Future Proofing the Unified Fibre Access Network:
Build, Fill, Perform

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Vodafone Group Technology

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Overview

1. Vodafone FTTH Context
2. Building FTTH Networks
3. Filling FTTH Networks
4. Performance of FTTH Networks

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Vodafone FTTH Context

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Gigabit Vodafone is a reality

NEW ZEALAND

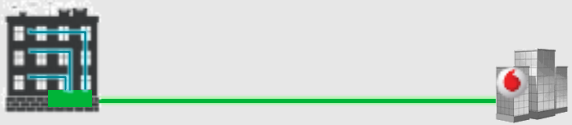
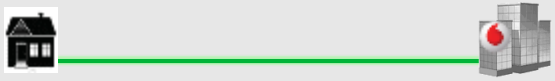
IRELAND

ITALY

PORTUGAL

SPAIN

All Next Generation Access (NGA) options require deeper fibre

Deployment model	Customer connection technology
FTTC  	VDSL2, Enhanced-VDSL2
FTTB  	VDSL2, G.fast, Fast Ethernet
FTTdp  	G.fast
FTTH  	GPON, XGS-PON, NG-PON2, Point2Point
HFC  	DOCSIS 3.1

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We have a flexible NGA infrastructure strategy

We've used M&A, self-build, JV, partnerships & regulated wholesale

Buy

Self Build where viable

Co-build or Strategic Partner with telcos or utility players

Participate in **Subsidised Government Rollout**

Regulated Wholesale

Continually optimising in each Local Market

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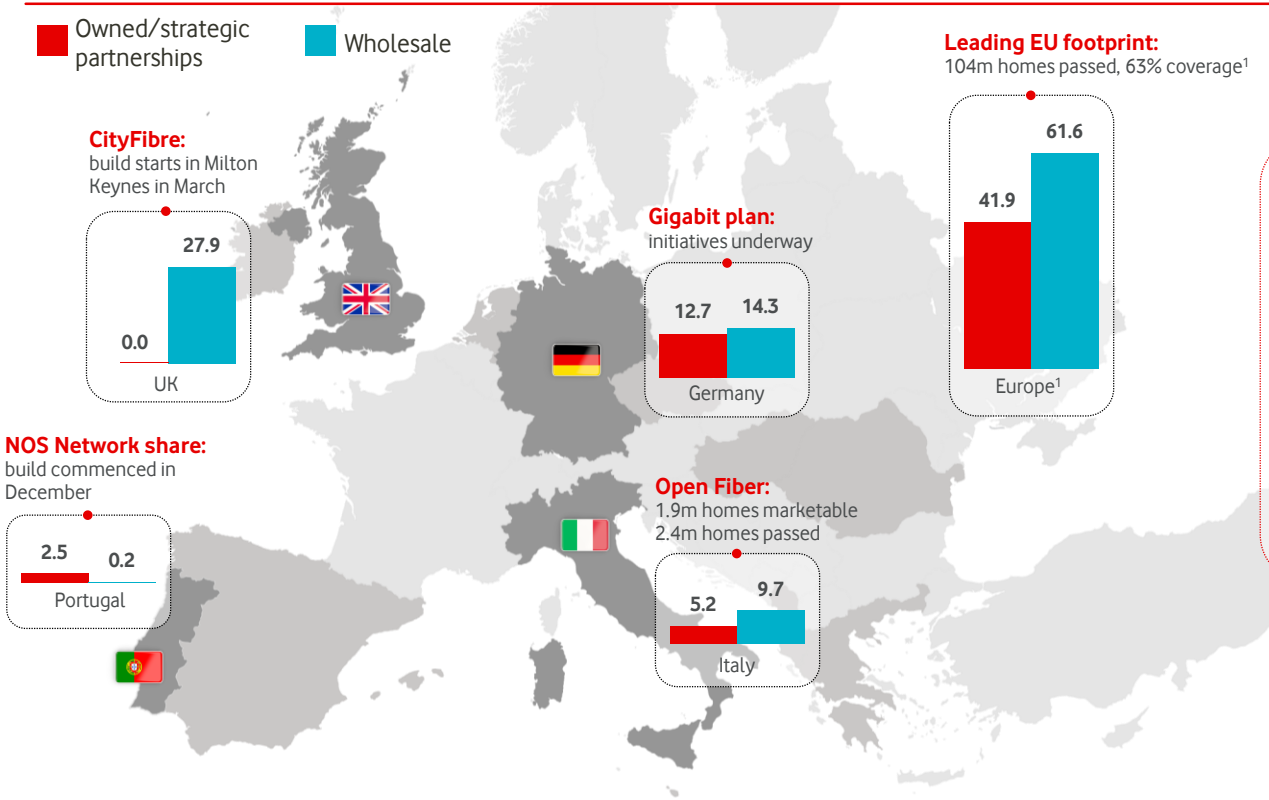
Fixed & Convergence: Driving scale

Europe NGN footprint expansion in Q3 17/18 (m) i.e. Pre Liberty Global announcement



LIBERTY GLOBAL

- Leading NGA owner in Europe
- EU NGA footprint: 110M
- 54M cable/fibre homes 'on-net'

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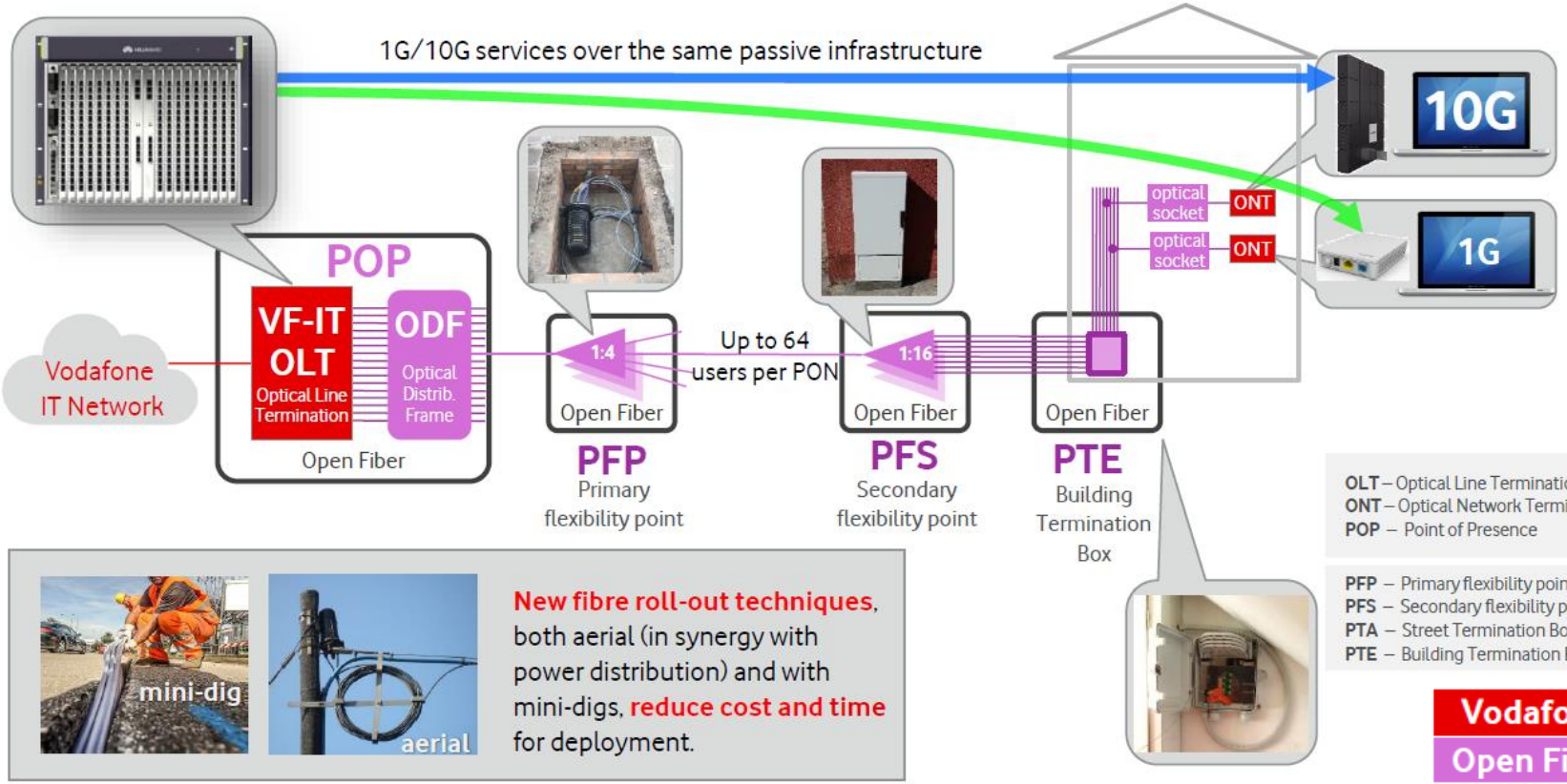
1. Includes VodafoneZiggo

Example Strategic Partner Deployment: Vodafone Italy with Open Fiber



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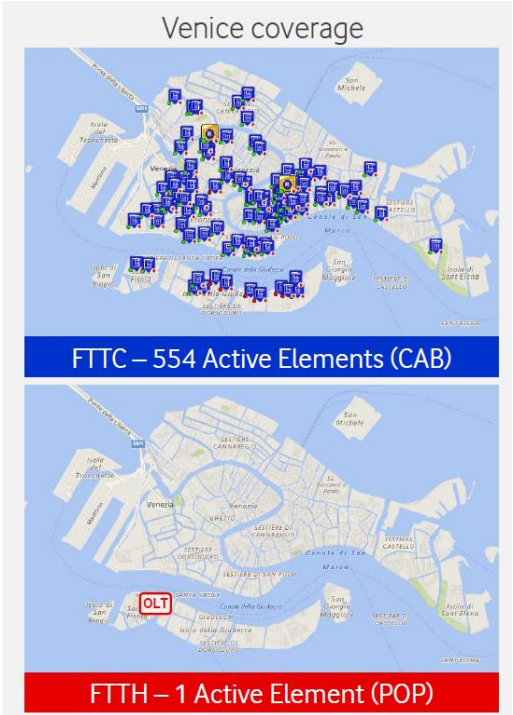
Strategic focus is Fibre & Cable



- **Single FTTH PoP** (instead of 554 VDSL cabinets) to cover Venice
- **No active equipment in the street**, half the fault rate of FTTC/VDSL

- FTTH service has **half the trouble tickets** compared to FTTC/VDSL

- **Vodafone is Europe's biggest copper Local Loop Unbundling operator**
  - Millions of lines of ADSL, ADSL2plus and SHDSL from Central Offices over rented copper lines
  - Tens of thousands of VDSL lines from cabinets using sub-loop Unbundling
- **But, fibre and coax have a clear roadmap to 10 Gbit/s with better quality too** (see later)

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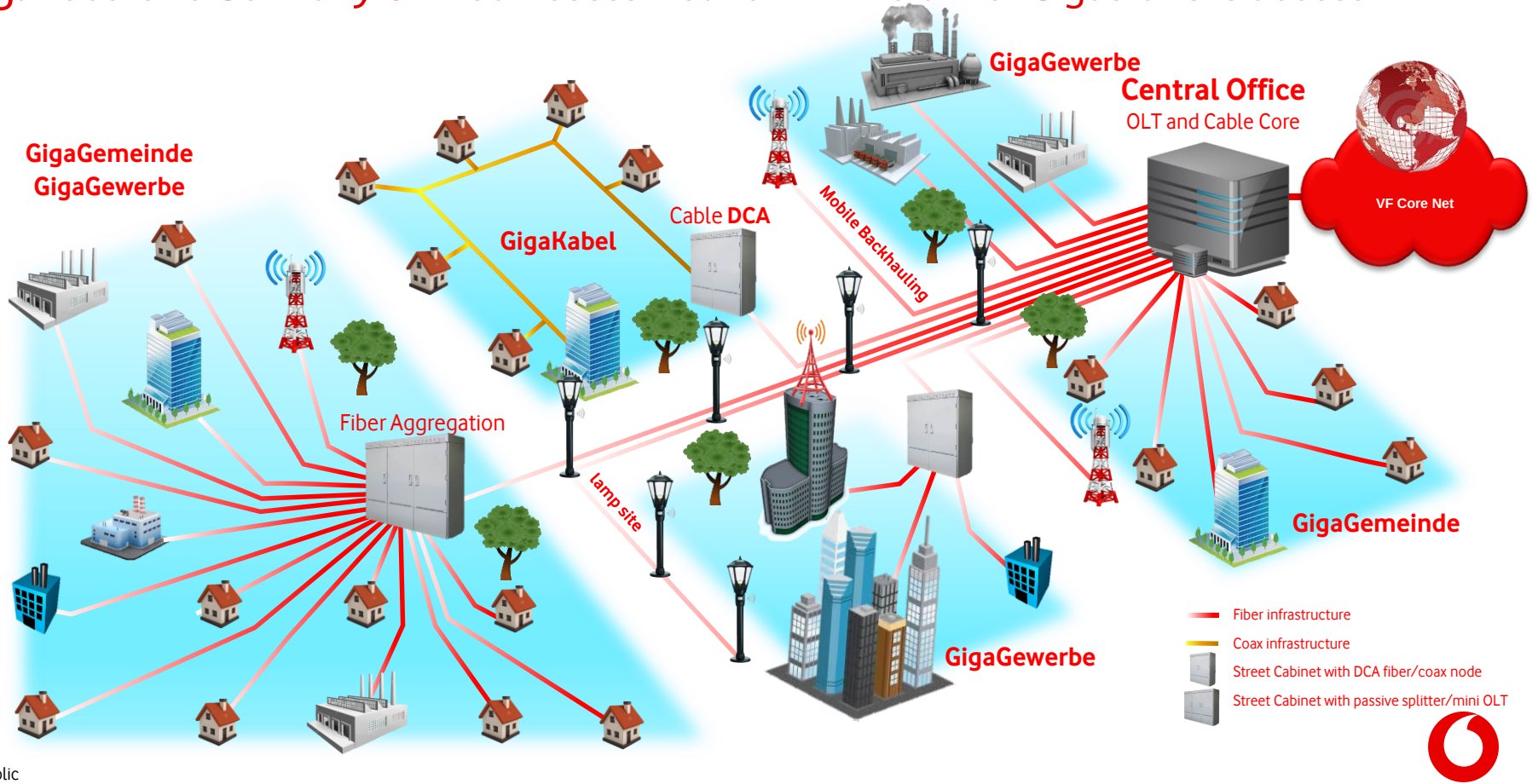
Investment continues

e.g. Vodafone Germany Unified Access Network - A vision for Gigabit fibre access



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Building FTTH Networks

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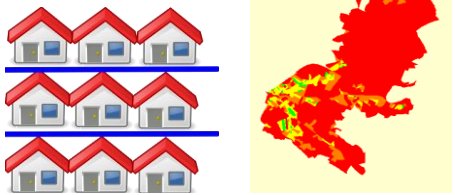
Plan FTTH in areas with highest probability to acquire customers

Build Costs:
Customer Density
Dig
BoM

Customer Demographics:
Wealth/socio-economic group
Existing Vodafone mobile users

Additional Upsides:
Enterprise customers
Mobile masts/Small Cells

Commercial Context:
Competitor presence
Existing broadband speeds



Cumulated "street /building profitability" Heatmap

1. In what customer locations should we build FTTH?
2. What fibre routes should we use to undertake the build?
3. What parts of the route should we build first to optimise time to revenue?

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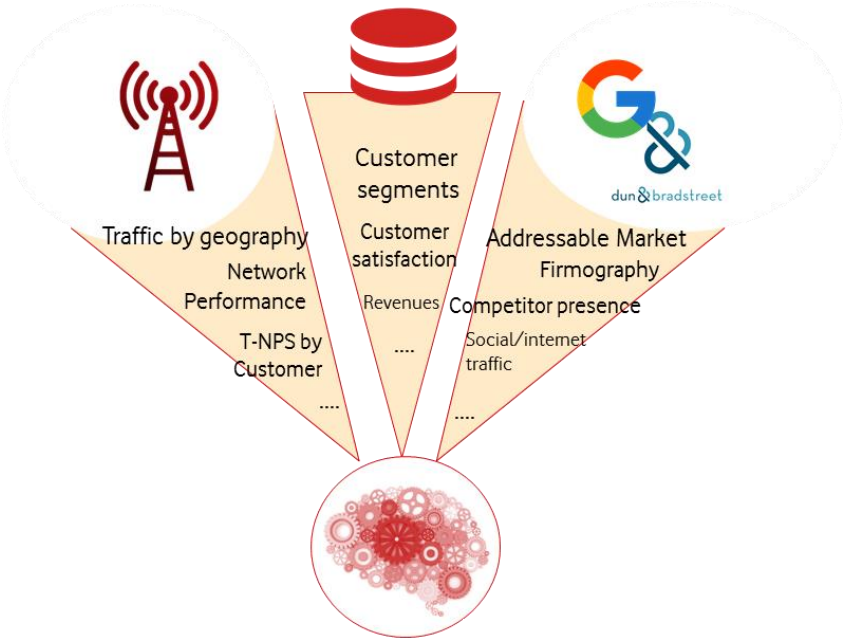
Use Geo-spatial & Predictive Analytics to optimise fibre build planning



- Different build scenarios and trade-offs can be evaluated and costed quickly
- Helps to optimize cost (per Home Passed & per Home Connected) and build sequence

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Examples of questions that fibre planning tools can help with

1. Can big-data analysis improves the economics of FTTH rollout?

2. Does the business case improve by building first those areas with higher expected revenue?

3. Is there more business benefit in optimising number, location & cost of central equipment (OLTs, fibre hubs) or minimising fibre distances?

4. What is the business case improvement of including Enterprise customers and Mobile base-stations (e.g. removal of leased line costs)?

5. What is the trade off between targeted "hotspot" versus contiguous (no gap) coverage that would include low ARPU areas like rental properties?
   - E.g. it is possible to build fewer homes with higher cost that can lead to higher revenue per Home-Passed

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Simple models can be surprisingly accurate

- E.g. Estimate **dig lengths** for a specific area characterized by **few high level parameters**

- Only three inputs:
  - A: the area of the urban area/city to be deployed
  - B: the average area of the block
  - k ≥1 : a shape factor to take into account that usually block are not a perfect square

$$S = \frac{A}{\sqrt{B}} \frac{(1+k)}{\sqrt{k}}$$

"Street connectivity and urban density: spatial measures and their correlation", J.Peponis et al, 2007

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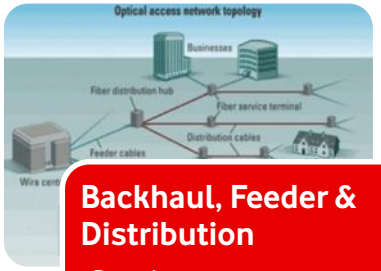
FTTH Build: Key Variable Parameters

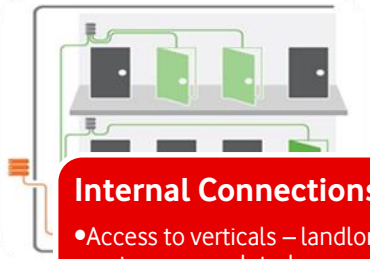


Backhaul, Feeder & Distribution

- Duct Access
- Dark Fibre
- Partner – wayleaves, ducts, poles

Drop to Building

- Façade Access
- Duct Access
- Pole Fibre
- Dig

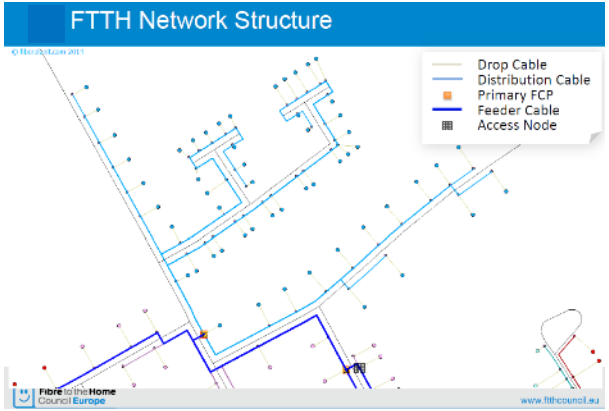


Internal Connections

- Access to verticals – landlord, partner or regulated
- Access to Existing Copper or Ethernet Cat5, Fibre
- Space, power for kit in Basement or Outside

Single Dwelling Unit (SDU)

Multiple Dwelling Unit (MDU)



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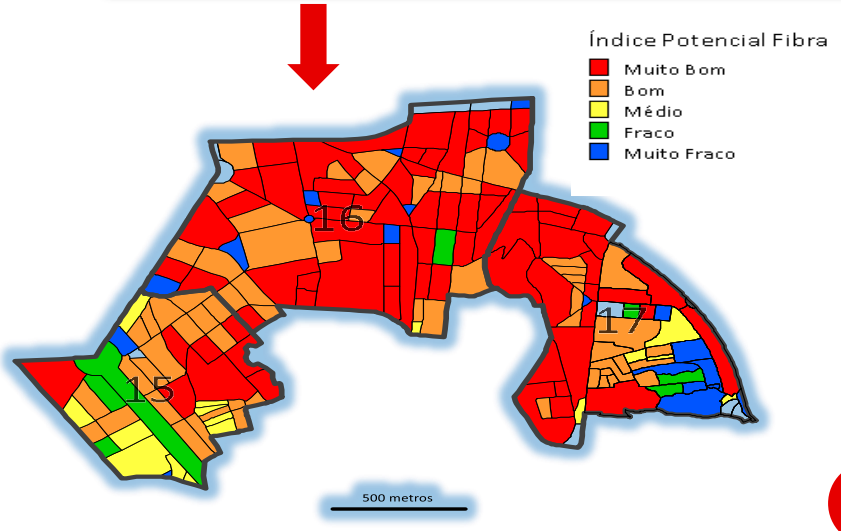
Heat Map Approach to Coverage Development in Vodafone Portugal

- Zoning used to identify areas with the greatest potential for fibre installation
- Geo-marketing analysis can be applied using indicators such as those related to:
  - Customer density
  - Alternative broadband technology availability
  - Business customer proximity
  - Potential future requirement for small cells etc.



A multi-disciplinary approach:

- Technology/engineering
- Business/finance
- Marketing & sales

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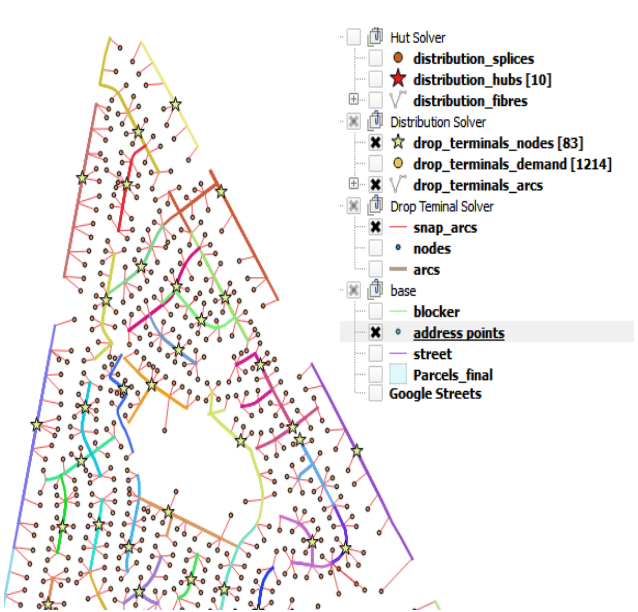
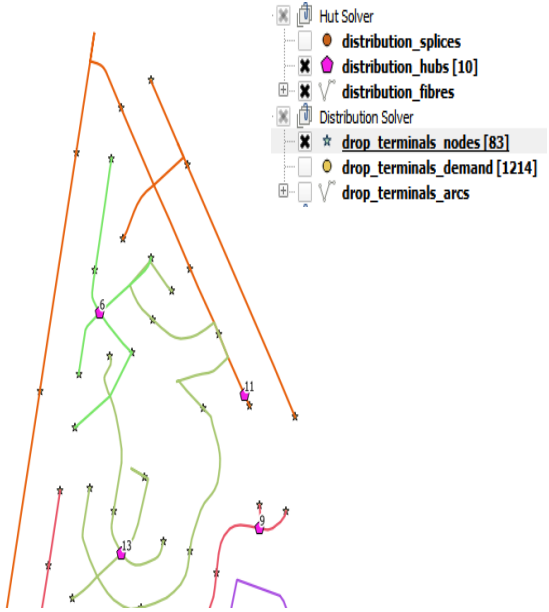
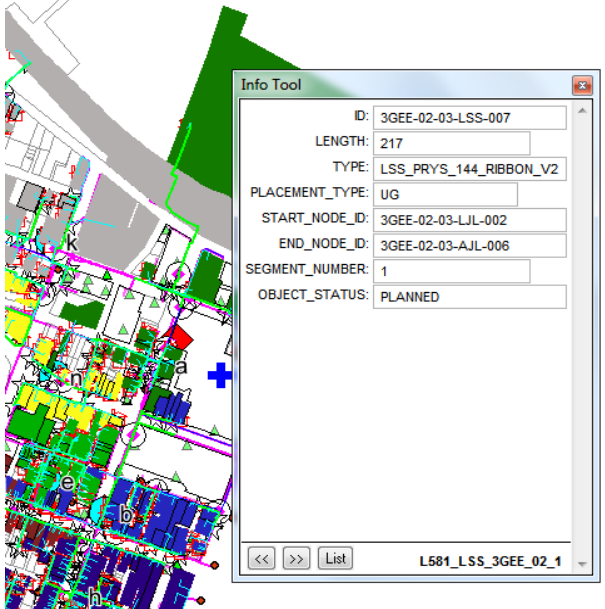
Example of Automated FTTH Design Tool: Biarri Networks

- Premises -> drop terminal node
- Drop terminal node -> distribution hub
- GIS information
- Client specific naming convention
- Client specific equipment types
- Construction ready designs
- Bottom-up cost estimations
- Bill of Materials for procurement







Models are not perfect - Reality Bites!

Abandoned cars where you want to dig

Water pipes not in the street plans
or not as deep as expected

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Lessons Learned

- Reality is usually more complex than a model suggest
- Conditions can change fast in the real world
- Data quality can have a significant impact (e.g. manhole location mismatched in GIS)

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Filling FTTH Networks

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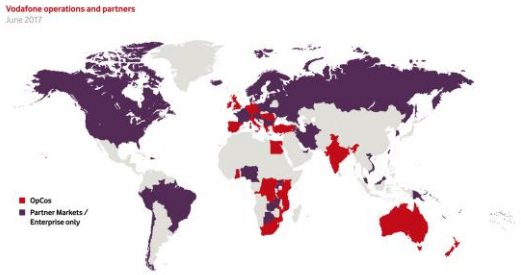
FTTH Challenges

COST

- FTTH is expensive to build
  - Co-investment / Partnerships can share costs
  - Sharing helps fill the network to get faster payback

DIFFERENTIATION

- A single 'wholesale' product set means a "me too" retail product
  - New product features depend on the network infrastructure provider's roadmap priorities



COVERAGE & SEAMLESS SERVICE

- Very few FTTH networks offer ~100% coverage
  - Providing a "national" service can necessitate working with partners to increase coverage footprint
  - Different parts of the network footprint can then have different features
    - "Post code lottery" or lowest common denominator?

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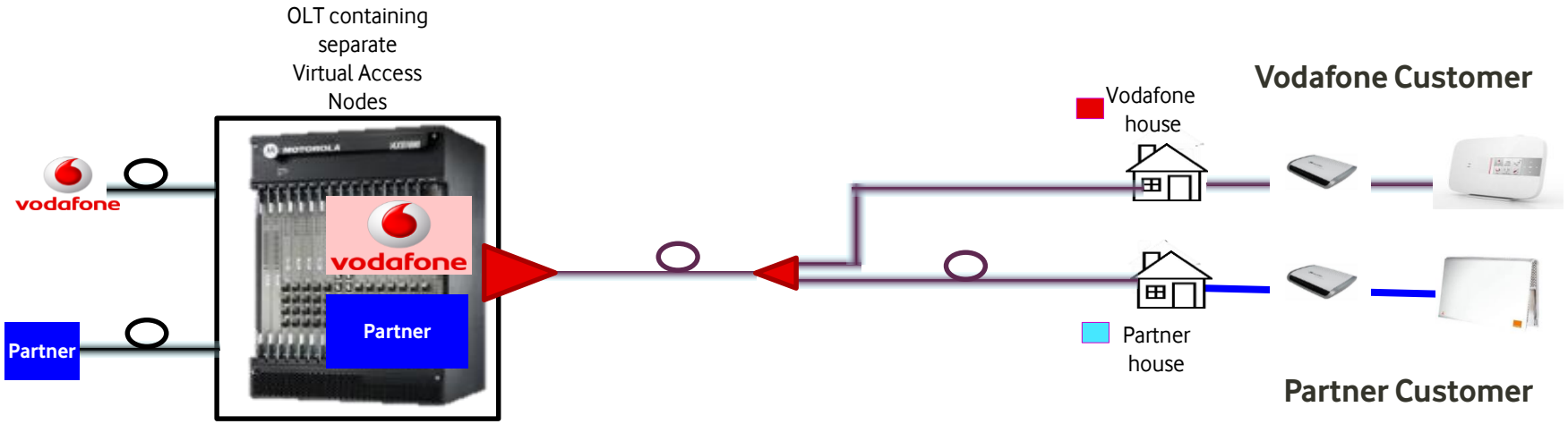
Fixed Access Network Sharing (FANS):

Enables partners to share fibre network and equipment



More Control

- Determine own features of Ethernet and IP layer products
- E.g. Design own speed & QoS profiles etc.

Use Cases

- Co-investment partnerships/JVs (slice per partner)
- Network slice per Ops team (enterprise, consumer, mobile backhaul)
- Post M&A scenario

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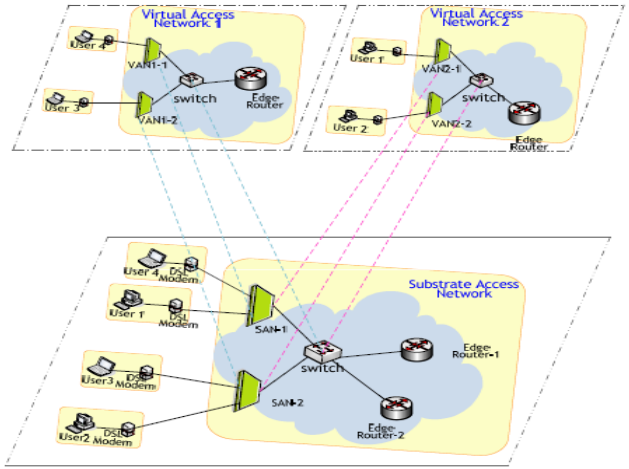
FANS Operator Roles



1. Virtual Network Operator (VNO) – The retail Broadband Service Provider

- Operate, control, and manage its own virtual network

2. Infrastructure Provider (InP)

- Own and maintain physical networking resources
- Enables physical resource virtualization – multitenancy "Network Platform as a Service" (NPaaS)
- Provide virtual resource 'control API' to VNOs

- Similar concept to 5G slicing but slices resources by service provider instead of by service type (FANS could do both)
- Initial product capability from vendors becoming available in 2018

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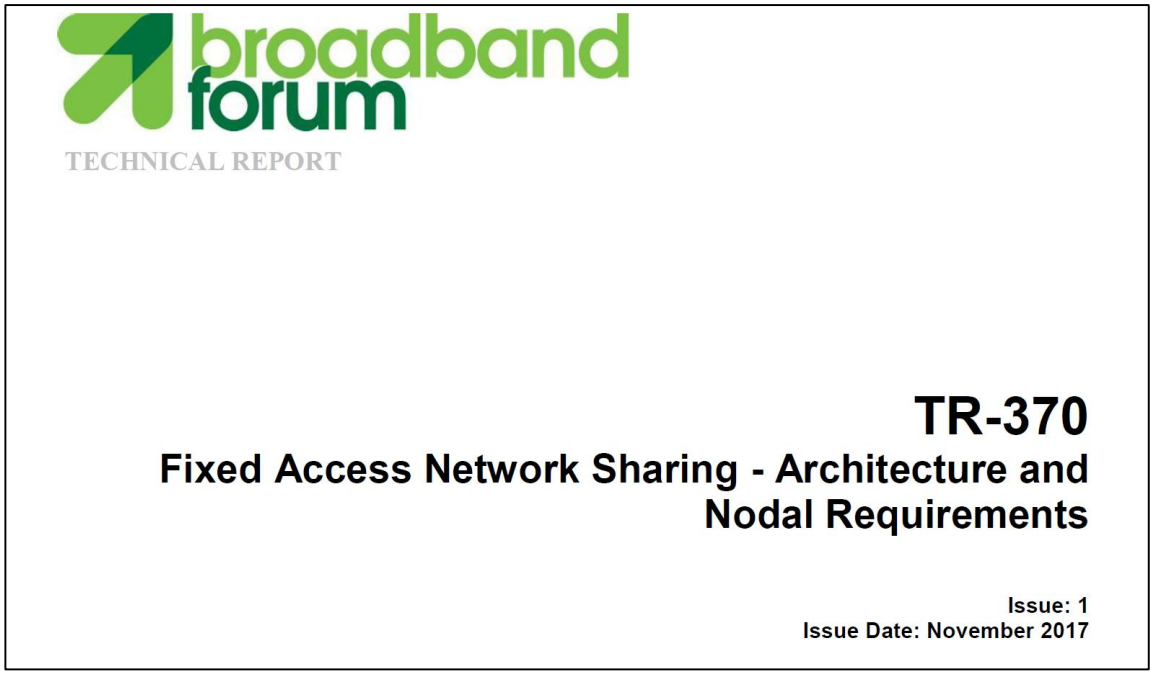
FANS Standardisation



- FANS architecture agreed
- Next Steps:
  - Agree interfaces
  - SDN control

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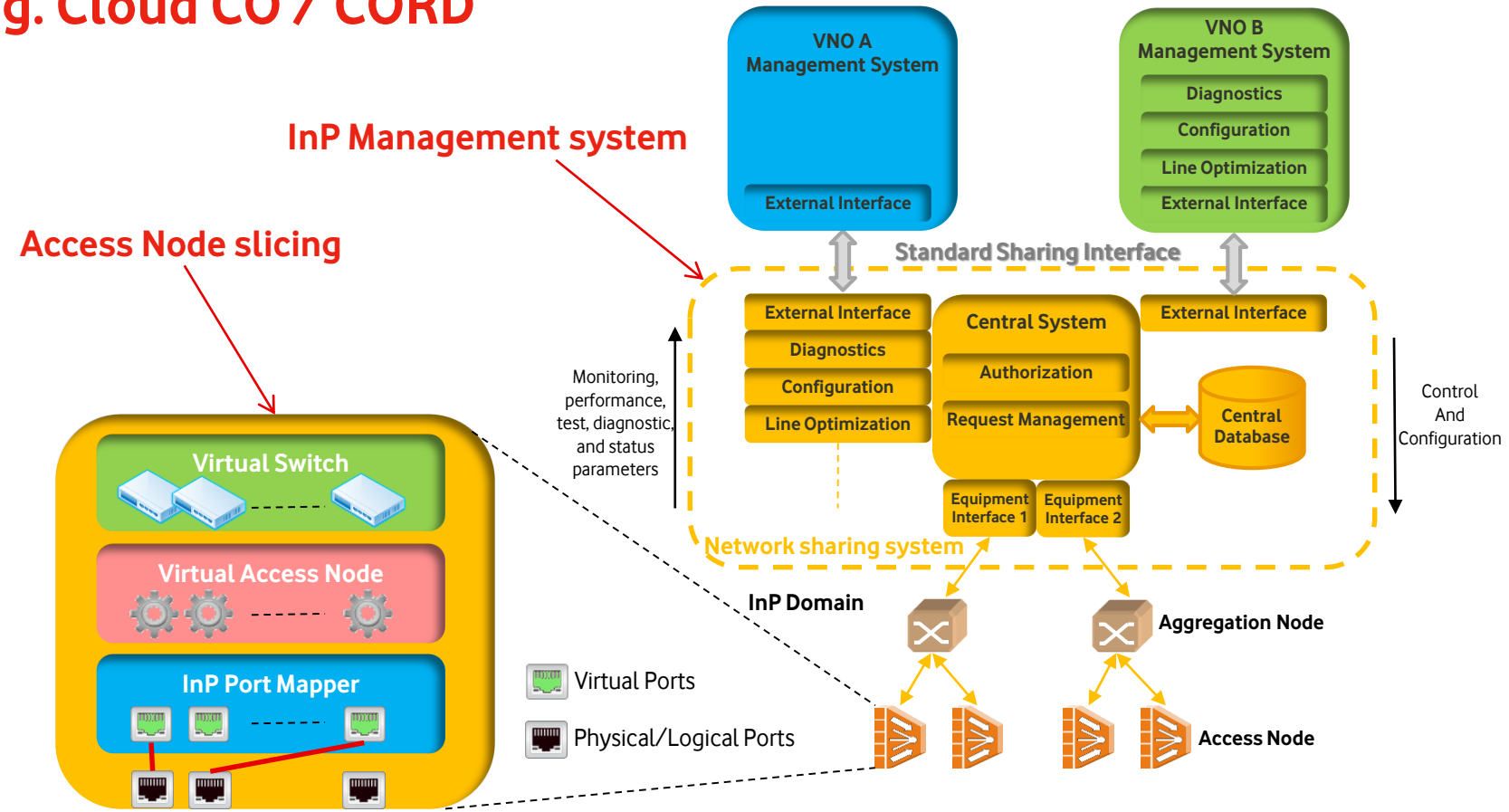
FANS is a Use-Case of Disaggregated/Virtualised Access Nodes e.g. Cloud CO / CORD



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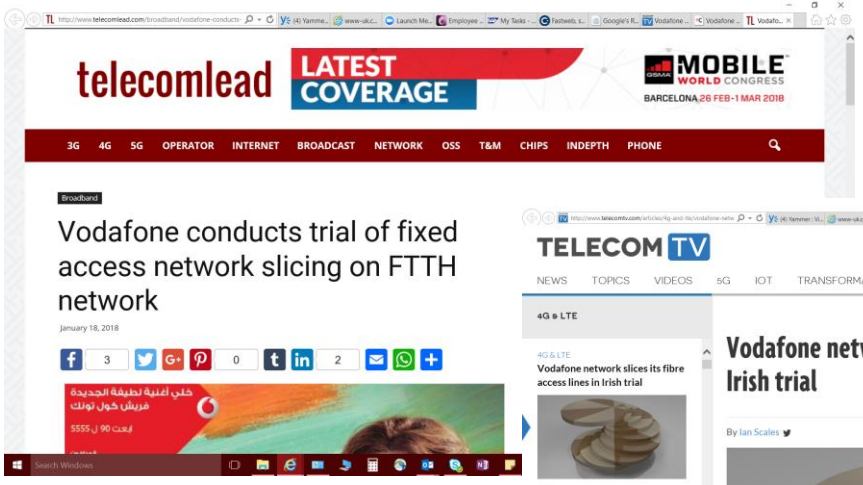
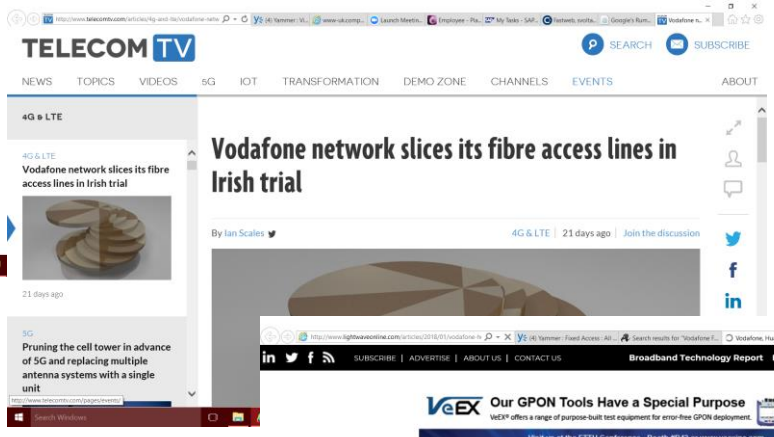
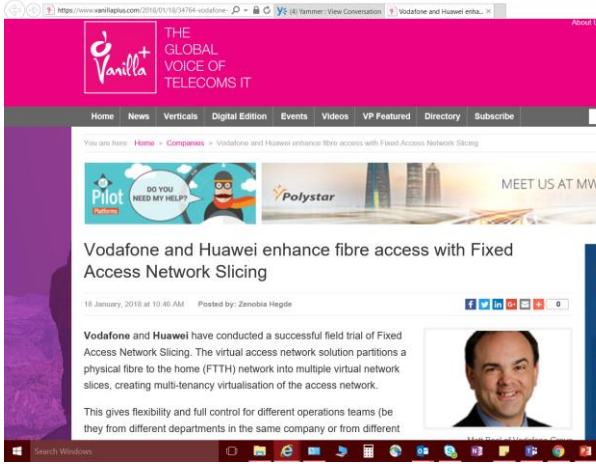
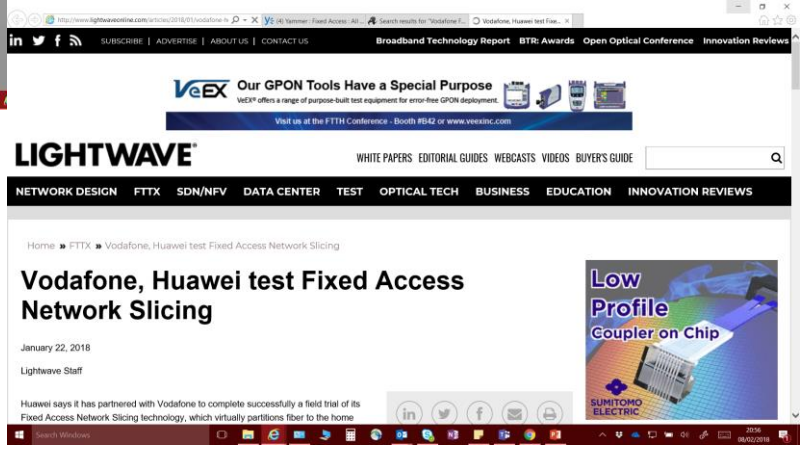
FANS trial with Vodafone Ireland: A European First









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Performance of FTTH Networks

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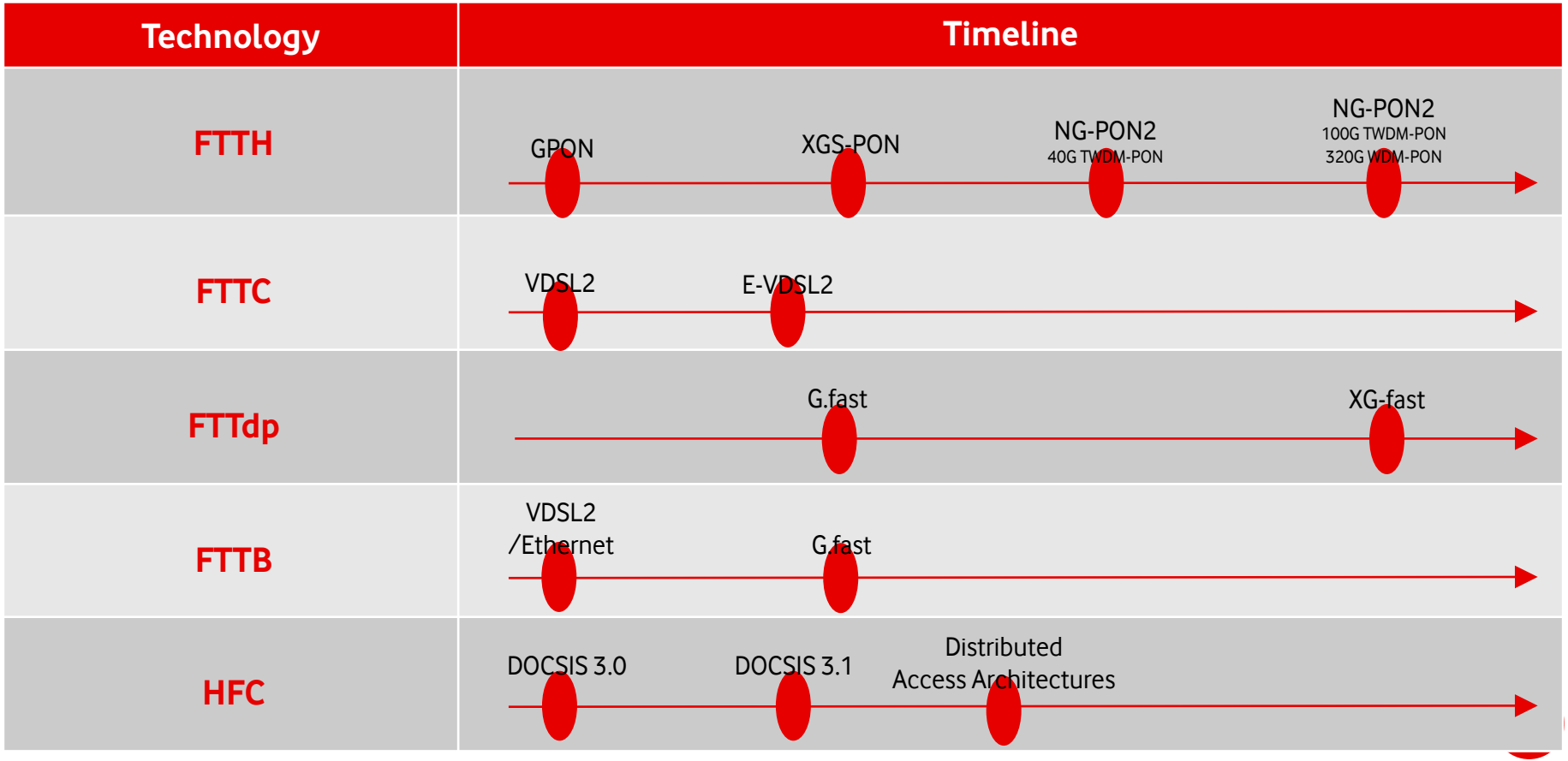
Evolution plans have previously been driven only by bandwidth



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Key Attributes of Broadband Connectivity

What can I do with it?

Functionality

e.g. Synchronisation support
(for small-cell/mobile backhaul)

How "Good"

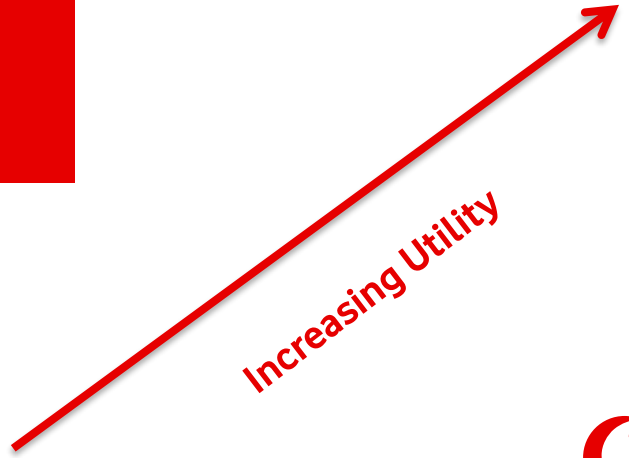
Quality

Latency & Consistency
(stability, stationarity & reliability)

How Much?

Quantity

Bandwidth



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Not all Bandwidth is Created Equal!

Queueing/buffering

- 50 Mbit/s on an empty network is **NOT** the same as 50 Mbit/s on a loaded network

Serialisation Delay

- 50 Mbit/s on a 100 Mbit/s Ethernet port is **NOT** the same as 50 Mbit/s on a 10 Gbit/s port
- 1/10th of 100Mbit/s is **NOT** the same as 10 Mbit/s

Physical Layer

- 50 Mbit/s on VDSL is **NOT** the same as 50 Mbit/s on GPON or 4G

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“When you cannot measure and manage quality, you can only differentiate on quantity.”

Martin Geddes (Just Right Networks), 5th February 2017

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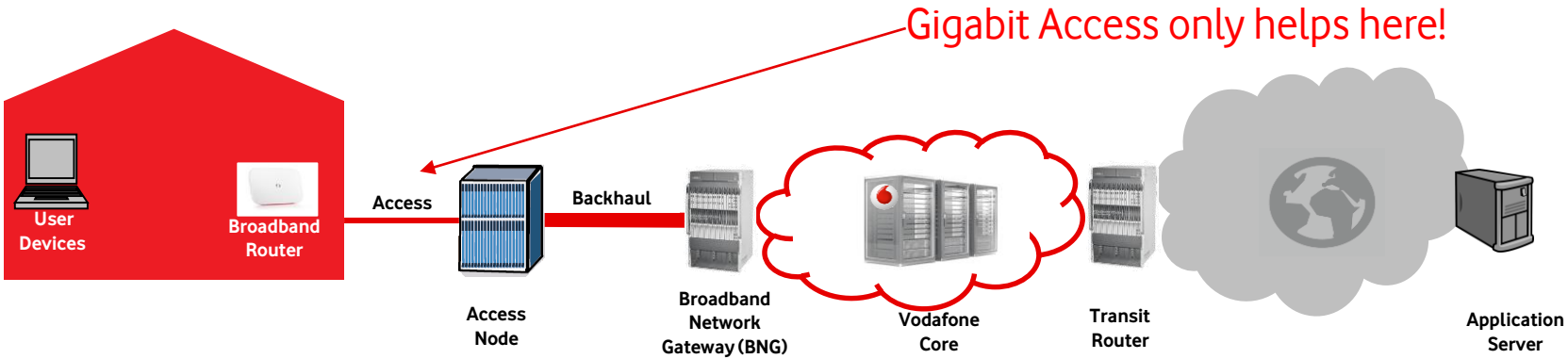
Fixed Broadband Digital Supply Chain



DOMAIN	Home/LAN	Access	Core ("ISP")	Internet	Server
3rd-Party Supplier Options	Customer DIYt	Backhaul / Off-Net Access		Transit/Peering	Application
IP ADDRESS	●	●	●	●	●
Example Issues	WiFi congestion Home router performance	Insufficient capacity	Traffic re-route increased latency	Fibre interconnect problem	App moved on servers

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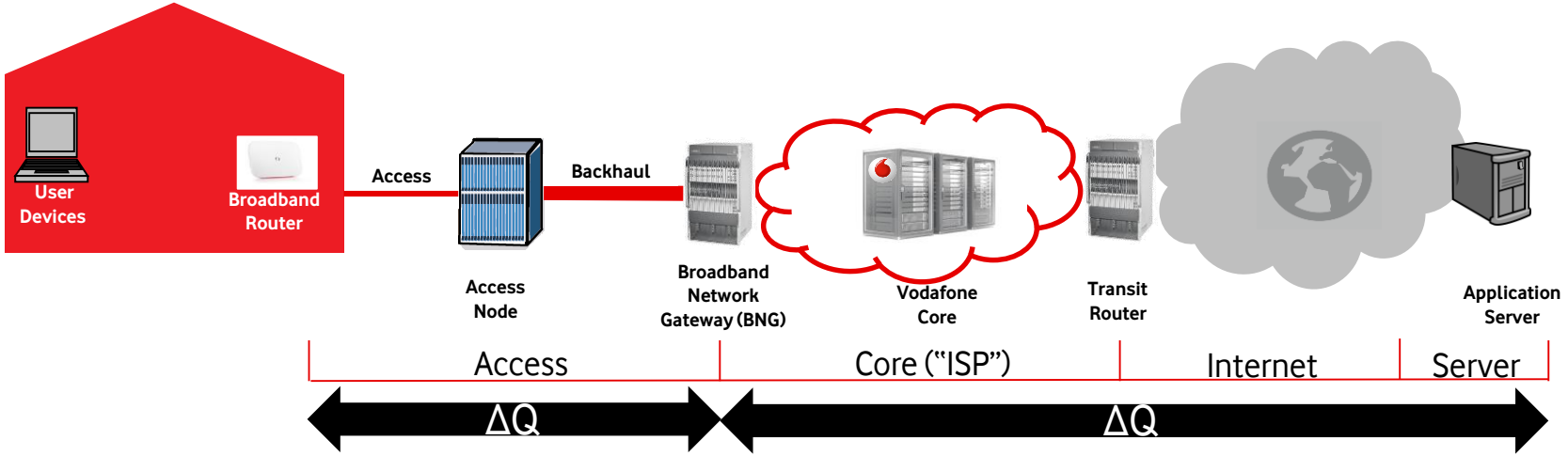
Quality Attenuation (ΔQ) Probe Locations



ΔQ Probe Locations

- A sequence of timestamped packets of specific sizes are sent between the probes (<32 kbit/s)
- Traces are matched and compared to analyse the performance.
- **Both round-trip and each direction**

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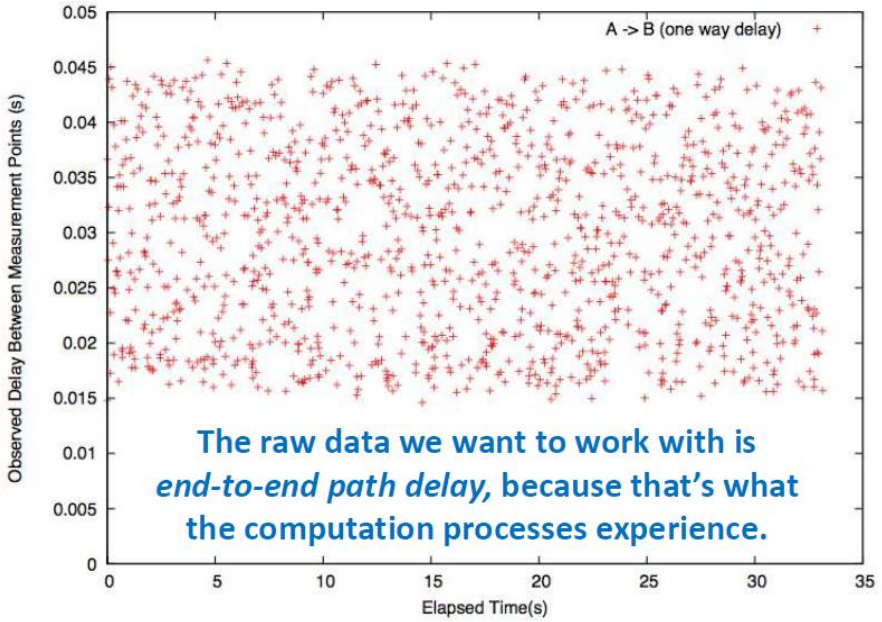
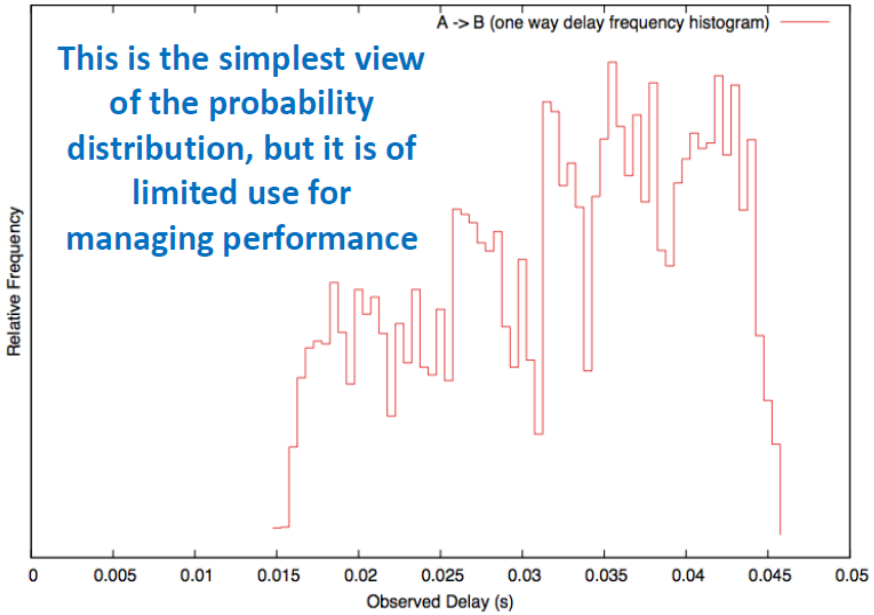
Performance analysis using "Quality Attenuation" (ΔQ)





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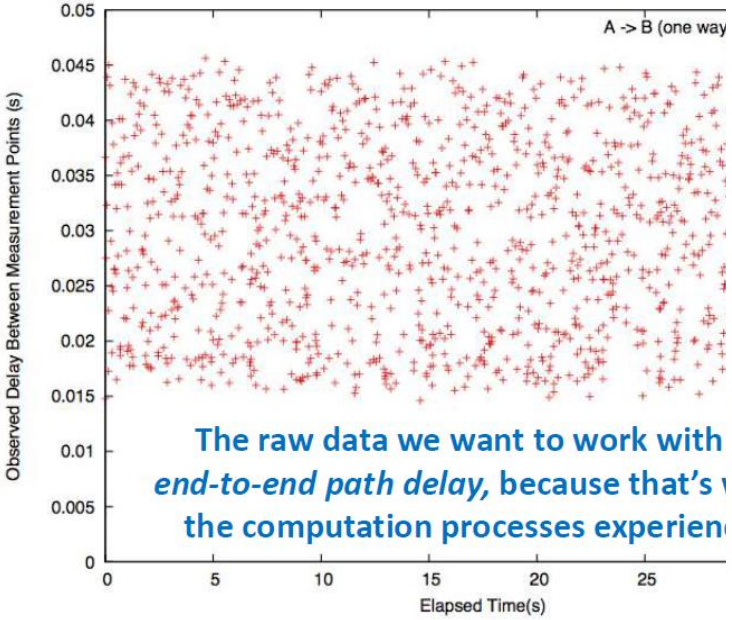
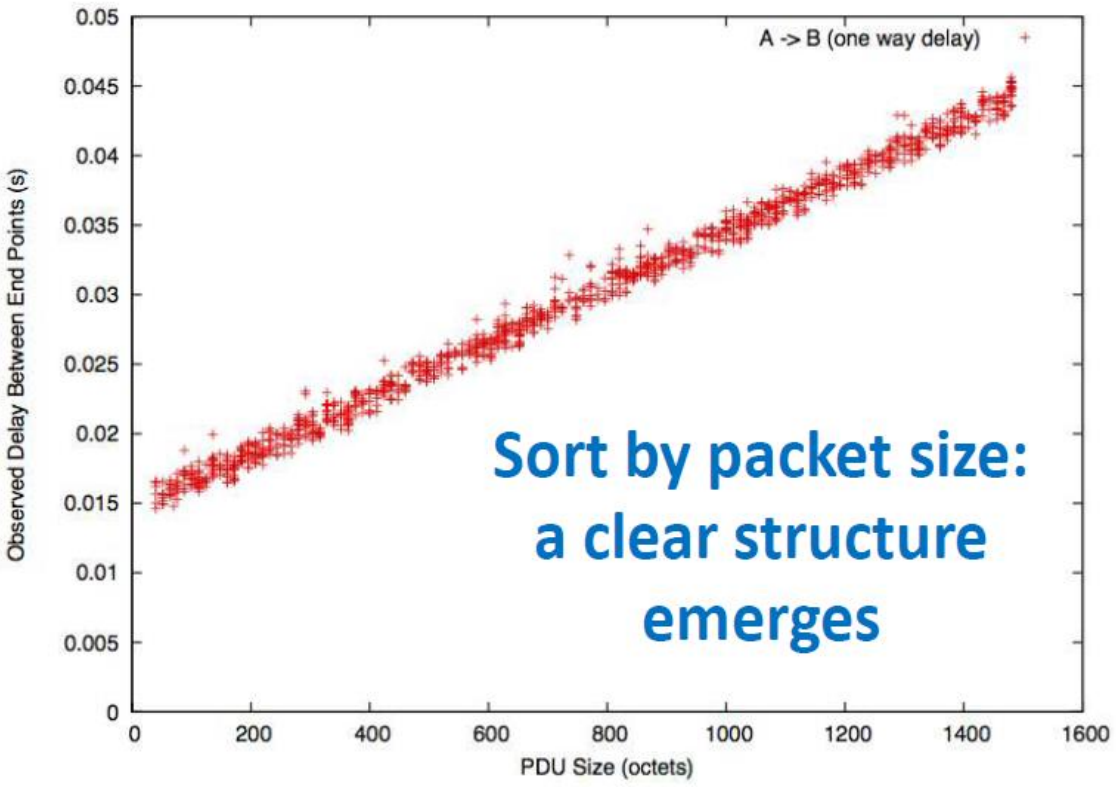
Performance analysis using "Quality Attenuation" (ΔQ)





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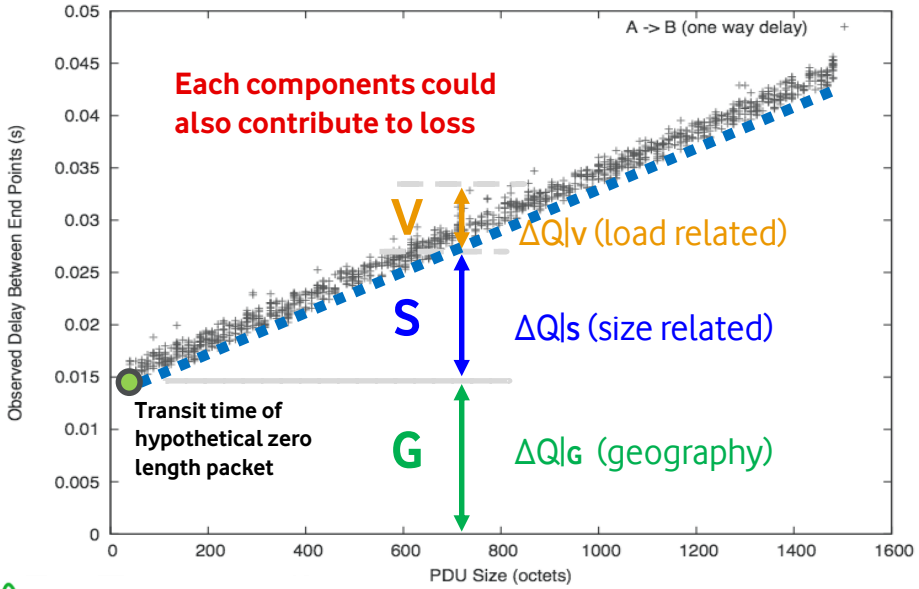
The "Quality Attenuation" (ΔQ) components

- ΔQ decomposes RTT into **3 separate latency components for both upstream & downstream** (so 6 in total)
- The statistical distribution is captured for each latency component



ΔQ | V

Queueing/buffering

Related to network load/congestion and scheduling/buffering

ΔQ | S

Serialisation Delay

Related to bandwidth (interface speed) and packet size

ΔQ | G

Geography Delay

Related to physical layer transmission (speed of light, distance)

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Performance is about a more than just having 'enough bandwidth'!

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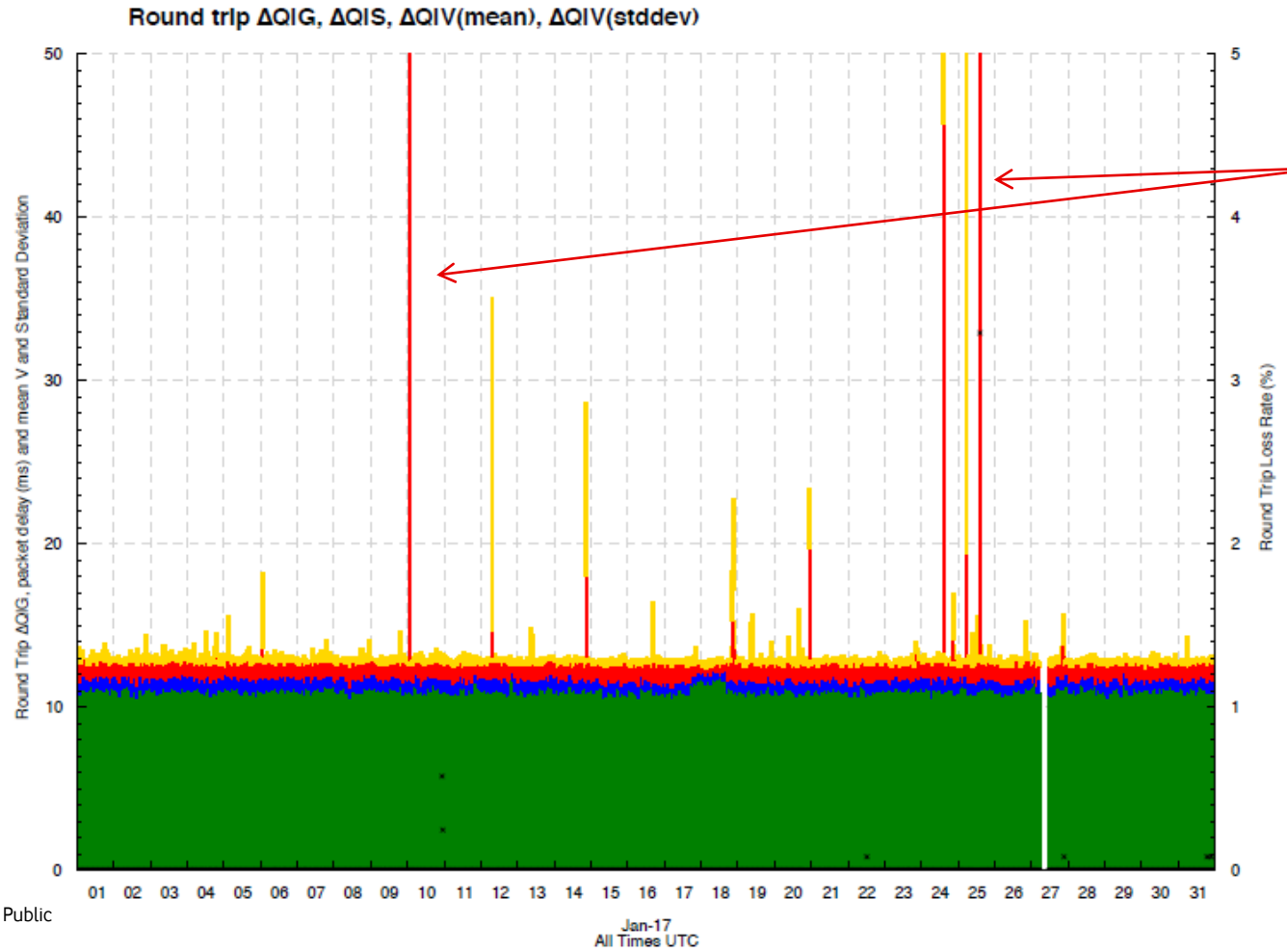
GPON to AWS in Frankfurt *(V, S & G Components together)*



These spikes are common to all countries VDSL & GPON Hence caused by international / Internet connectivity or AWS

KEY:

Red = **V** mean

Yellow = **V** standard Dev

Blue = **S**

Green = **G**

Blue Dots = % Loss

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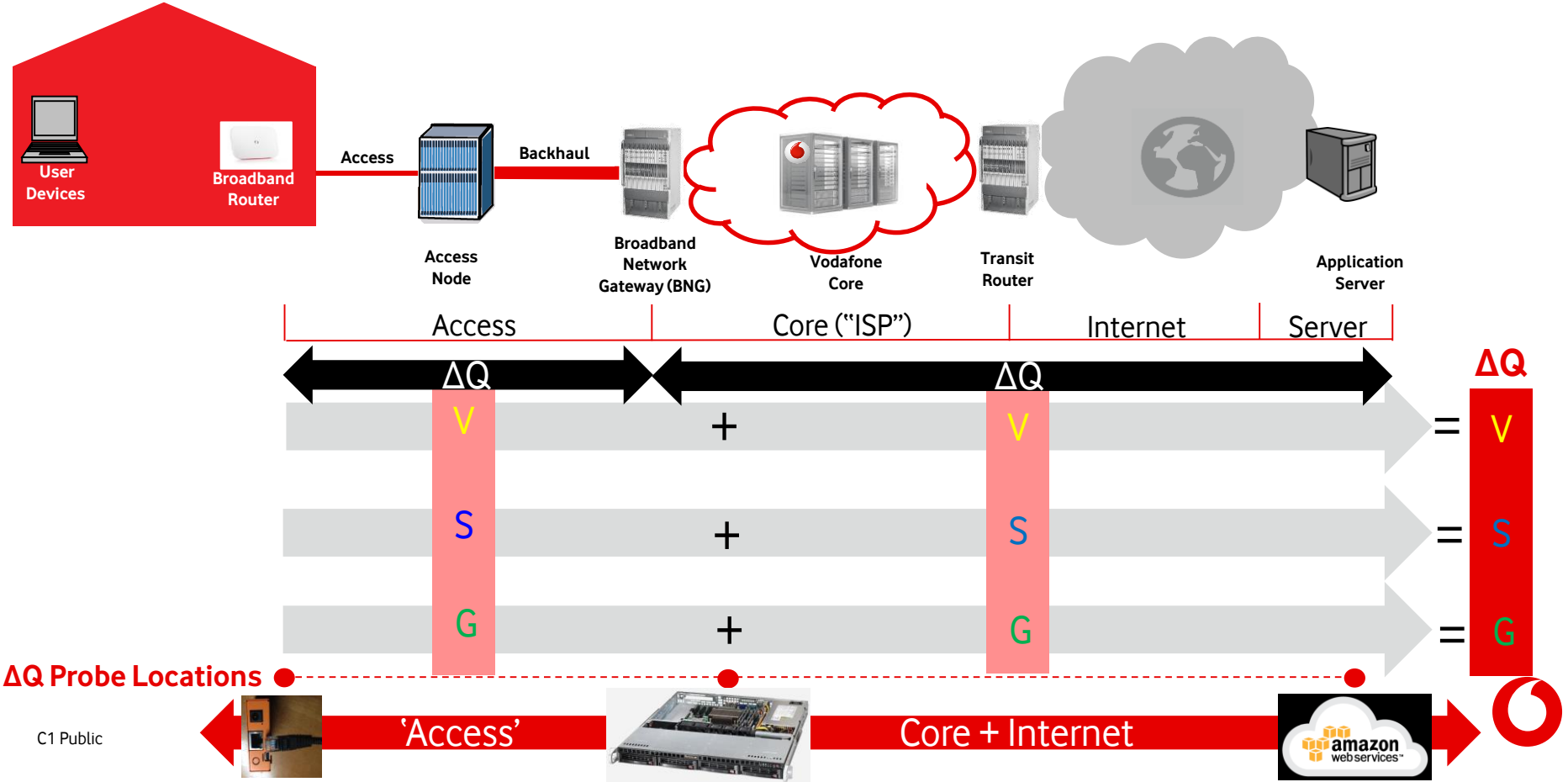
ΔQ Measurements are mathematically composable



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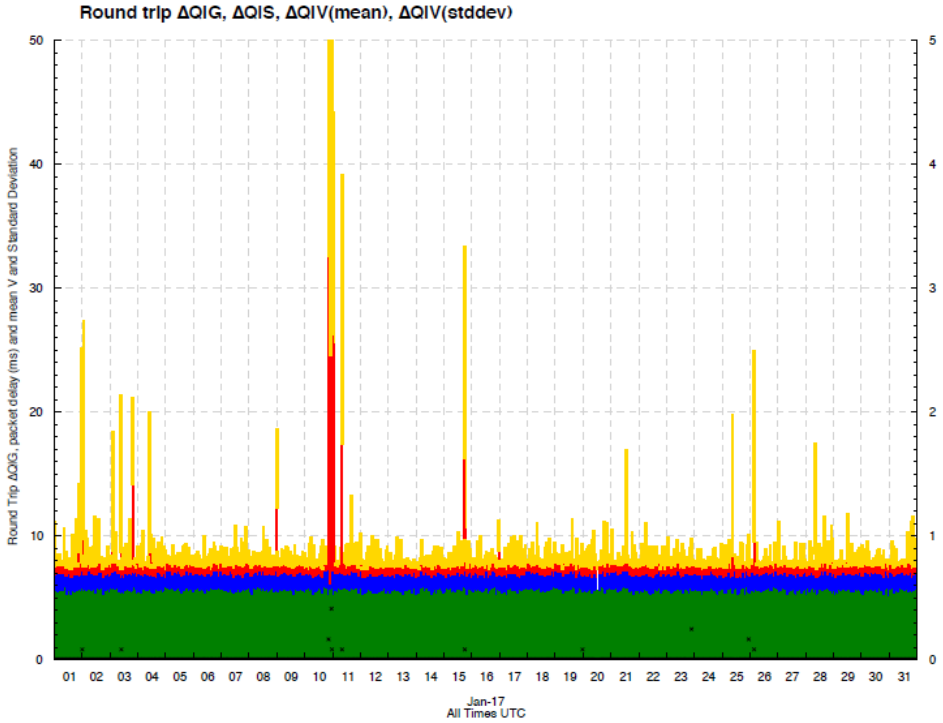
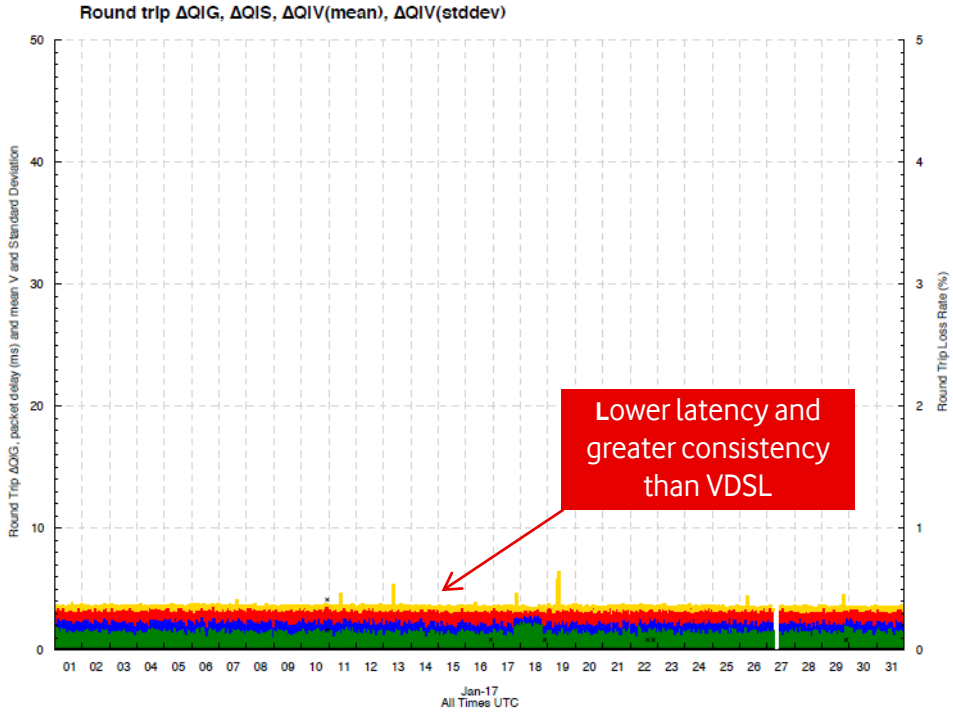
VDSL versus GPON, to Local BNG Probe



VDSL
(Copper)



GPON
(Fibre)

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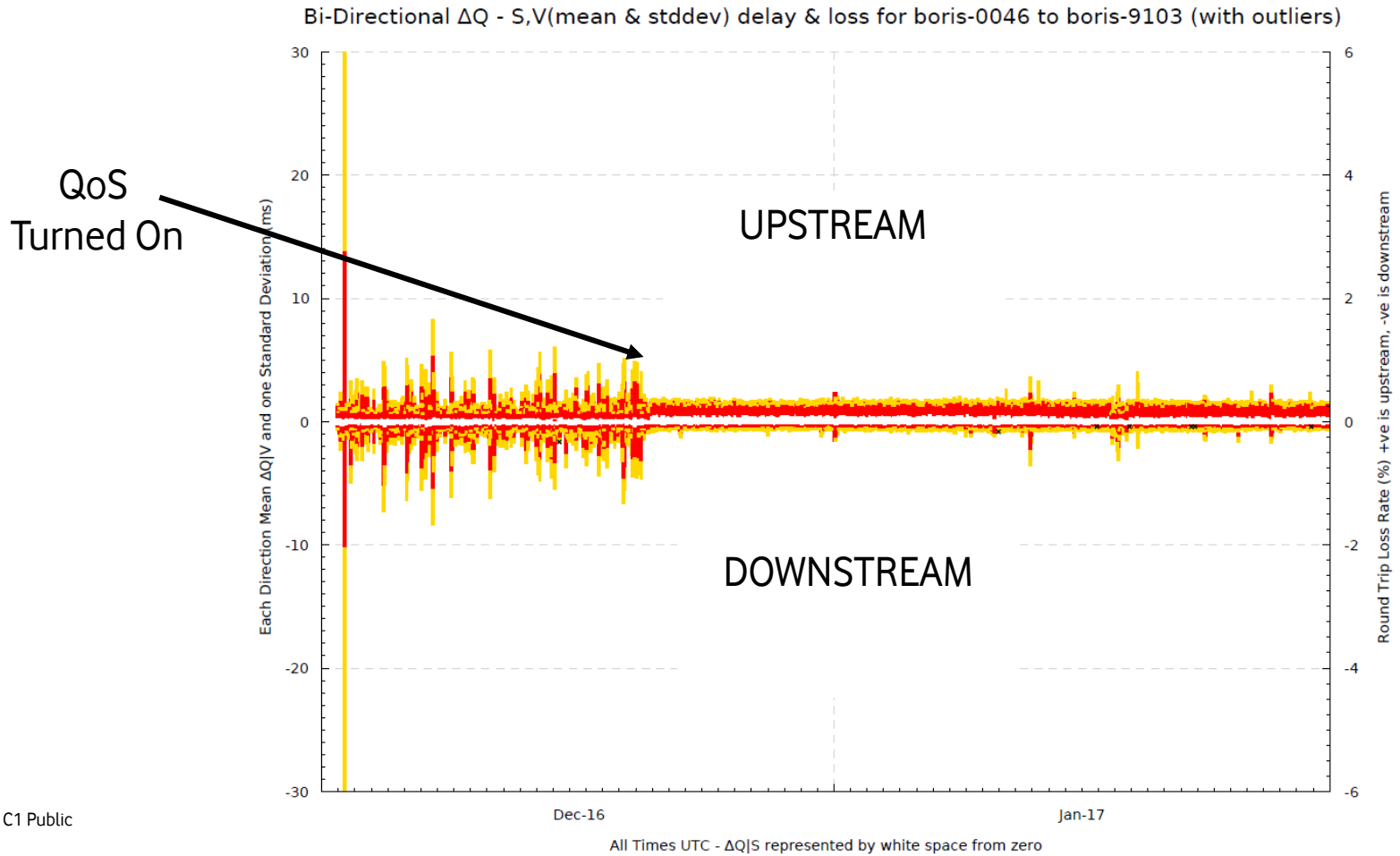
Impact of turning on QoS on GPON



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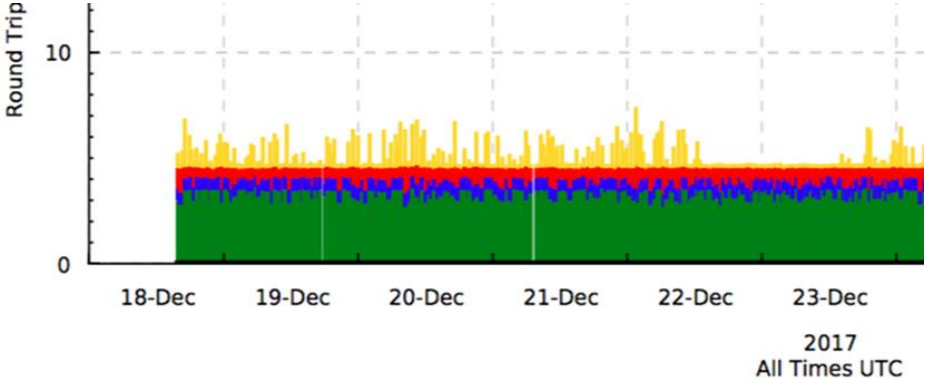
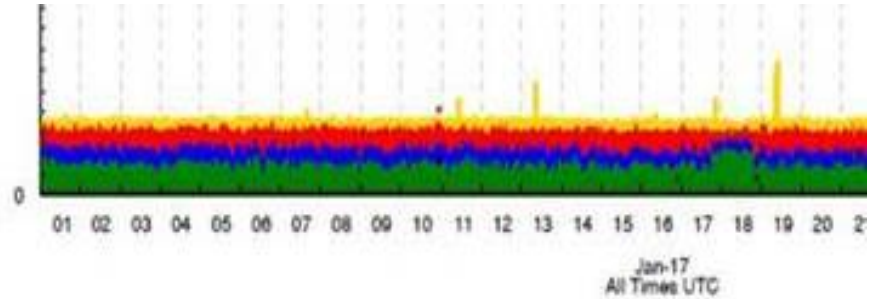
Comparing GPON Configuration Impact





- ΔQ can be used to analyse performance impact of different GPON configuration/profile parameters:
  - QoS & T-Cont types – Performance variation under load
  - DBA: Status Reporting (SR) vs Non-Status Reporting (NSR)
  - Future: vDBA performance ...

- The implications for supporting more demanding applications can then be assessed
  - IEEE 1588 synch packets, for small cell connectivity
  - Enterprise services with tight SLAs
  - AR/VR applications

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Examples of Observable Phenomenon using ΔQ

- Re-routing
- Load balancing
- Packet fragmentation
- DSL Dynamic Line Management (DLM) & Seamless Rate Adaptation (SRA) profile changes
- CPE processor maxed out & impact of WiFi scanning "distracting" from packet processing
- Misconfigured schedulers (queue saturation & bufferbloat etc.)
- QoS benefits/differentiation under congestion
- Maxed out transmission links
- Technology & architecture upgrades
- 3G to 4G bearer change on FMS

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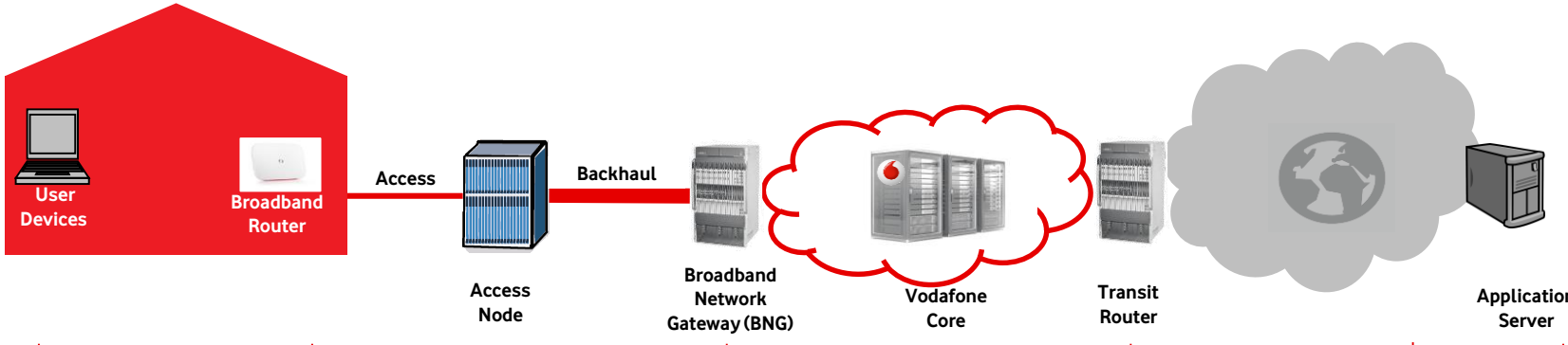
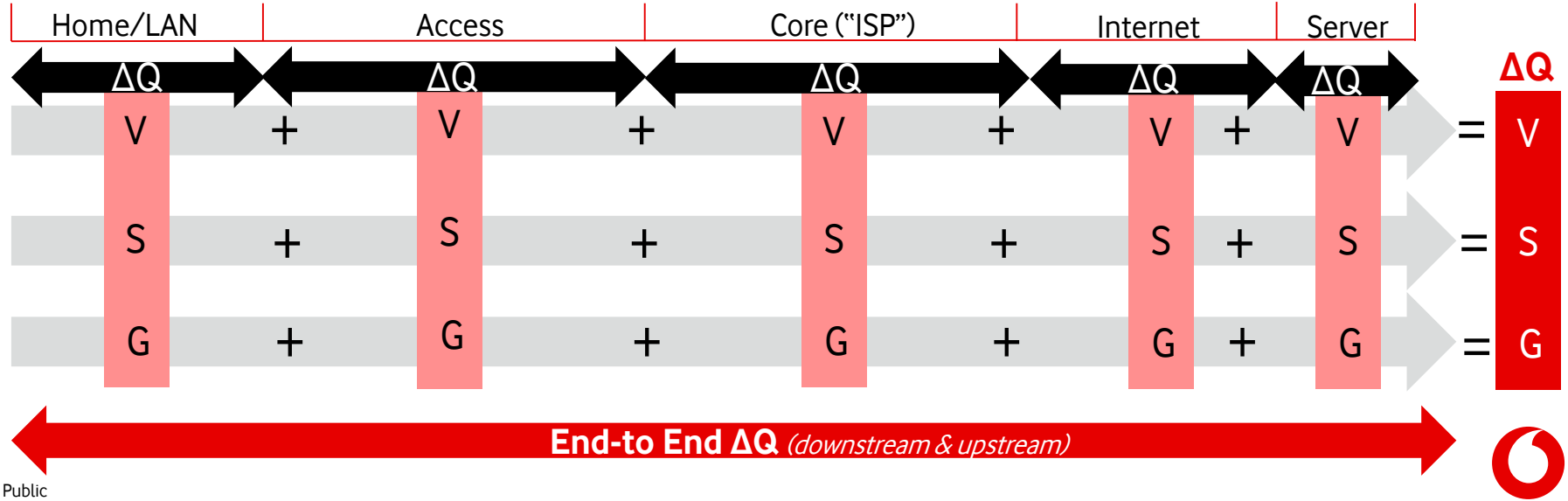
The vision: Full ΔQ 'End-to-End' Across the Digital Supply Chain





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Conclusion

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SUMMARY

- Vodafone sees FTTH as a strategic technology to drive the Gigabit society

- Active areas of study include:
  - Optimisation of FTTH build
  - Virtualisation of FTTH networks to share build costs and facilitate new business models
  - Performance measurement techniques and subsequent optimisation of PON configuration parameters

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Thank You

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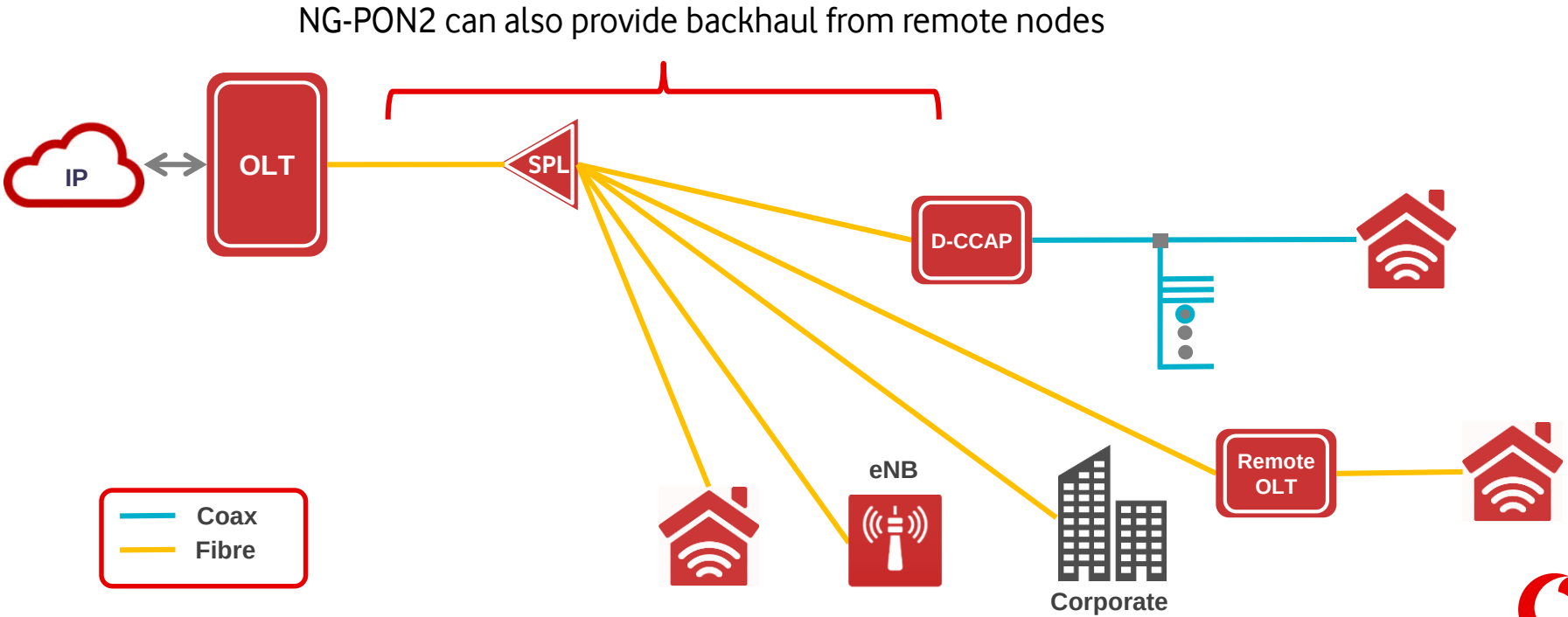
Unified Access Network for an efficient access network



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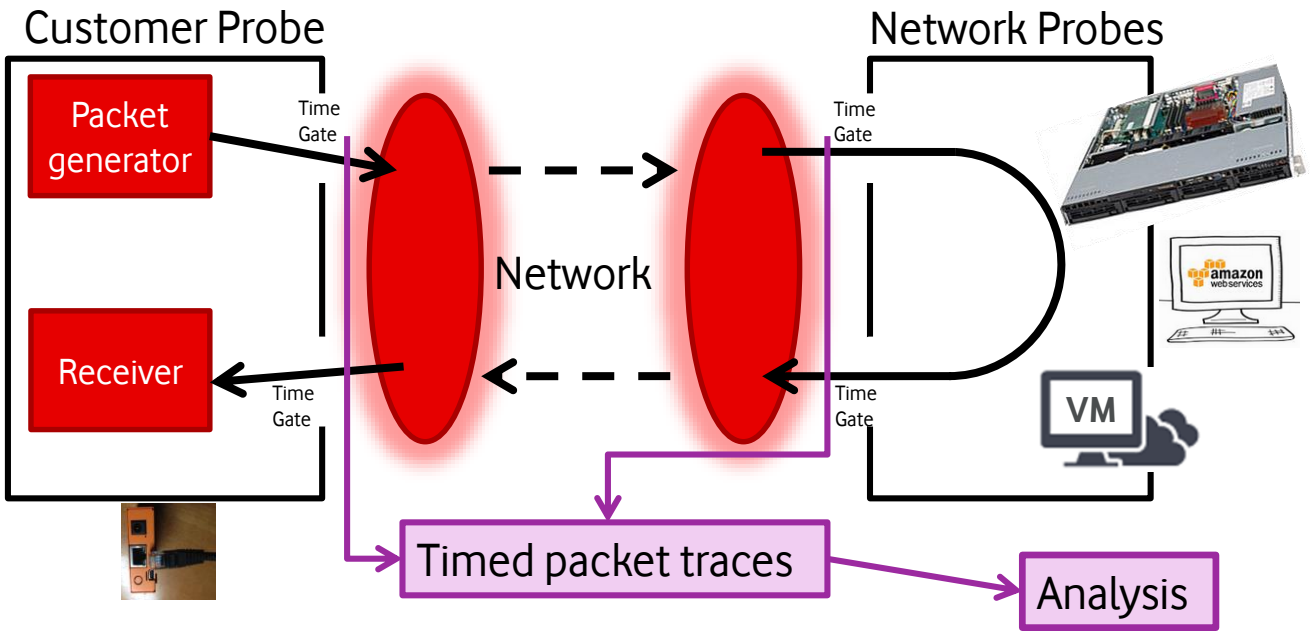
Measuring "Quality Attenuation" (ΔQ)



- Each packet is sent through a loop between the edge probe and the network probe.
- The packets are timed in and out of the test equipment at the moment it is sent
- Traces are matched and compared to analyse the performance.
- **Both round-trip and each direction**

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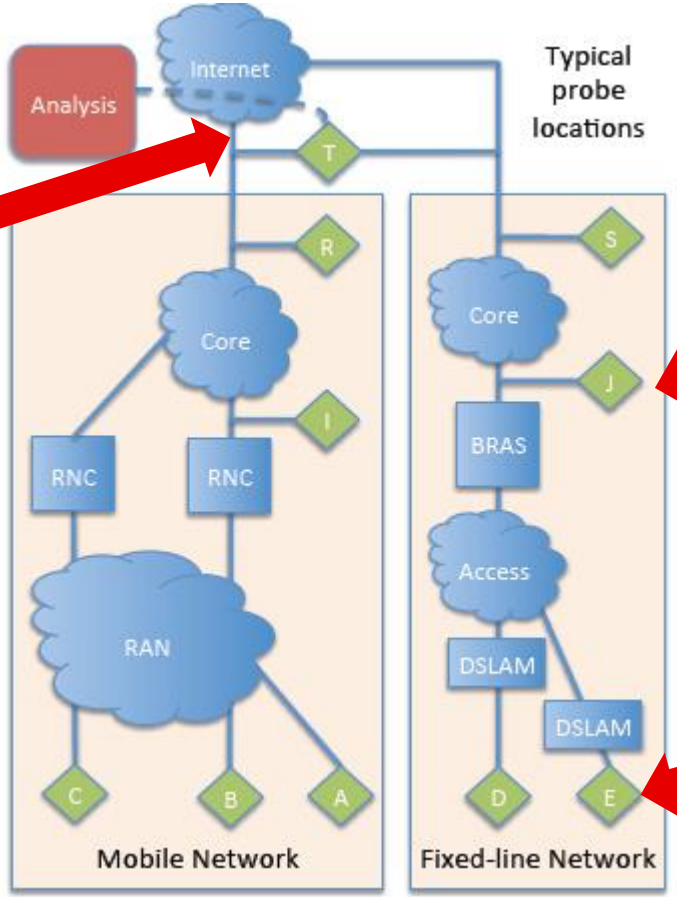
"BORIS" Probe (Basic Observer of Realtime Internet Service)

A BORIS probe at AWS in Frankfurt



A network BORIS probe at BNG/CMTS location

A small BORIS probe at the customer premises

Comparison to traditional approaches

- Traditional measurement approaches and probes just **give 2 or 3 simple metrics**, e.g.
  - Round Trip Delay (RTT)
  - Average & Peak Delay

- ΔQ = Quality Attenuation. Characterised by **6 metrics** (with statistical distribution of each)
  - ΔQ | v, ΔQ | s and ΔQ | G for both upstream & downstream

- The generic ΔQ measurement approach is independent of:
  - technology
  - equipment vendors
  - connectivity suppliers

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Back-Up Slide: Quality Impairment (ΔQ) Derivation / References

- A perfect network would convey IP packet traffic with zero loss & zero delay
- In reality, packets are dropped or delayed resulting in a "delta" compared to the ideal scenario
- The concept of ΔQ encompasses the instantaneous distribution of delay and loss
  - ΔQ applies along a path from a source to a sink
- ΔQ is derived by generating appropriately chosen IP packet samples
  - Uses low-rate test streams with the right pattern to give the full loss/delay distribution
- Further Reading on **ΔQ** approach
  - https://www.slideshare.net/mgeddes/stationarity-is-the-new-speed/1
  - https://www.slideshare.net/mgeddes/example-highfidelity-network-measures-using-q-metrics
  - https://docs.google.com/document/d/1yH5R59fNDgZJKs24caFCWMy2QCoGKiFwqVAcj5JPByw/edit