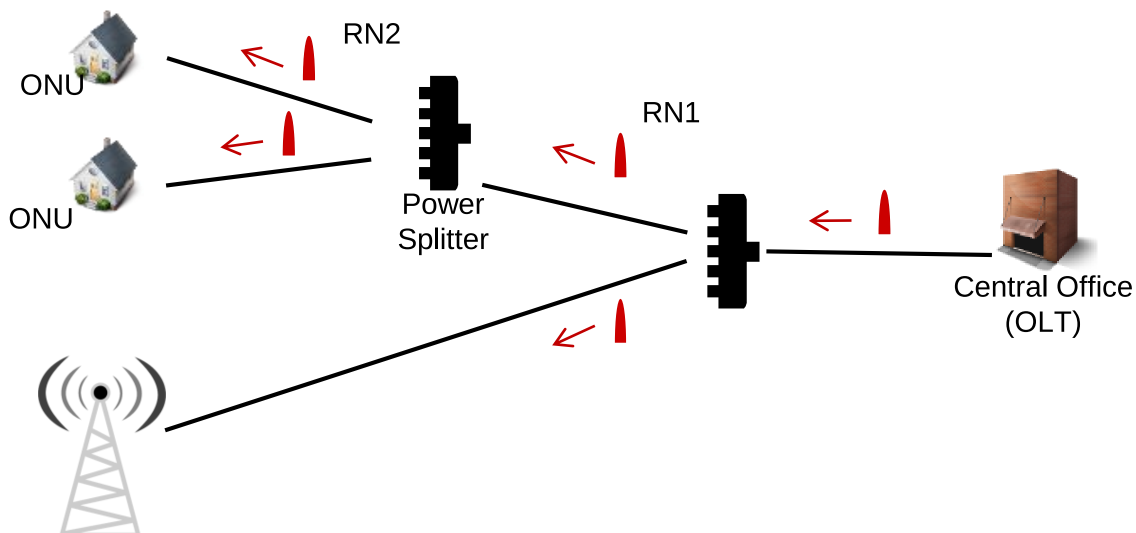
Examples of some solutions without protection

Converged access network planning

Methodology

Scenario → Models → Planning → Evaluation

- Area
- GF/BF
- Technology
- Architecture



Examples of some solutions without protection

Converged access network planning

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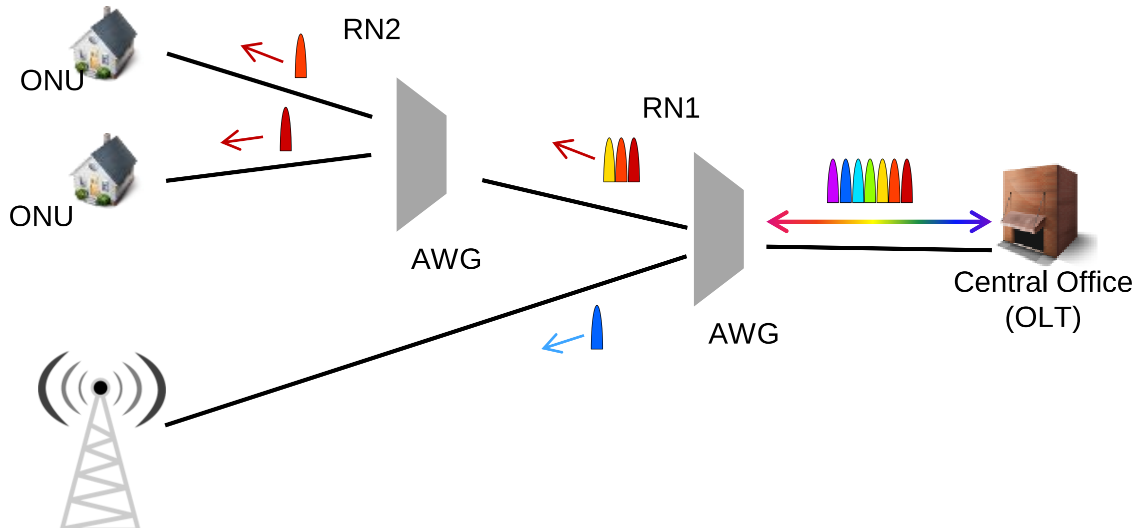


Examples of some solutions without protection

Converged access network planning

Methodology

Scenario → Models → Planning → Evaluation

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

The location is crucial to be known....

Converged access network planning

Methodology

Scenario → Models → Planning → Evaluation

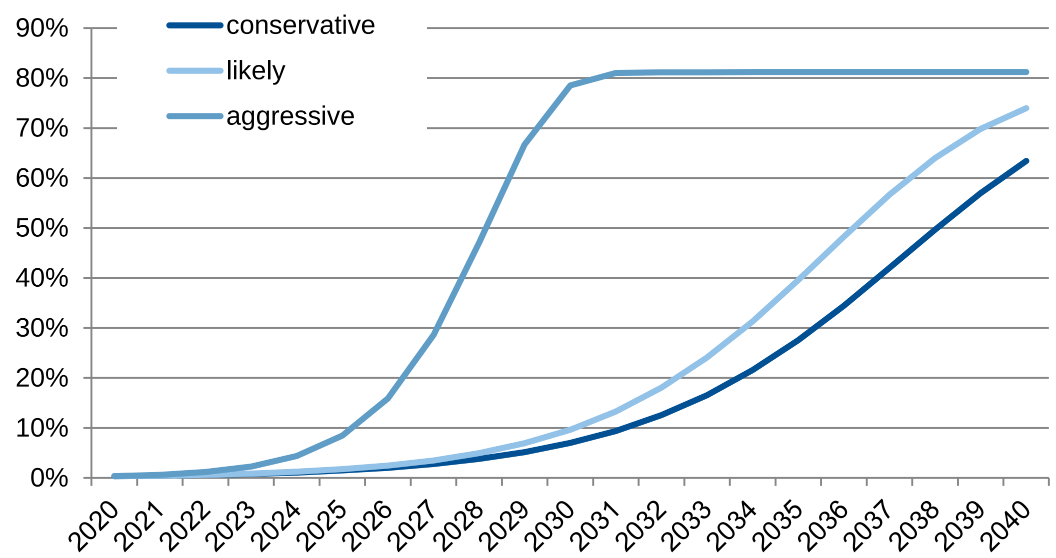
Residential	Based on maps. Based on building size and area→ Number of HH/Building
Business	If no real data available→ some models: e.g., based on building size and area
MBS	If no real data available→ some models: e.g., grid. Realignment is required.
SC	If no real data available→ some models: e.g., based on building type (hospital, shopping mall, etc.)
RSU	Distributed along streets/roads.

Converged access network planning

Methodology

Scenario → Models → Planning → Evaluation

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



Impact of the location of new customers

Converged access network planning

Methodology

Scenario → **Models** → Planning → Evaluation

- Cost models

CAPEX

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

OPEX

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

Depreciation

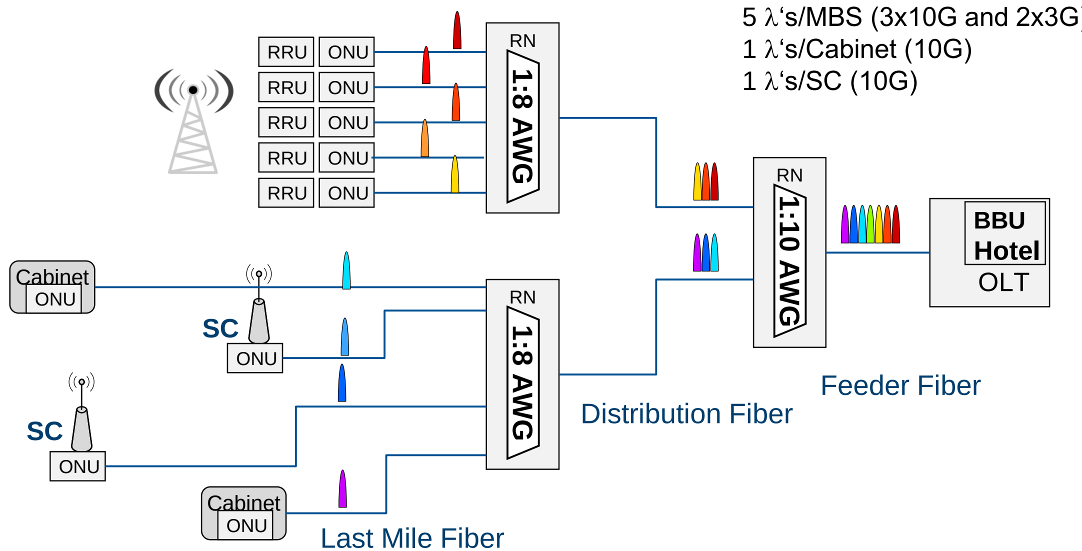
- Straight line
- Declining method
- Double declining method

Converged access network planning

Methodology

Scenario → **Models** → Planning → Evaluation

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



Fronthaul of MBS and SC
(FH WR WDM-PON)

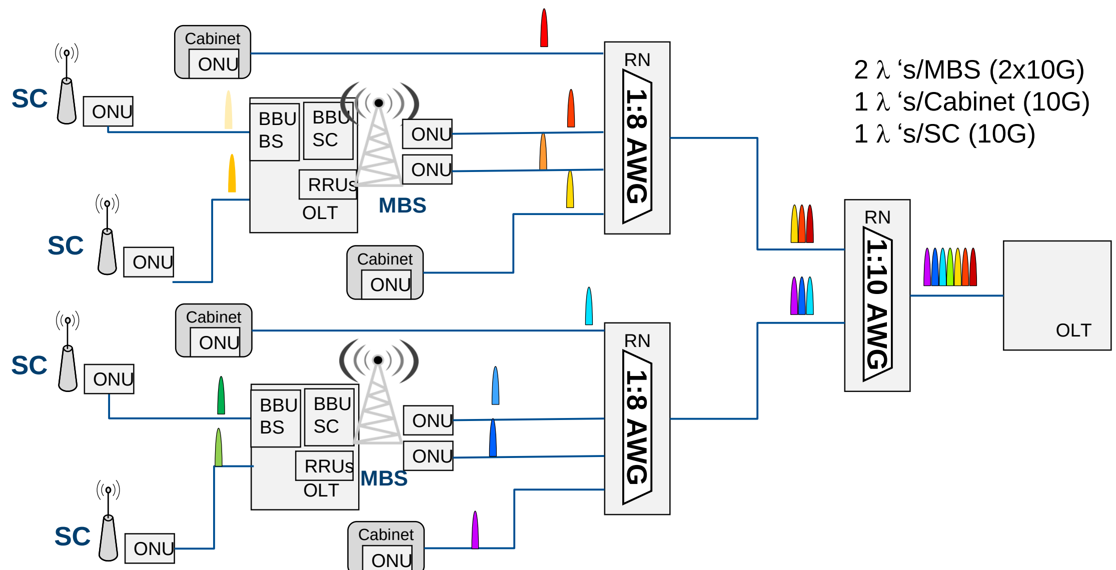
ONU: Optical Network Unit
MBS: Macro Base Station
AWG: Array Waveguide
BBU: Base Band Unit
RRU: Radio Remote Unit

Converged access network planning

Methodology

Scenario → **Models** → Planning → Evaluation

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



2 λ 's/MBS (2x10G)
1 λ 's/Cabinet (10G)
1 λ 's/SC (10G)

SC fronthauled to MBS and MBS backhauled to OLT (FBH WR WDM-PON)

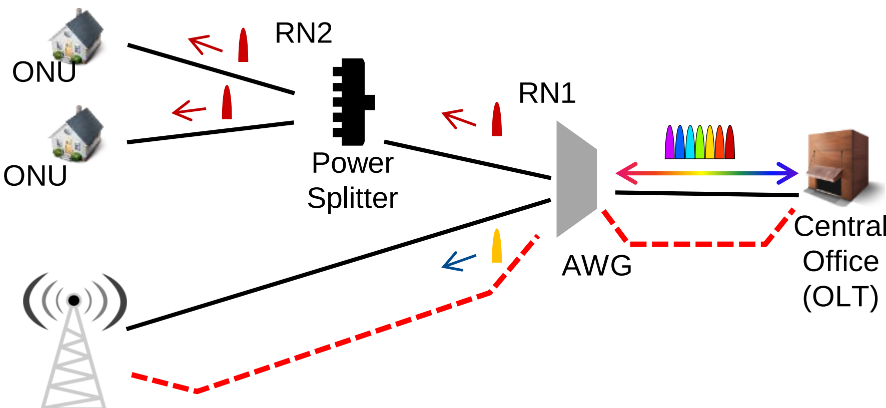
ONU: Optical Network Unit
MBS: Macro Base Station
AWG: Array Waveguide
BBU: Base Band Unit
RRU: Radio Remote Unit

Converged access network planning

Methodology

Scenario → **Models** → Planning → Evaluation

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



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Converged access network planning

Methodology

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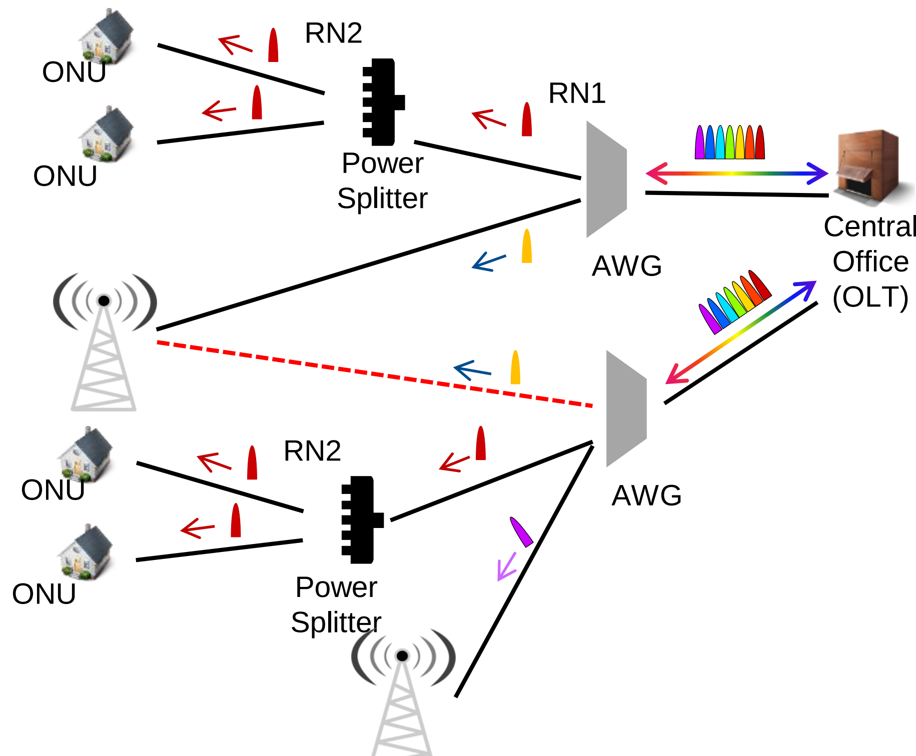
- Architecture model
  - Splitting points
    - Single
    - Multiple
  - BW
  - Protection
    - Disjoint fibers:
      - FF
      - FF and DF
      - Inter DF



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Converged access network planning

Methodology

Scenario → **Models** → Planning → Evaluation

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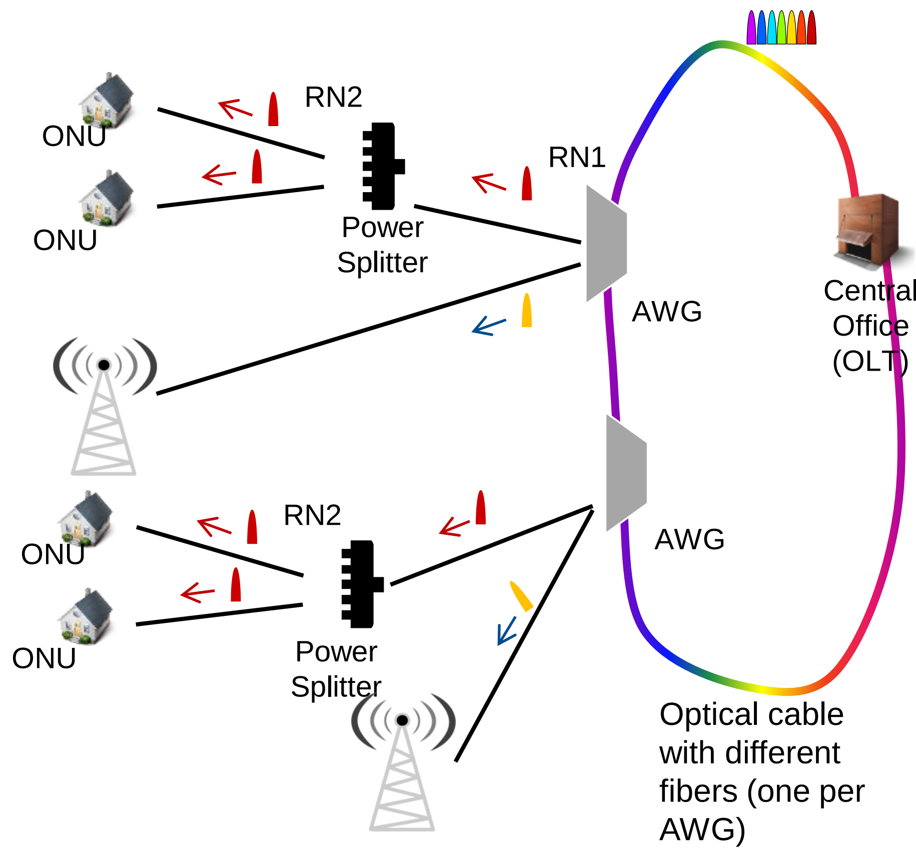
    - Multiple
  - BW
  - Protection
    - Disjoint fibers:
      - FF
      - FF and DF
      - Inter DF
    - FF Ring



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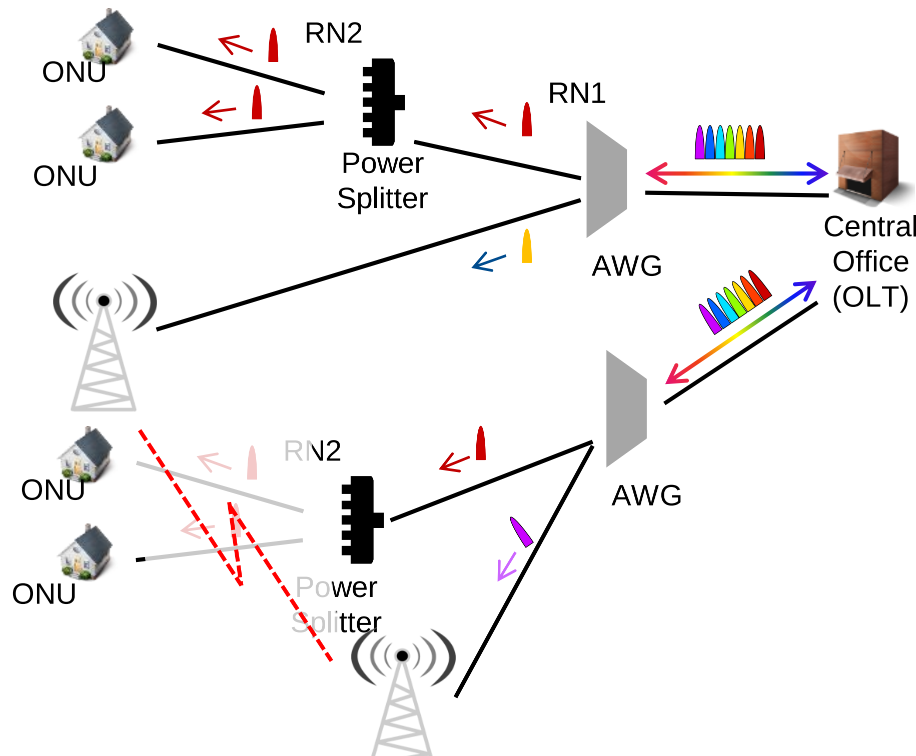
Converged access network planning

Methodology

Scenario → **Models** → Planning → Evaluation

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



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Converged access network planning

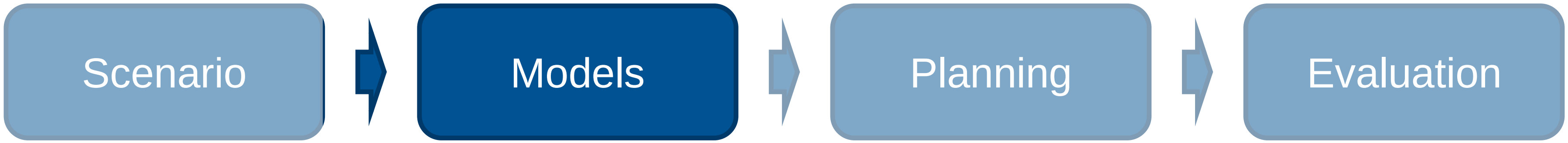
Methodology

Scenario → **Models** → Planning → Evaluation

- Cost models
- Architecture model
- Component model

Converged access network planning

Methodology



- Cost models
- Architecture model
- Component model
- Area models

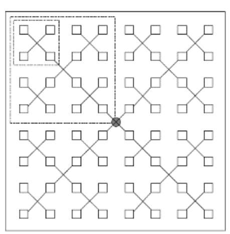
Converged access network planning

Methodology

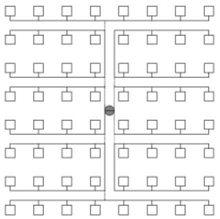
Scenario → **Models** → Planning → Evaluation

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

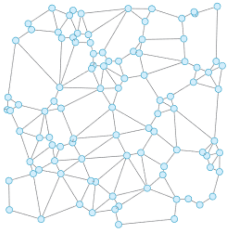
Random geometric model



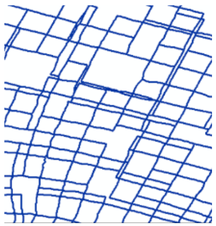
Tree street model



Parallel street model



Gabriel graph model



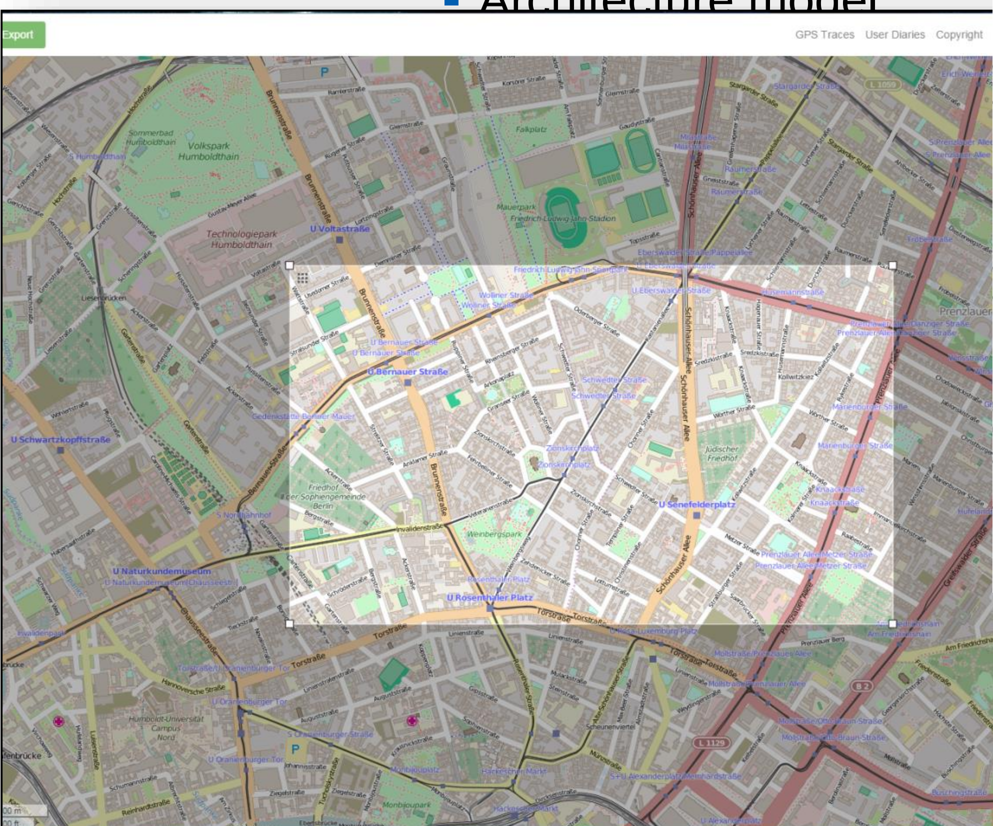
Procedurally Generated Topologies

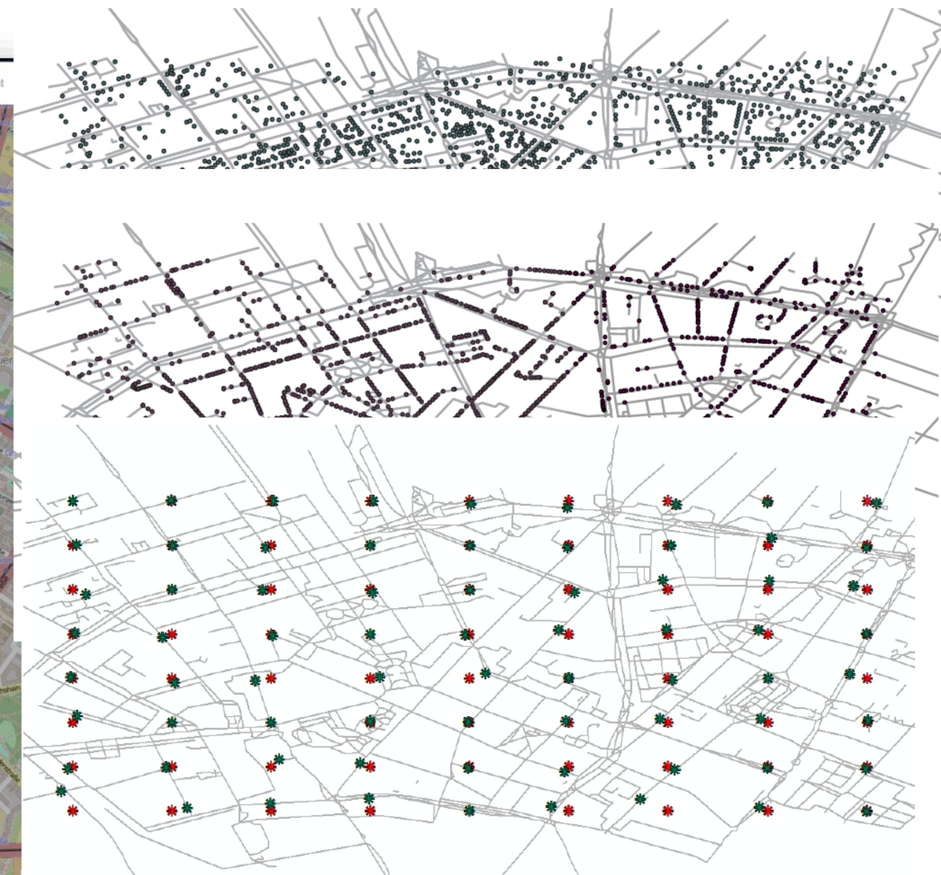
Converged access network planning

Methodology

Scenario → **Models** → Planning → Evaluation

- Cost models
- Architecture model





ArcGIS

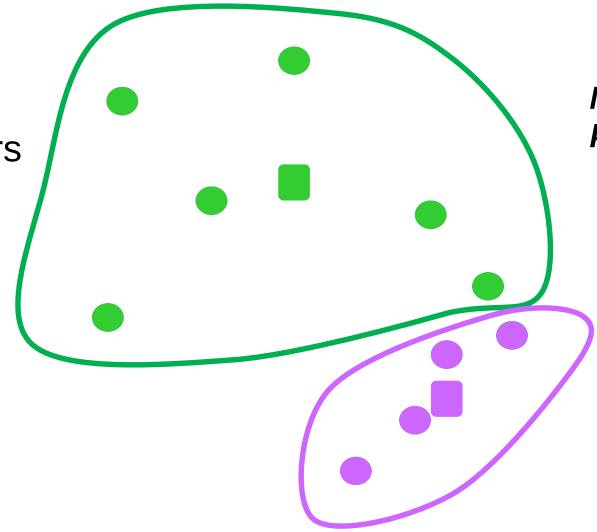
Converged access network planning

Methodology

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 cluters centroids
    - Assign nodes to closest seed point



N=10
k=2

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
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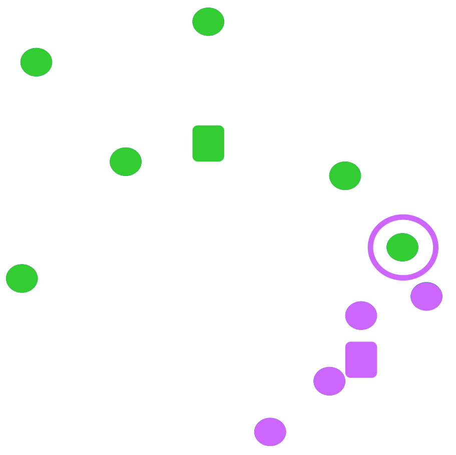


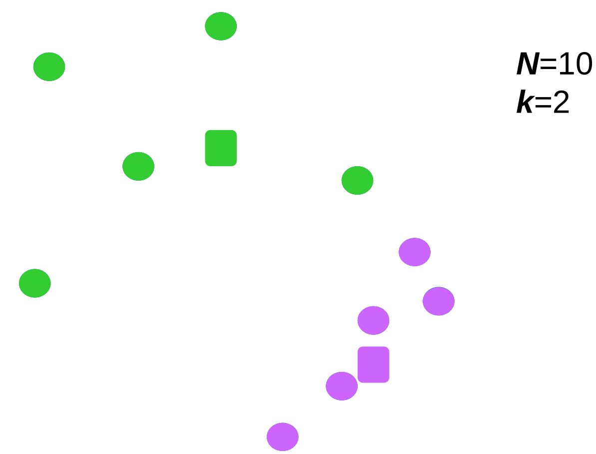
Converged access network planning

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 cluters centroids
    - Assign nodes to closest seed point
    - Repeat until no new assignment is done



Converges fast but usually in a local optimum.

Global optimum→ deterministic annealing and genetic algorithms

How to determine best k in advance?

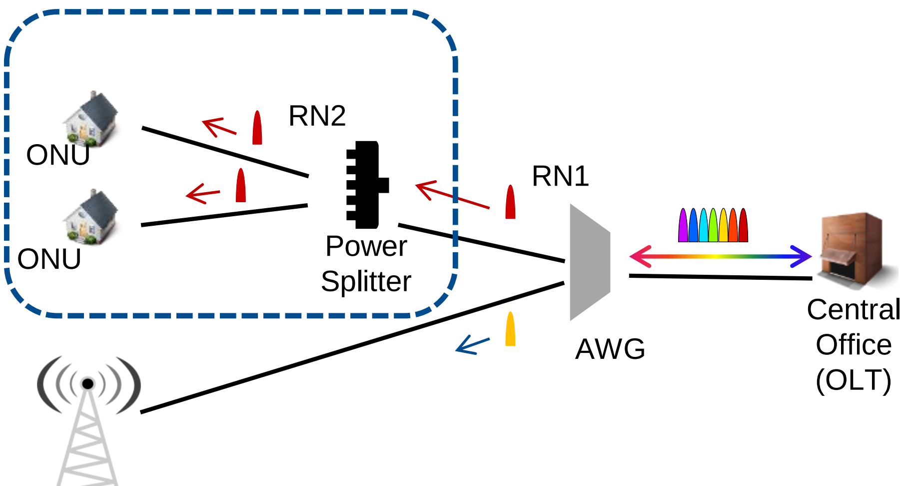
Converged access network planning

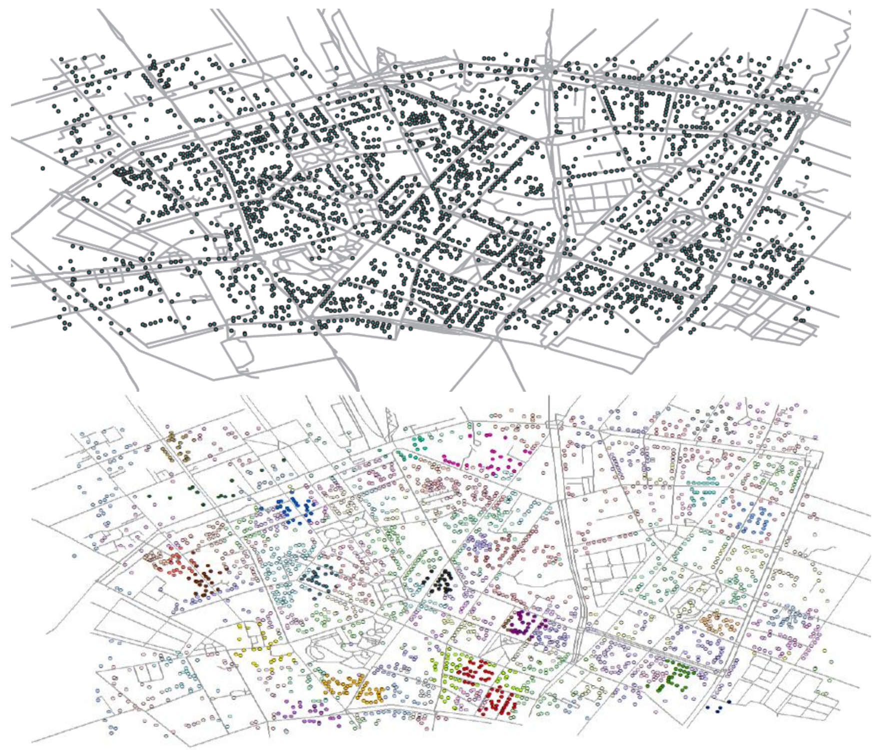
Methodology

Scenario → Models → **Planning** → Evaluation

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

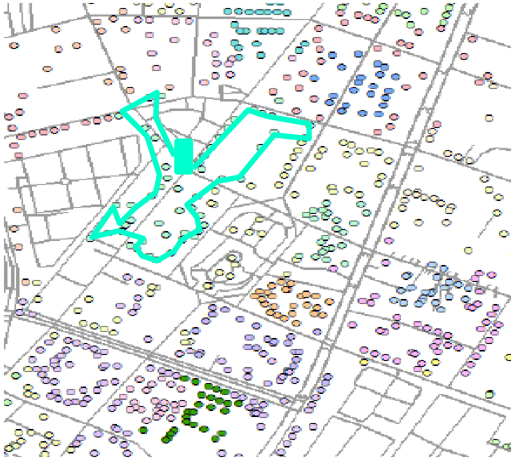
Methodology

Scenario → Models → **Planning** → Evaluation

Heuristics

- Fiber layout:

Duct is the cost driver compared to fiber



Minimum Spanning tree: Very long paths

Converged access network planning

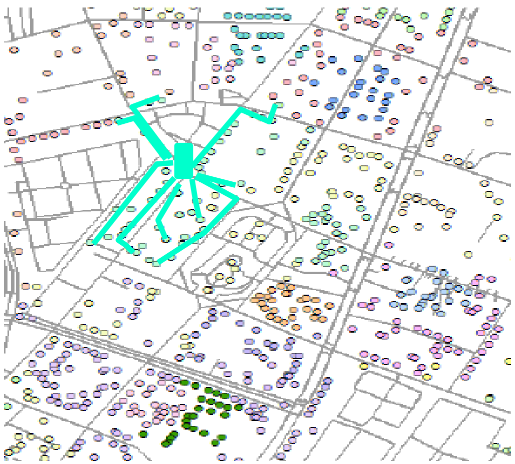
Methodology

Scenario → Models → **Planning** → Evaluation

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

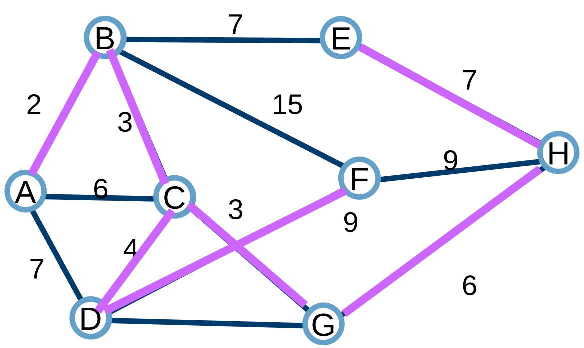
Heuristics

- Fiber layout:

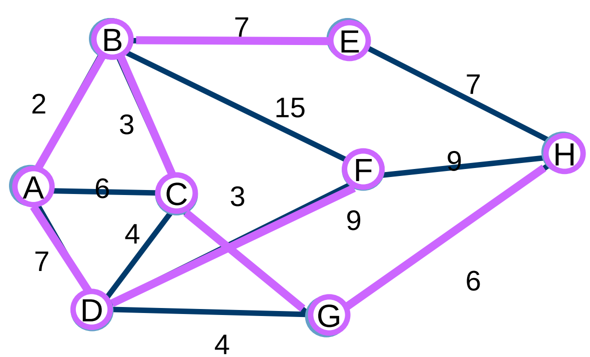
  Duct is the cost driver compared to fiber

  - 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)

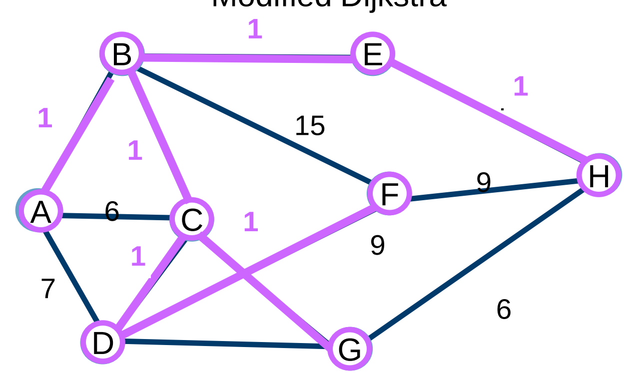
Kruskal's algorithm



Prim's algorithm



Modified Dijkstra

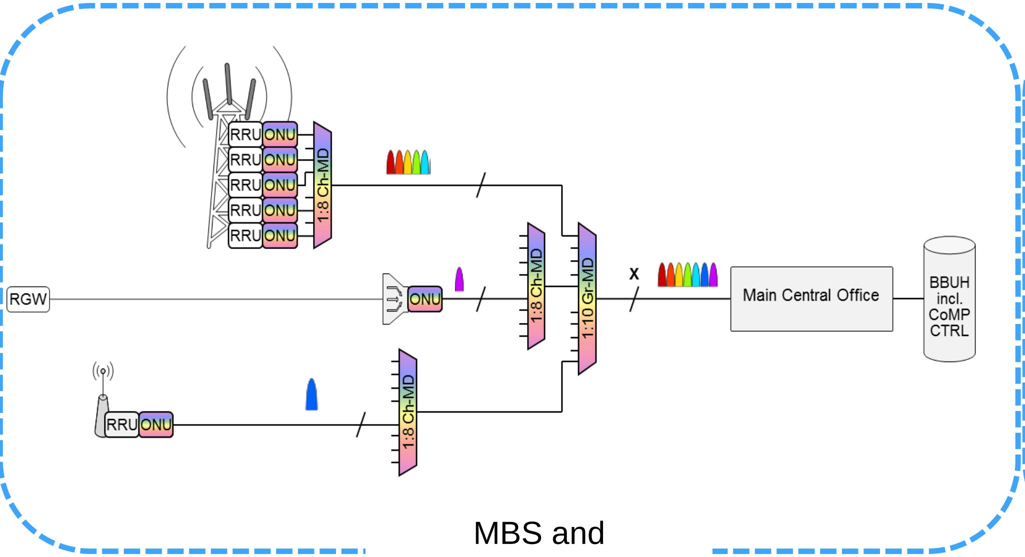


Converged access network planning

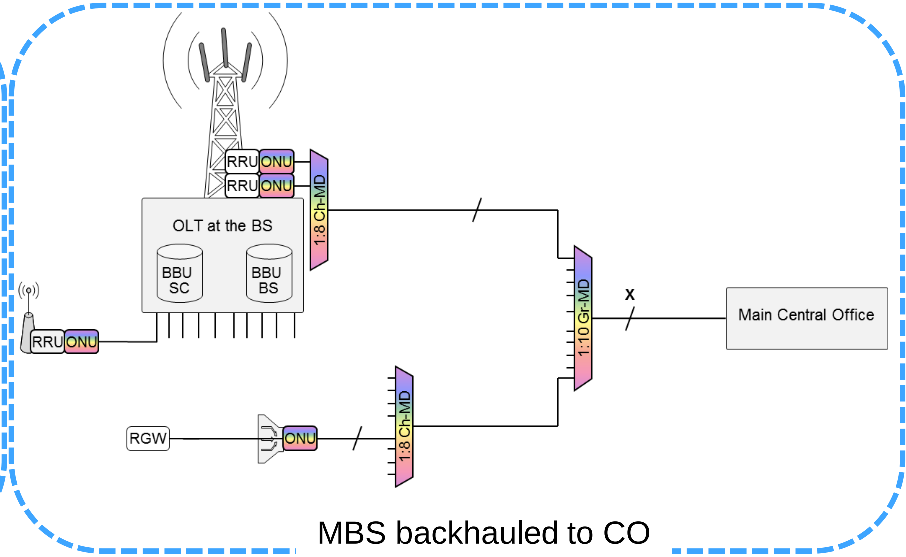
Methodology

Scenario → Models → **Planning** → Evaluation

ILP



MBS and
SC fronthauled to CO

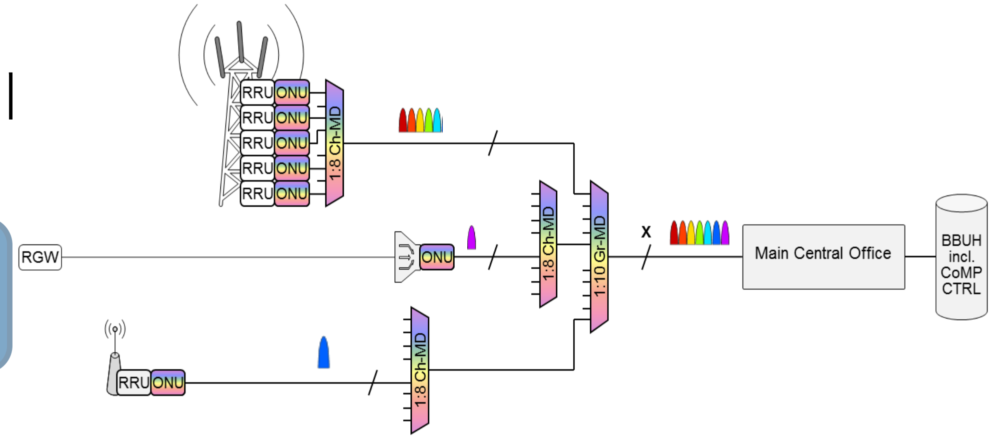


MBS backhauled to CO
SC fronthauled to MBS

Converged access network |

Methodology

Scenario → Models



ILP

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

$\sum_{i=0}^{n*m} C_{AWG2} * AWG2_i \quad +$	AWG costs at RN2 locations
$\sum_{i=0}^{n*m} (C_{AWG1} + C_{OLT/FF}) * AWG1_i \quad +$	AWG and CO costs based on number of RN1
$C_f * \sum_{i=0}^{n*m} (\sum_{i=0}^{n*m} d_{i\,j} * D_{MCO-AWG1j}) \quad +$	FF cost
$C_f * \sum_{i=0}^{n*m} (\sum_{i=0}^{n*m} e_{12ij} * D_{AWG1i-AWG2j}) \quad +$	DF cost
$C_f * \sum_{i=0}^{n*m} (\sum_{i=0}^{n*m} e_{i\,j} * D_{AWG2i-Cabj}) \quad +$ $C_f * \sum_{i=0}^{n*m} (\sum_{i=0}^{n*m} SC_{i\,j} * D_{AWG2i-SCj}) \quad +$ $C_f * \sum_{i=0}^{n*m} (\sum_{i=0}^{n*m} BS_{i\,j} * D_{AWG2i-BSj}) \quad +$	LMF cost
$C_t * \sum_{i=0}^{n*m} (Dt_j)$	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 :**

$$\text{For every j,} \quad \sum_{i=0}^{n*m} \mathrm{e}_{ij} = 1$$

$$\text{For every j,} \quad \sum_{i=0}^{n*m} \mathrm{SC}_{ij} = 1$$

$$\text{For every j,} \quad \sum_{i=0}^{n*m} \mathrm{BS}_{ij} = 1$$

  - **Every AWG1 must be connected to the MCO :**

$$\text{For every j,} \quad \sum_{i=0}^{n*m} \mathrm{d}_{ij} = 1$$

  - **The sum of the connections between one RN and its connected Cabinets, SC and BS must be smaller than the AWG2 capacity (k_2)**

$$\text{For every i ,} \sum_{j=0}^{n*m} (\mathrm{e}_{ij} + \text{Number\_per\_SC}_{\mathrm{j}} * \mathrm{SC}_{ij} + \text{Number\_per\_BS} * \mathrm{BS}_{ij}) \leq \mathrm{k}_2$$

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 :

$$d_{ij} * D_{MCOi\text{-}AWG1j} + e_{12jl} * D_{AWG1j\text{-}AWG2l} + e_{lv} * D_{AWG2l\text{-}Cabv} \leq D_{max}$$

Converged access network planning

Methodology

Scenario → Models → Planning → **Evaluation**

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

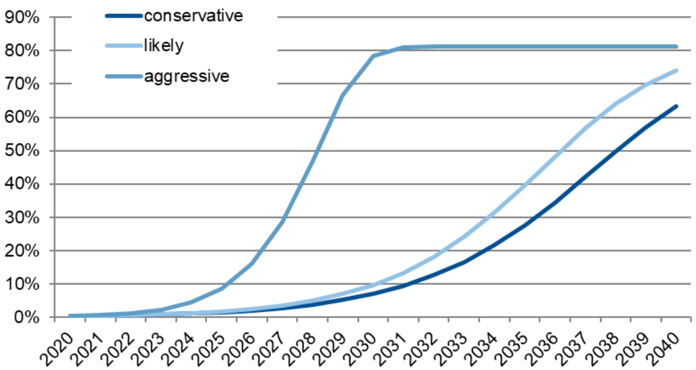
Outline

- Fixed Access Networks
- Optical Access Networks
- Access Network Planning methodology
- **Case Studies**

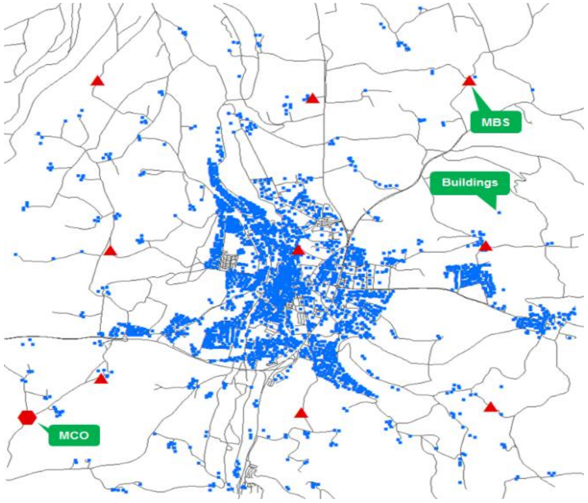
Converged access network planning

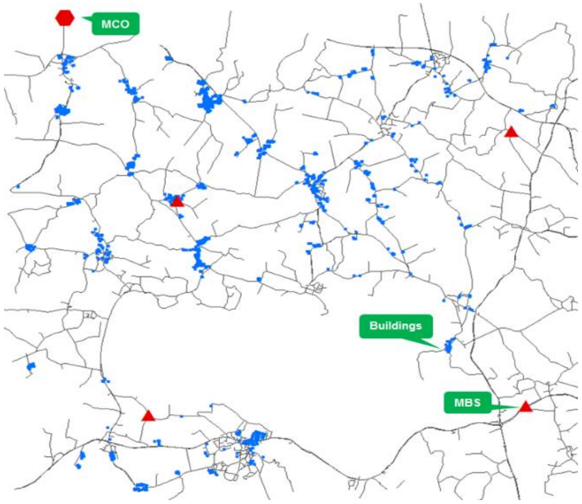
Hybrid PON Analysis

Scenario → Models → Planning → Evaluation



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





Converged access network planning

Hybrid PON Analysis

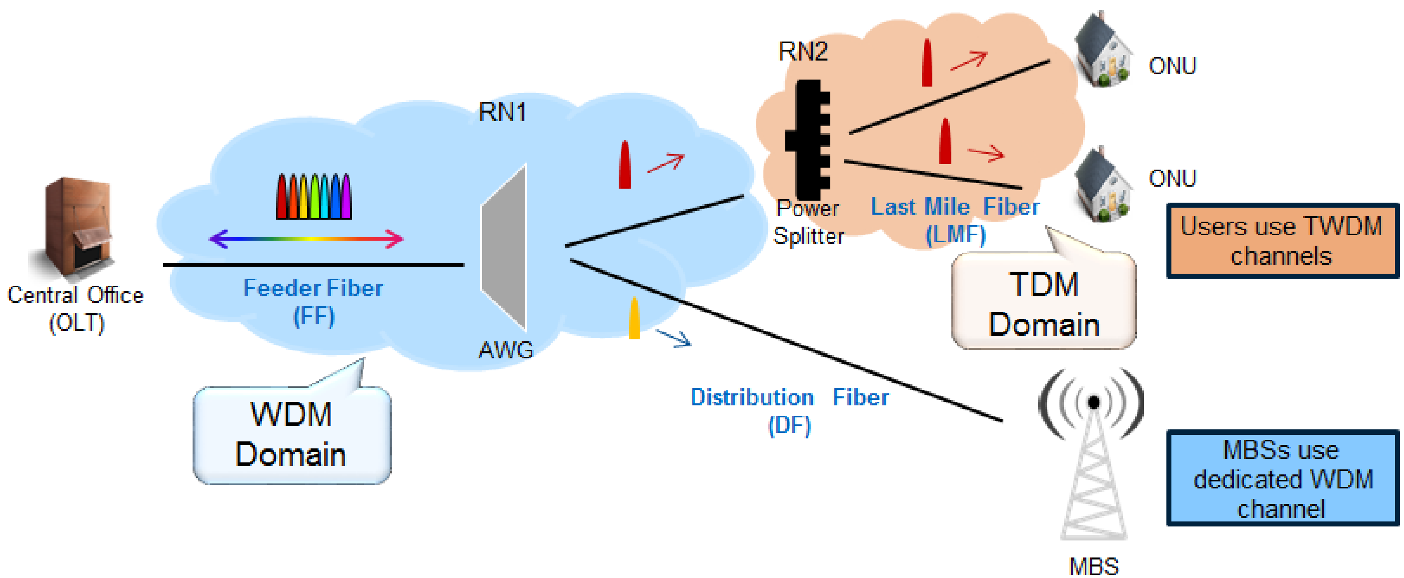
Scenario → **Models** → Planning → Evaluation

Market penetration models:
- Random
- Bass model

BS distribution
- Grid with different interBS distances depending on the area

Geographic topology

Name	Type	Area	Total Buildings	Building Density	Total MBS	MBS Density
Munich	DU	$4km^2$	2042	$510/km^2$	12	$3/km^2$
Miesbach	U	$28km^2$	2730	$98/km^2$	9	$0.3/km^2$
Höhndorf	R	$150km^2$	1163	$8/km^2$	4	$0.02/km^2$



Converged access network planning

Hybrid PON Analysis

Scenario → Models → Planning → Evaluation

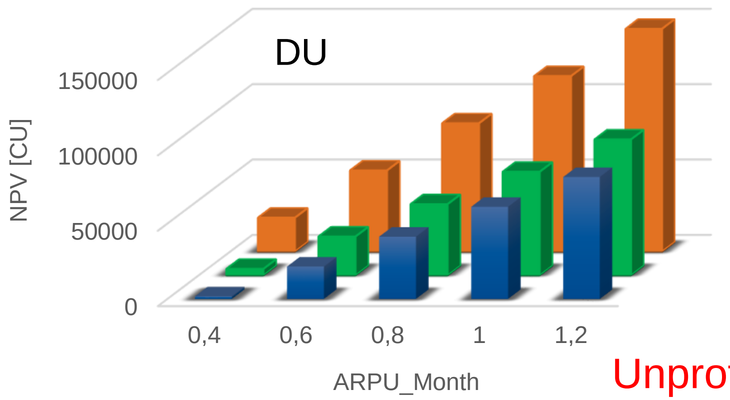
Heuristics
https://github.com/EGrigoreva/FixedNetworkPlanningTool

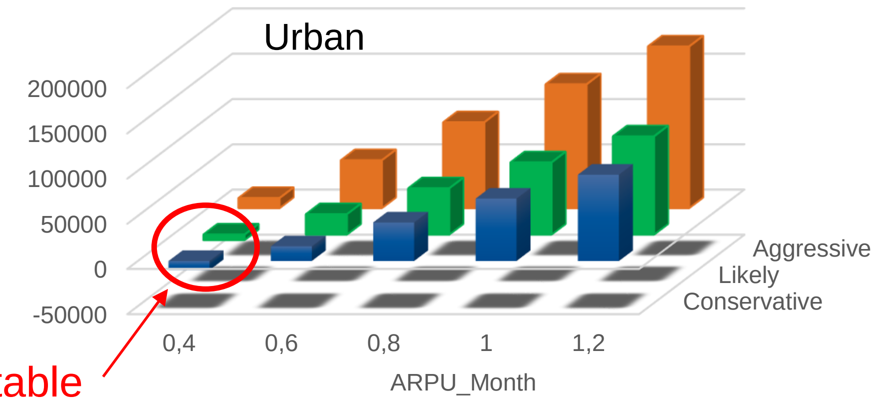
Converged access network planning

Hybrid PON Analysis

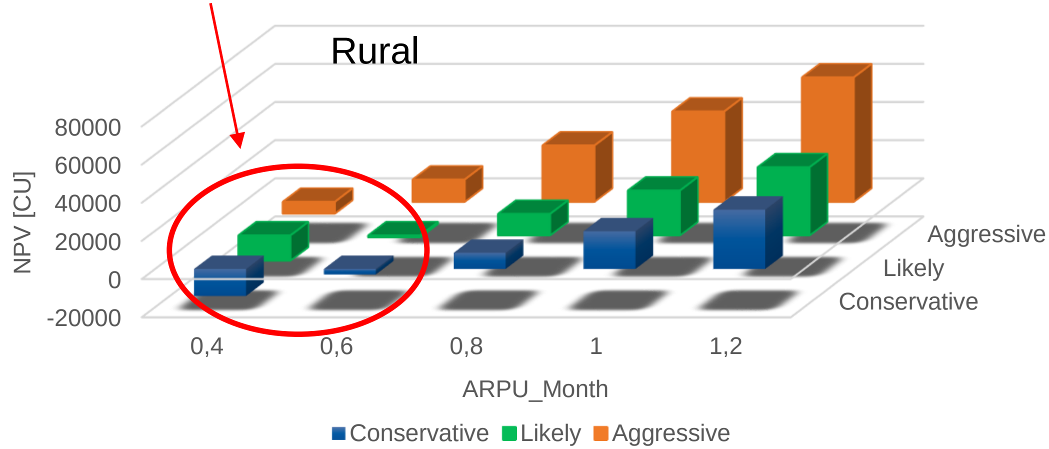
Scenario → Models → Planning → Evaluation

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





Unprofitable



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

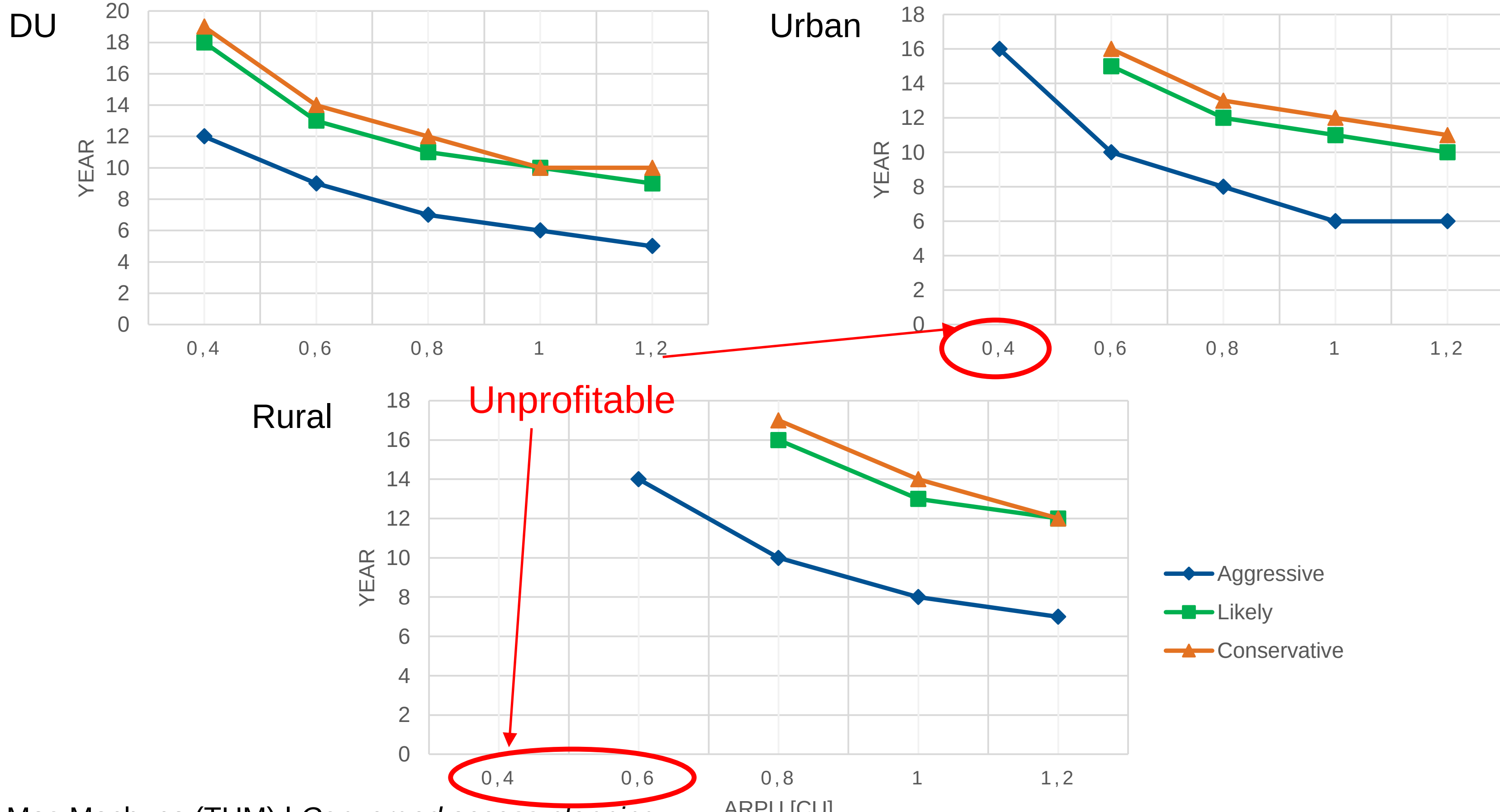
- R: Revenue of Buildings
- C: TCO
- r: Discount Rate (8%)
- n: time frame (20 years)

Converged access network planning

Hybrid PON Analysis

Scenario → Models → Planning → Evaluation

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



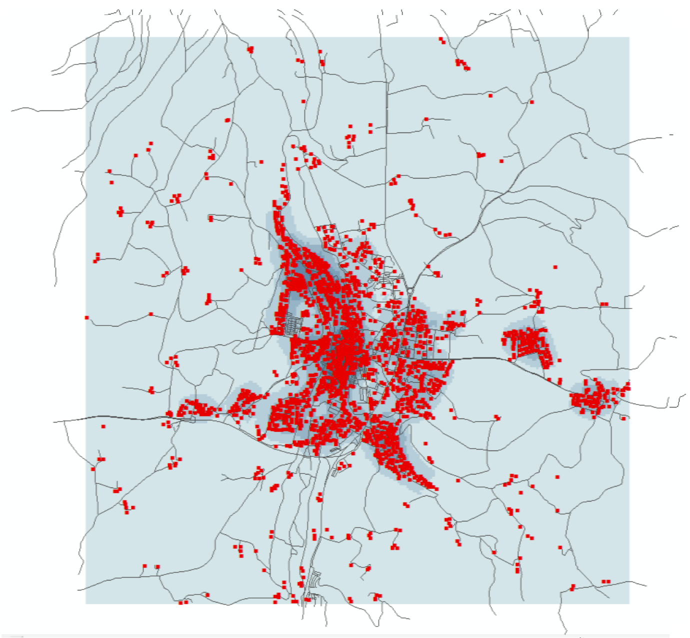
Converged access network planning

Hybrid PON Analysis

Scenario → Models → Planning → Evaluation

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

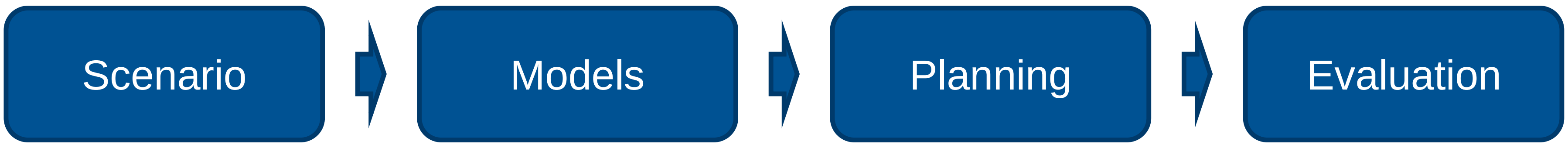
- First year users, then spread outwards following the adoption curves



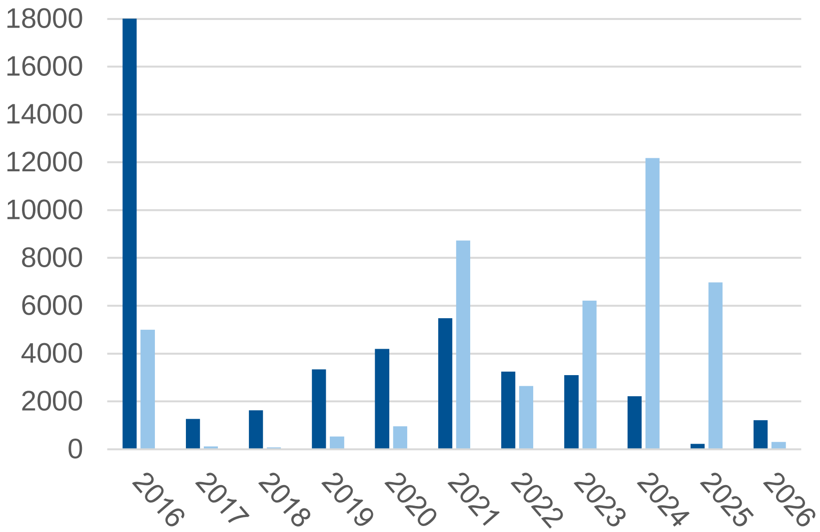
Which is the impact of planning according to Bass??

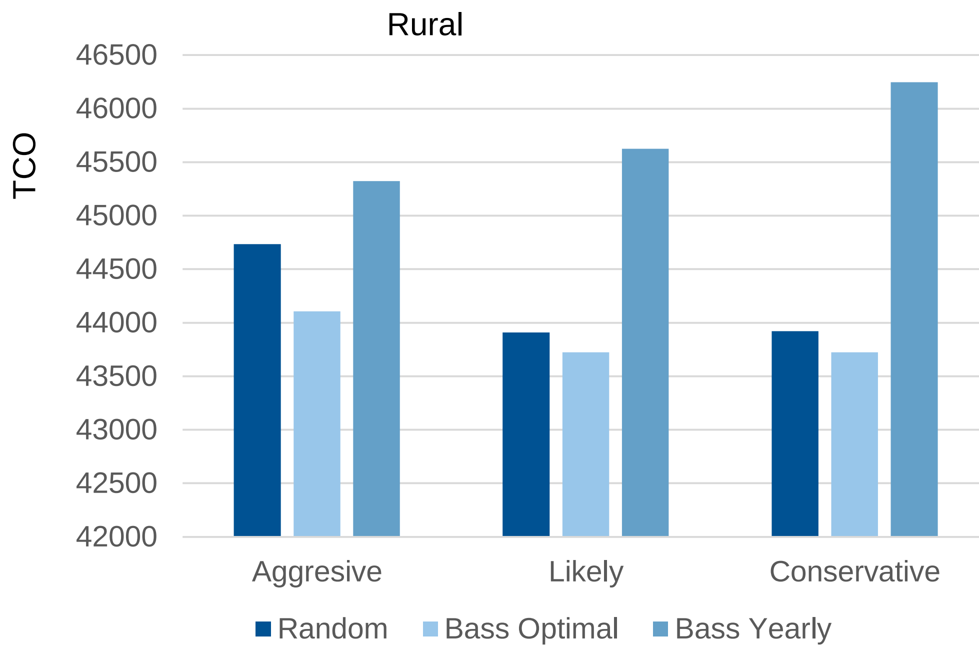
Converged access network planning

Hybrid PON Analysis



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





Tutorial Take away

- Strategic planning required by operators but also for manufacturers, regulators and goverments.
- 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 understimate OPEX!!!

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

Questions?