D 3.7

Final report on regulation, policy and multi-business model usage

Dissemination Level:

- **Dissemination level:**

  PU = Public,
  RE = Restricted to a group specified by the consortium (including the Commission Services),
  PP = Restricted to other programme participants (including the Commission Services),
  CO = Confidential, only for members of the consortium (including the Commission Services)

Abstract:

This deliverable is a review of deliverable D3.2, which gave origin to two white papers published by the DISCUS project consortium in November 2013. After discussions with many stakeholders on topics of regulation and business models for next generation fibre access network architectures, we have analysed a number of case studies around the world on both open access and vertically integrated ownership models, and report here our updated view.

The DISCUS Consortium consists of:

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1	Trinity College Dublin	TCD	Ireland
Other Beneficiaries			
2	Alcatel-Lucent Deutschland AG	ALUD	Germany
3	Coriant R&D GMBH	COR	Germany
4	Telefonica Investigacion Y Desarrollo SA	TID	Spain
5	Telecom Italia S.p.A	TI	Italy
6	Aston Universtity	ASTON	United Kingdom
7	Interuniversitair Micro-Electronica Centrum VZW	IMEC	Belgium
8	III V Lab GIE	III-V	France
9	University College Cork, National University of Ireland, Cork	Tyndall & UCC	Ireland
10	Polatis Ltd	POLATIS	United Kingdom
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1. Introduction (TCD)

The DISCUS project published two White Papers entitled "Wavelength usage options in access networks" and "Business and ownership models for future broadband networks". These were initial report presenting how business and regulatory model could support the main concepts of the project.

These white papers are freely available for download in the DISCUS website, and in addition we actively disseminated them to a restricted number of institutions, in order to gather feedback. We intentionally disseminated to a well-targeted number of stake-holders in order to receive feedback on the topics discussed. In addition we have agreed not to disclose the name and affiliation of any of the sources as network ownership and regulations are very sensitive topics for operators, vendors and regulators.

This deliverable builds on the feedback we have received and generates a new final document on business models and regulations for next generation optical access networks.

The document is organized as follows. Section two reports a brief summary of our previous white papers, so that the reader does not need to refer back to the previously published documents. This section also reports on the feedback we have received by the institutions we have targeted.

Section three reports on a number of case studies, which allow us to investigate what business and regulatory options have been selected in different countries around the world giving us an idea of what options might be acceptable and might work best.

Section four gives an update on the proposed DISCUS business and ownership models, considering the received feedback and the use case studied.

Finally, before concluding the document, section five revisits the DISCUS architecture in reference to the wavelength usage and ownership models discussed above.

2. Summary of initial DISCUS white papers and feedback form stake holders.

2.1. Summary of the white papers

The major objective of the DISCUS project is to enable a future network that would address two major problems arising due to the huge growth in network capacity demand. These problems are:

- the cost of network provision and financial viability of the telecoms sector

- the need to avoid a "digital divide" being created between those customers in dense urban areas and those in the sparser rural communities, without the need for massive government subsidies.

Solving these problems has major implications for the regulatory policy, for the distribution and assignment of network resources at all layers and all users of the network, including the service providers, and for the nature of the ownership and business model structures that need to be supported.

It is expected that the future optical access networks will be based on multi-wavelength transmission in optical fibre to provide the scalable capacity. However how wavelengths are used and what they are used for can have a significant impact not only on the costs and efficiency of the future network but also on the opportunities for competition and the service creation environment.

In the project four wavelength usage options have been considered: (1) wavelengths assigned to service providers, (2) wavelengths assigned to services, (3) wavelength used flexibly for bandwidth management and (4) wavelengths assigned to users.

The DISCUS project is proposing a new flexible network architecture which could support all four options. However, we have concluded that it is preferable to have an option offering fully flexible bandwidth management providing the potential for lowest upfront costs, the most efficient usage of network resources and the greatest opportunity for creating a fair competitive environment while encouraging a greater entrepreneurial, innovative and competitive spirit for service provision. One of the driving philosophies of the DISCUS architecture is to use sharing of network resources as much as possible as a way of reducing cost per user. The dynamic sharing of bandwidth across wavelengths and within wavelength channels (i.e., when using the wavelengths for managing bandwidth option) maximises the resource sharing potential and minimises cost per user. To enable this vision, regulations for competition would need to be reconsidered from a shared network perspective rather than the simple unbundling strategies currently employed for the copper access network. However, it is recognised that the current regulatory environment may only slowly change and therefore the DISCUS architecture is designed to also support wavelength and bit-stream unbundling within the different wavelength usage options.

Three general business model structures have been discussed in the project:

1. Separation of the business operations and ownership into:
    - a service provision business,
    - a network provision/operation business and
    - an infrastructure provision business.

2. Business structures where some level of vertical integration occurs between these three ownership/business models. For example, the fact that the network operator could also own the access infrastructure or the service provider owns the OLT etc.
3. The sharing versus ownership, by the three entities, of network resource (such as optical wavelengths over the access network) and its assignment to end users and service providers.

The DISCUS architecture needs to support future ultra-high capacity networks, while encouraging service provision competition and enabling customers to access any service from any provider at any time. The aim is to achieve these objectives while minimising equipment and infrastructure build, by maximising sharing of network resources.

The business models most compatible with these objectives are the partial vertical integration of the network provider/operator and the infrastructure provider at least for the access network, optical switch layer and the access switch in the metro-core node. There would be complete separation of the service provider business, although ownership of IP layer service routers by service providers would also be compatible with such objectives.

The preferred model for network resources would be full wavelength and resource sharing so that service providers would be assigned capacity on demand and a customer with a simple single wavelength ONU could obtain simultaneous access to multiple service providers for any service at any time: that is using the time domain for dynamic bandwidth assignment and the wavelength domain for capacity management. However, this level of vertical integration would need strong regulation to ensure no restrictive practices limiting open access can be implemented and that all service providers get fair access to customers and capacity.

As far as ONU ownership is concerned end-user ownership or the network provider ownership models are most compatible with open access and service competition. Service provider ownership is instead the model that leads to less competition as it enables locking of the ONU to the provider and should be avoided if possible.

Network provider ownership of network equipment has the advantage of allowing the active equipment to be controlled by the same entity, with better management, better utilization and protection against failure. Multiple operators competing in the access network and optical and layer-2 switching space come at the expense of a less efficient network, due to duplication of equipment from different providers. Multiple network providers serving the same customer base could also restrict customer access to service providers as those service providers using only one or a subset of network operators would not be able to access customers connected via the other competing network providers. A fairer and better economic solution would be a single network provider owner but with a strong and knowledgeable regulatory environment to ensure fairness and value for money pricing. However, to have some level of competitive comparison at the network provider level a franchising system could also be considered where a network provider operates the access and metro-core node in a given geographical area, similar to the way cable operators have had franchise arrangements in defined geographical areas.

Finally, ownership of service routers is both viable for service providers and competing network providers/operators. One advantage of network operator ownership is that it can lower entrance barriers for small service providers, which in this case do not need to own their own service router. Lowering the entry cost barrier for small startup service providers could play a major role for the development of new applications and services. A flexible high capacity access network as proposed by the DISCUS project, when combined with efficient business models like the shared resources and infrastructure can lower such barriers, since new service providers can share capacity and access cost with other providers, keeping initial investment costs low and enabling a "pay as you grow" business model for startups.

DISCUS has proposed a sharing economy approach to future network provision and operation with appropriate regulation which together will maximise open access and competition for services while minimising cost for users and the risk of a digital divide. It also minimises the cost for innovative new startup service providers to obtain access to network capacity and provide services and an extended customer base.

2.2 Summary of the feedback to the white papers

This section summarises the main feedback received by the stake holders that were interrogated. We do not report the name or affiliation of the entity that provided the feedback but we provide a differentiation by category.

<u>**Telecom Regulators and government bodies**</u>:

Regulator 1 stated that the complete separation model is better than the active sharing model, because bringing competition in the active layer is important to incentivize innovation. Currently, in the rural areas the model for access sharing is based on bitstream access. This can be also up to the access point so that another operator can plug its own infrastructure. Having more operators (thus duplicated equipment) can be good for pushing innovation and bring down cost of operations.

They did not agree that a user should be charged by consumption, and initially did not agreed that users should pay for services rather than capacity, and that the service provider should then pay for the capacity to the operator. However, it seems that such an agreement was recently carried out between Comcast and Netflix, which creates a precedent for such a business model.

Besides, the following high level points were given:

The objective of rationalizing and simplifying the network architecture with rebalancing investment from core/metro towards access and sharing of infrastructure and equipment has major implications for the traditional and existing network owners. In essence this model would have most appeal if used in a government funded deployment of a national broadband plan into White areas. Additionally, any proposal in a particular country will need to be assessed in terms of a cost/benefit analysis, whereby not only would the largest player need to rationalize its network, but existing competing infrastructure players would incur sunken investment.

The option of Wavelength uses for bandwidth management or shared wavelengths (SW), though efficient and cost effective, may prove to be complex in terms of management, transparency and customer billing. Timely use of capacity auctions may prove challenging. In order to apply the DISCUS model to a national broadband plan, it would be necessary to get approval for State Aid from the EU. The European Commission is adamant that competition of networks yields the best results for consumers and productivity. Hence it is believed that the one network owner model may fall short of the desired level of competition. It would need to be proven that the level of unbundling proposed, e.g., at the services level gives sufficient control to the service provider.

The EU regulatory framework favours deployment of FTTH. However, it has conceded and is facilitating virtual unbundling. This will shape network operator investment.

The proposed model needs to consider the regulatory implications of either structural or functional separation. Economic evaluation of separation highlights both pros and cons of separation namely:

- Though vertical integration produces incentives to exclude and discriminate there are other factors which need to be taken into account.
- Vertical Integration (VI) is often thought to be cost effective and thus to reduce prices, increase volumes and eliminate double marginalisation (which is where the same services are charged for twice).
- Firms operational efficiency and investment incentives is often reduced when a network operator is not vertically integrated. However, a monopoly position tends to mean a sluggish approach to innovation, particularly where the network owner is not at the coal face of managing downstream customer needs and expectations.
- Competition usually is the best stimulus to innovation.
- Separation and indeed rationalization of networks would lead to significant costs and operational disruption in the short to medium term.

Regulator 2 is pointing out that the EU Commission has issued a new recommendation for future regulation of NGA, which has to be fully implemented by all countries at the latest by the 1st of Jan 2017. The commission has come to the conclusion that it is difficult to stimulate parallel FTTx access networks. Focus has therefore shifted from infrastructure competition to retail level competition. The incumbent has to be provide wholesale fibre on a much stricter form of Equivalence of Input (EoI) than Other Licensed Operators (OLOs), the same way as the retail arm of the vertical integrated incumbent operator with Significant Market Power (SMP). Thus, the SMP operator needs to provide the OLOs and its retail arm with exactly the same product/service/input to exactly the same wholesale price. This in return will allow National Regulatory Authorities (NRAs) to lift the wholesale price regulation of passive and active fibre. Moreover, NRA needs to conduct a Margin Squeeze test at the retail level of certain products. This means that the SMP operator must keep a certain cost margin between its retail and wholesale price. This Margin will be set by the NRA and it must allow OLO to buy the FTTx at the wholesale price set by the SMP and sell the same "flagship" products as the SMP operator such as triple play at the retail market with profit. A prerequisite to making profit is that there is enough margin between the retail price and the wholesale price of the vertical integrated operator. In this sense it will be important to calculate cost of the customer-premises equipment (CPE), active equipment/service platform/retail and sales cost. This new form of regulation will change the incentives for the network owner to own the CPE.

As it is now in some countries, the first ONU is paid by the network owner. In this sense a very expensive set-top box (STB) for example will decrease the margin, which is not good for the network owner, but could still be a barrier for the end user to switch network provider.

It is pointed out that IP-TV is an important service different from others since it requires so much scale of economy to provide. On the other hand, the DISCUS network model is in some sense similar to the model with Communications Operators (CO) in countries like Sweden. For example, in many locations passive fibre network is owned by the municipality (infrastructure owner), where the CO is a network provider, and there are several service providers in the portal of the CO that the end user can choose between and actually switch between them dynamically. For this model to succeed the CO needs to have a strong provider of IPTV, which requires substantial investment and it is the most expensive service in triple play. Only few operators can provide IPTV at a reasonable cost because they already have a strong customer base. This is required in order to manage the high cost of backhaul, in a multicast network. If a CO cannot include a strong IPTV provider it becomes difficult to sell the other services, which may make it difficult for the CO to survive. End user wants to buy services in bundle where TV is an important service. It is relatively easy today for service providers to enter the portfolio of a CO and offer their services on layer 3 to end users, however the profit margin is also very low for these service providers since the major part of the profit goes to the infrastructure owner and the CO.

Feedback from the government telecommunication department

The department does not support the idea of having only one regulated active operator, because it leads to a regulated monopoly that will hinder innovation, as well as the use of sub-optimal processes, therefore it might void the economic advantage that was gained from the higher efficiency in matching passive and active layers.

When considering open access there is a security issue about the infrastructure, in terms of letting a number of different operators get access to the physical infrastructure (both passive and active). It's also an issue of liability. The liability assurance might be too high for a small operator.

Moreover, one cannot easily prevent an infrastructure competition, even where a monopoly was decided. Also, only having one network operator might create resiliency issues at a policy level. A typical case is if the network operator goes on strike.

In terms of state aid, there are general EU rules that apply, and the conditions imposed might be not be very attractive to investors.

Feedback from three telecom operators

The feedback of telecom operators is bundled together in order to provide a coherent summary of their view.

The main points raised were the following:

- There was disagreement on the idea of zero infrastructure competition, as it was deemed this would not promote innovation through competition. They suggested that while there might be one owner of passive infrastructure for a given area, competition should be promoted at the active layer.

- There was uncertainty on the benefit of providing users with the ability to change service provider for any service on the fly, and also the possibility of having multiple service providers at the same time was questioned. The reason being that it is deemed that users might prefer bundled and convergent offers (e.g., TV, Internet, fixed phone and mobile services).

- It was suggested that case studies be carried out to understand whether different business models have worked in the field. These should include any case of full separation, as well as vertical integration, as that seems to be still a quite successful model.

- It was also suggested to analyse pros and cons on the way copper unbundling was implemented, in order to learn from the past, for applying unbundling to fibre networks.

- Another consideration was the fact that regulations are not very stable in Europe and this creates uncertainty on the operators for making investments in the fibre access network.

Feedback from three telecom vendors

The feedback of the telecom vendors is also bundled together in order to provide a coherent summary of their view. Some discussion points were similar to those previously introduced, so we only report items that have not been previously introduced.

The main points raised were the following:

- The idea of having wavelengths per service type or shared wavelength might require an entity mastering the PON, in order to allow controlled access to the network. It seems this entity should be the Network Provider, although it is not clear how this access type can be regulated. In addition, it should be noticed that regulated prices tend to be higher for customers than prices set by a competitive environment.

- The idea of a fixed-wavelength ONU can be removed as the idea of tuneable ONU is already accepted in the NG-PON2 standard.

- There is reason to believe that enforcing open access to fibre infrastructure will reduce incentives for an operator to install fibre access infrastructure.

- Having only one NP would require approval by EU convincing them that competition at service level is enough. Physical layer competition is important for innovation.

- Vertical integration vs. separation is a very open question. The former is considered cost efficient (increase volumes and eliminate double marginalisation), however it creates a monopoly that will demote innovation and decrease the value of the service to the user.

- If the ONU is owned by the end user, there is likely to be interoperability issues between OLTs and ONUs, and would require a stronger standardisation of the ONU.

- Open access will bring issues with the access of the physical layer by different entities, such as security and intervention-induced faults.

Overall we have received very interesting feedback, much of which has converged towards a number of key topics. While it is not possible to tackle all the comments received, especially as many of the comments touch questions that do not have an answer yet, we have decided to investigate a number of case studies around the world in order to assess issues and solution carried out in different parts of the world.

The next session targets a number of case studies. The first part focuses on a detailed study of how an incumbent operator network satisfies the open access requirements and also discusses operations of Local Loop Unbundling and Bitstream services. The second part provides a general overview of access sharing case studies for a number of countries around the world.

3. Case studies:

3.1. Vertically integrated operators

This first section reports a detailed study on the Telecom Italia network, describing how a vertically integrated operator would typically open an FTTH network to other operators when required by the national regulation authority.

3.1.1. Local Loop Unbundling

The idea under local loop unbundling (LLU) is to put under regulatory ex-ante surveillance economic non replicable assets. Under this basis, for more than 10 years unbundling has been applied to telecommunications aiming to stimulate competition. However, despite its assumed positive effects on market entry and competition intensity, the negative effects on network investment incentives are widely shown in the literature.

The rationale for access regulation is to increase competition and therewith improve efficiency and social welfare. Considering a static situation, with open access to competitors, competition is increased, which decreases prices and margins, finally leading to a higher consumer demand. In a dynamic environment (which is usually the case for telecommunication markets) the unbundling might bring some benefits for citizens, but the relationship between access regulation and welfare is more complex. The effect of unbundling can be positive, since open access to the physical infrastructure (copper pairs) reduces market entry barriers and, as a consequence, many actors can play in the telecommunication arena bringing potentially a twofold goal: the services price decrease for consumers and a greater innovation in offered services (both driven by tough competition). On the other hand, new entrants might see lower incentives to invest in their own network since the infrastructure can be leased from incumbents at prescribed prices and incumbents are not pushed towards new investment on the infrastructure since it is not a source of large revenues for them.

Experts, using a panel of European countries for a time period of 17 years, affirm that the effect of unbundling on telecommunications services penetration is positive when a moderate level of broadband take-up has been reached in a country. However, this impact turns damaging if the initial level of broadband penetration is either rather low or is high [1]. These observations lead to the confirmation of the negative effects on investment incentives, but may positively lower prices to favour increased demand. These are the two forces which should be carefully taken into account by policy makers when deciding on unbundling policies.

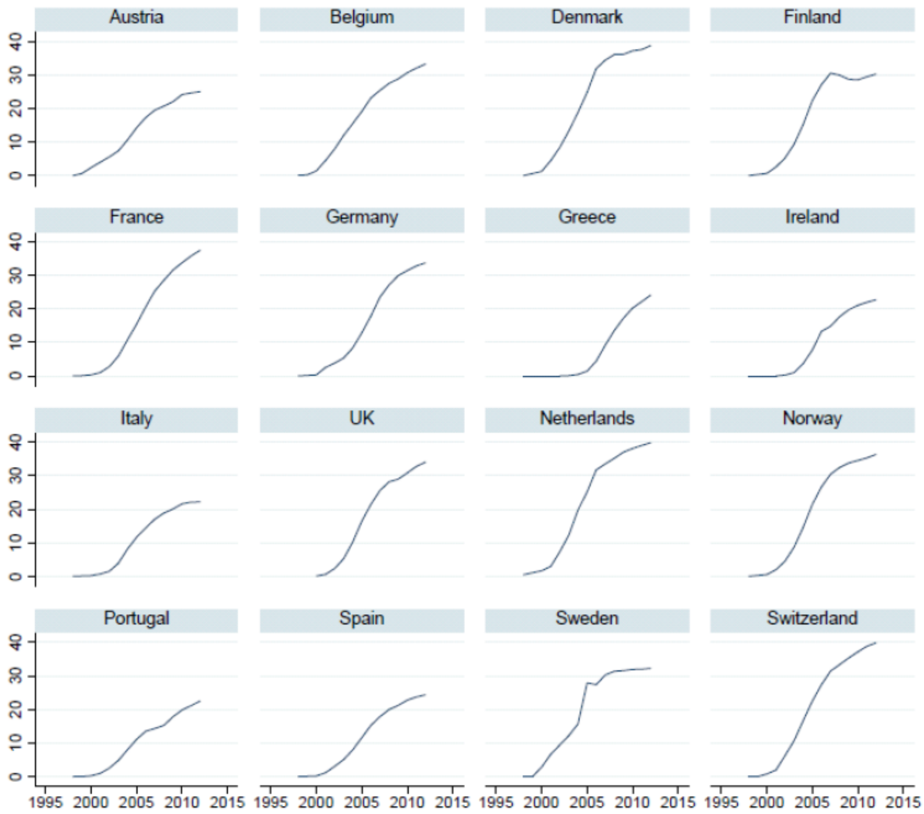

Figure 31 - Fixed broadband subscriptions per 100 inhabitants over time (source ITU-T)

Figure 31 shows statistics on ICT access for European countries on an annual basis and provides us with the broadband penetration in terms of subscriptions per 100 inhabitants, provided by the International Telecommunication Union (ITU) (mobile broadband is not considered in these figures). The result is that for every country the broadband penetration develops in an S-curvature. Considering the introduction of Local Loop Unbundling (LLU) and Bitstream Access (BSA), we notice an important difference in the amount the new entrants have to invest to get access to the incumbents' network.

Local loop unbundling requires the entrants to build a core network down to the local exchanges of the incumbent operator, and to install their own broadband equipment. Otherwise, with Bitstream access the entrant leases access to the incumbents' high bandwidth architecture. Therefore, Bitstream Access is a type of retail unbundling. Since for Local Loop Unbundling a higher level of investment is necessary, w.r.t. Bitstream Access, this latter increases retail competition more quickly.

By a detailed observation of Figure 31, it is possible to note that, as a side result, the long-run effects of LLU are different to those of BSA. While more positive long-run effects of LLU are evident, BSA seems to have negative long-run effects on developed networks.

Table 1 - Introduction Dates Local Loop and Bitstream Access

Country	**Full Unbundling**	**Bitsream access**
Austria	1999	2000

Belgium	2000	2001
Denmark	1998	2000
Finland	1996	2004
Germany	1998	2006
Greece	2001	2006
Ireland	2001	2000
Italy	2000	2000
Netherlands	1999	2003
Norway	2001	2001
Portugal	2001	2000
Spain	2001	1999
Sweden	2001	2004
Switzerland	2007	2007
UK	1999	2004

To complete the analysis Table 1 shows the formal introduction of Full Unbundling Bitsream access in different European countries (the particular introduction date is taken from OECD (2005), Cullen International [2]).

In European Countries the telecommunication sector widely adopted a regulatory approach, which includes the idea of a "ladder of investment," as proposed by [3]. This concept should reproduce the idea that entrants acquire, as a first step, access to the incumbents' infrastructure at a level which typically needs little investment to provide immediately a service (for instance bandwidth resale). New entrants are supposed to climb this ladder from this time, motivated by increasing prices and therefore revenue as the steps are climbed. If the real validity of the ladder of investment is stimulating new entrants, the empirical evidence did not verify its clear presence [4] and practical problems in its implementation exist. One problem is that this approach is clearly in favour of entrants, while incumbents (that should increment investments in new lines) have no interest in new infrastructure investments with its poor return on the capital required for such investments.

In conclusion, local loop unbundling permits new competitors to enter the telecoms broadband service provision markets by using parts of the incumbent's network infrastructure, namely the access copper pair between local exchange and customer premises. The aim is to support to increased competition and also produce complementary investment in final customer's markets. On the other hand however, investment incentives of incumbents are lowered, which may have had negative long run effects on the overall broadband penetration.

3.1.2. Bitstream and Virtual Unbundling Line Access (VULA) services for open access

The Bitstream NGA (New Generation Access) and VULA (Virtual Unbundled Local Access) services enable all licensed OLOs wishing to offer ultra-broadband services to their end customers to re-use the New Generation Network of an incumbent operator without having to deploy their own access networks. The services provide all the technical and operational elements to allow OLOs to connect their own backbones to the Incumbent Operator ultra-broadband access network. The Bitstream NGA and VULA offers can provide ultra-broadband services that can fit the specific technical and commercial needs of any OLO.

3.1.2.1. The Bitstream NGA service

The Bitstream NGA service consists of the provisioning of packet switching bandwidth from an end user to an OLO's backbone. The Bitstream NGA reference network architecture for Telecom Italia is shown in Figure 32, its supply chain is made of the following main elements:

- Delivery
- Backhaul
- Access.

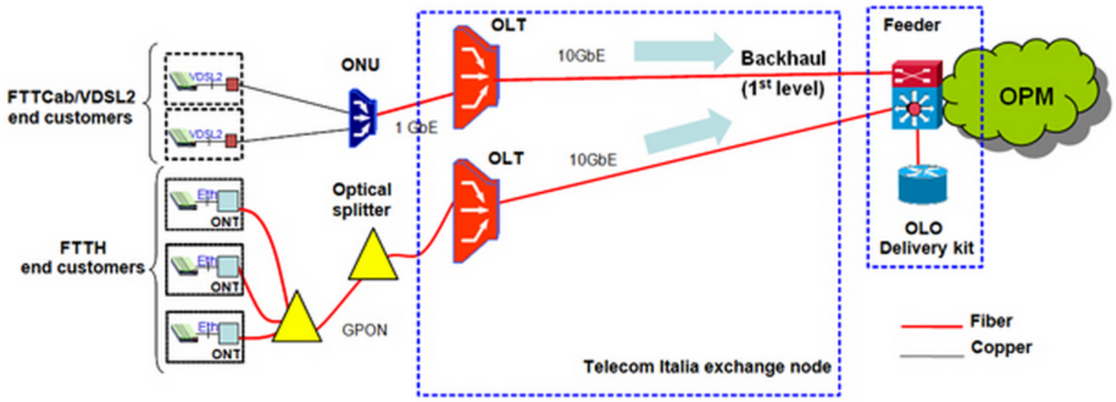

Figure 32 – Bitstream NGA reference architecture

3.1.2.1.1. Delivery

Traffic delivery to the OLO can be done through different kinds of connection to the network owned by the Incumbent but it always requires the use of a proper dedicated end device usually owned by the OLO (though the Incumbent Operator also offers the possibility to share end devices among different OLOs), that must be connected to specific nodes of the incumbent's network that are designed for this purpose. The delivery end devices work as "edge" devices for the OLO's network, and are used to make the Incumbent and OLOs networks mutually independent.

As an example, the available kinds of connection to Telecom Italia network is reported as follow:

1. Connection to Parent Node: A "Parent" node is the first node of the Telecom Italia network that can be found from the exchange node where an OLT is located moving outbound towards the network (i.e. it is the Telecom Italia node that a node containing an OLT is directly connected to). OLOs connected to Parent Nodes can only collect traffic from exchange nodes directly connected to them (the whole of which is called an "Area di Raccolta" or "Collection Area": any Parent Node has its own "Area di Raccolta"). Traffic carried from Parent Nodes only includes (and charges) the backhaul from the OLT to the Parent Node itself (also called "First level Backhaul"), but does not include traffic among different nodes of the Telecom Italia network (which is called "Second level Backhaul").

2. Connection to Distant Node (also known as "Macroarea Collection"): through this kind of connection, OLOs can collect traffic coming from/going to any exchange node included in the "Collection Macroarea" (also called "Macroarea di Raccolta") the Node belongs to (where a "Macroarea di Raccolta" is formed by a specific set of "Collection Areas"). For the scope of the Bitstream NGA service, the Italian territory is divided into 30 "Macroarea di raccolta", so extending the set of exchange nodes from which traffic can be collected. Traffic carrying for this kind of connection includes (and charges) both the "First level Backhaul" and the "Second level Backhaul": the latter because of the need to carry traffic through different nodes of Telecom Italia network that are located in the same "Collection Macroarea"). To get the Bitstream NGA service through connection to Distant Node, OLOs must specifically request its delivery kit to be a "Collection Macroarea" kit when applying for it. Any Telecom Italia connection node that is suitable for Bitstream NGA delivery can be used for connection to Distant Node. Note that the Telecom Italia nodes to be used for the delivery of the VULA service described in the following cannot also be used to deliver Bitstream NGA. The Bitstream NGA service, when delivered through connection to Distant Node, can also be used to collect traffic from/to different "Collection Macroareas" in a single delivery kit: in this case, the service additionally charges traffic carrying through different "Collection Macroareas" (that is called "Long Distance Backhaul").

3. Connection to IP Node. Through this kind of connection, the traffic carrying to the OLOs backbone goes through the IP backbone of the Telecom Italia network.

When either the connection to Parent Node or the connection to Distant node is adopted, some Incumbent operators offer the possibility to deliver both the Bitstream NGA and the Bitstream Ethernet on the same delivery kit, provided that the proper conditions are verified to do so.

3.1.2.1.2. Backhaul and traffic carrying through different feeder nodes

The backhaul component is the traffic carrying entity from the end customer access line to the OLO network. Different models are available for traffic aggregation, together with different Classes of Service (CoS).

For traffic aggregation, the following models are available:

- "Shared bandwidth": Through this model, the OLO requests a desired amount of bandwidth that will be used to deliver and carry traffic of more than one end customer access line. The available bandwidth is managed through a contention model among the access lines.

- "Dedicated bandwidth": Each access line has its own dedicated bandwidth.

Regarding the Quality of service management, in general two models of CoS models are available:

- "Single-CoS": Traffic is carried using one VLAN for each CoS value, i.e. for each Class of quality. This model is available only with the shared bandwidth aggregation model. The available CoS values[1] are 0, 1, 3, 5.

- "Multi-CoS": Traffic is carried using multi-CoS VLANs (i.e. VLANs with more than one different CoS values). The multi-CoS model is available for both the traffic aggregation models, and the available CoS values differ depending on the aggregation model itself, so having:

    - Shared bandwidth multi-CoS model: the supported CoS values are 0, 1, 3, 5

    - Dedicated bandwidth multi-CoS model: the supported CoS values are 0, 1, 2, 3, 5, 6

The OLOs can request bandwidth changes at any time and it will be provided without interrupting the service.

3.1.2.1.3. Access

The access portion is the link between the end customer and its associated exchange node (owned by the Incumbent where the OLT is located), and varies according to the access technology on the customer side:

FTTCab/VDSL2: like ADSL lines, the end customer has a local loop through which it can use both the PSTN service (that may also be offered through the Wholesale Line Rental (WLR) service and data connectivity service, the latter in VDSL2 technology (Very High Speed DSL 2). Data connectivity service requires the customer to have a VDSL2 modem (not included with service provisioning). The customer local loop is terminated on a cabinet (typically located near the customer home/office) on the top of which an ONU (Optical Network Unit) is installed. ONUs terminate the copper pair via a low pass filter

[1] CoS values are defined according to the 802.1D standard. Numbers are ordered so that 0 is he lowest priority and 7 the highest.

that separates the baseband voice channels (where active), which are subsequently terminated on the phone exchange (owned by the Incumbent), from the ultra-broadband data channel. The ONUs in turn are connected through fibre links to their associated OLTs (Optical Line Termination), that are usually located in the same Incumbent's phone exchanges where PSTN lines are terminated (but not always). The OLTs terminate the ultra-broadband channels.

VDSL2 access lines can be requested both in "shared mode", i.e. sharing with the PSTN/WLR service (but NOT with the ISDN service, which requires an additional dedicated line) and in "naked" mode, i.e. without any PSTN service associated.

The following Figure 33 shows the VDSL2 access architecture.

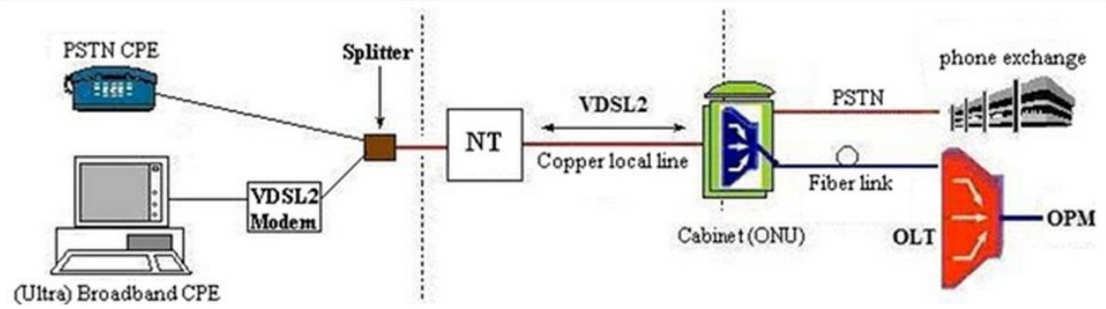

Figure 33 – FTTCab/VDSL2 access architecture

The demarcation point between the Incumbent operator and the OLO is the network termination (NT) located at the end customer's home/office, where the VDSL2 modem is connected.

FTTH: The end customer has a fibre in its home/office. When the access line is activated, the Incumbent Operator will bring and install an OTO (Optical Telecommunications Outlet) and an ONT (Optical Network Termination) in the customer's environment. The Customer Premise Equipment (CPE) that will be connected to the ONT is not included with the service provisioning). The fibre in the customer's living environment is terminated on an OLT located in the Incumbent's exchange node, according to GPON network architecture.

FTTH access lines can be requested only in "naked" mode, i.e. without a PSTN component. Figure 34 shows the FTTH access architecture.

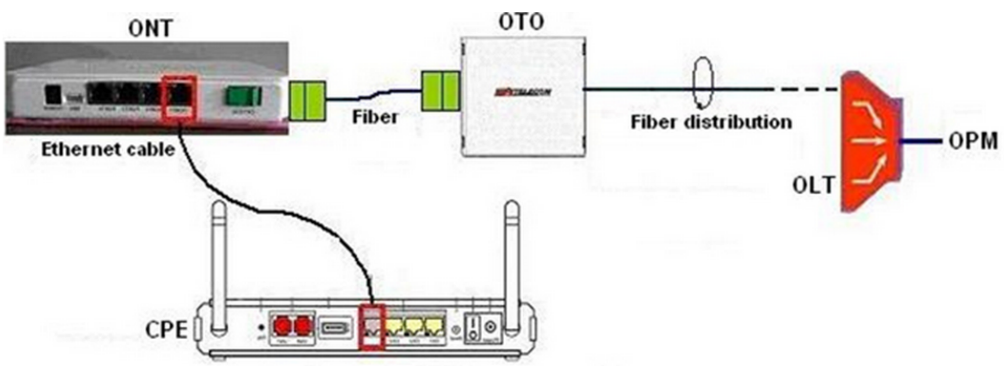

Figure 34 – FTTH access architecture

Different profiles are available for VDSL2 and FTTH accesses: at present, only asymmetric profiles can be requested for VDSL2 (with downstream speed greater than upstream speed), while both asymmetric and symmetric profiles (upstream speed equal to downstream speed) can be requested for FTTH.

Moreover, up to 4 User VLANs can be associated to any access line: they can be either single-CoS or multi-CoS VLANs, but it is requested that they fit the backhaul traffic model the access line has been associated with.

3.1.2.2. The VULA service

The VULA (Virtual Unbundling Line Access) service is about the same as the Bitstream NGA service, except for some specific aspects that are detailed in the following.

The service supply chain is again made of the 3 main elements: delivery, backhaul, access. The reference network architecture is shown in Figure 35.

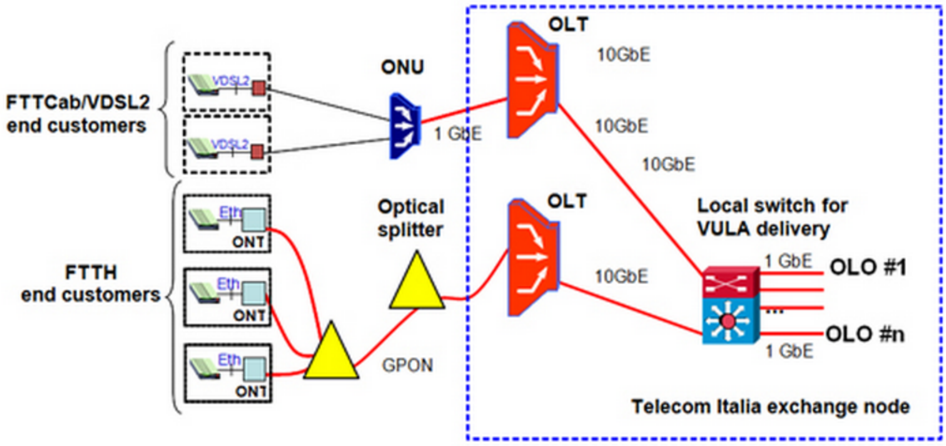

Figure 35 – VULA reference architecture

3.1.2.2.1. Delivery

Traffic delivery to OLOs is done uniquely at an "exchange node level". In other words, the VULA service allows OLOs to collect only traffic from/to end customers of any single exchange node where an OLT is installed. Any OLO wishing to use VULA to collect traffic from/to more than one exchange node will have to request VULA delivery for each desired exchange node.

Unlike Bitstream NGA, the VULA service is not delivered through end devices dedicated to OLOs: instead, in each exchange node where there is an OLT at least, the incumbent operator will install a switch that will be dedicated to VULA delivery; the switch will be shared among all the OLOs requesting VULA delivery for that exchange node, and won't be connected to the other nodes of the Incumbent's network.

3.1.2.2.2. Backhaul

As for traffic aggregation and quality management, only the "Dedicated bandwidth multi-CoS model" is available for the VULA service. Besides, it is important to point out that unlike the Bitstream NGA service, the backhaul bandwidth component is not charged at all in the VULA service.

3.1.2.2.3. Access

The access component of the VULA supply chain is exactly the same as the Bitstream NGA access component, except that the only kind of allowed User VLAN for the access lines is the dedicated bandwidth multi-CoS.

3.1.3. A causal analysis of NGN investment: FTTH case in Spain

Entrepreneurs are constantly looking for new opportunities for profits, that is, gaps between current and expected prices of resources, which is achieved by market calculation guiding investment decisions. The market competition can be understood as a process of discovery generated by entrepreneurs. Detecting a profit opportunity is to detect a more valuable use for a commodity: the entrepreneur acquires the supposedly undervalued resource and mixes it with other resources in the productive process, then sells the product at a price allowing recovery of the investment with interest rated over the period of the venture. If, after the process, a profit remains, it means his anticipation was correct and the commodity is more valuable in the new use. Profit opportunities depend on the gaps between current prices of resources and expected prices of them.

In this section, we provide a causal analysis of the FTTH deployment in Spain considering the market competition as a discovery process and its relation with the regulatory situation.

3.1.3.1. Possible negative effects of regulation in the market discovery process

According to Kirzner analysis [5], regulation alters opportunities for entrepreneurial gain, and influences the prices emerging from entrepreneurial competition. The competitive-entrepreneurial process, being a process of discovery of as yet unknown opportunities, can hardly be predicted in any but the broadest terms. The imposition of regulatory constraints may result in a pattern of consequences different from what would have occurred in the unregulated market. Kirzner identifies four categories for impact regulation on the discovery process:

1. Undiscovered discovery process. Regulators may not correctly address what would have been the market course in the absence of regulation.
2. The un-simulated discovery process. The regulation process cannot simulate the market process, because regulators have no incentives for conventional profit seeking. In consequence, it is very unlikely that they are able to discover opportunities that the market process has not already discovered.
3. The stifled discovery process. Regulation may inhibit, discourage or hamper the discovery processes which the market might have generated. For example, price ceilings may not only restrict supply from known sources, but also inhibit the discovery of wholly unknown sources.
4. The wholly superfluous discovery process: Regulation may create opportunities for new market discovery process which would not be relevant in an unregulated market. Regulation constraints introduce profit opportunities that otherwise would have been absent. Such consequences may be wholly undesired by authorities.

3.1.3.2. Effect of Unbundled Local Loop (ULL) regulation

Around 2000, public internet access started evolving to DSL based services supported on the incumbent copper network. At the same time cable-based access was also available in the coverage areas of cable-operators.

The Spanish NRA, the CMT, approved in 2000 made Telefonica provide wholesale access products at regulated prices. By that time Telefonica already had the obligation to provide indirect access (bitstream) for broadband to its copper network (known as GigADSL). The evolution of wholesale broadband and penetration are shown in the following graphs:

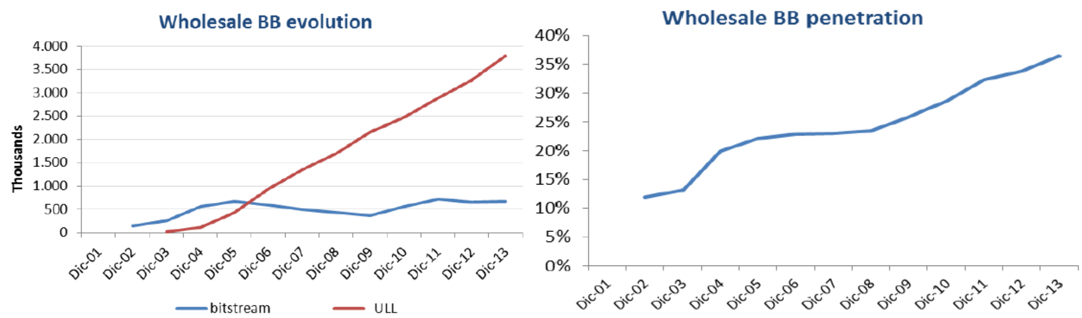

Figure 36 Wholesale broadband evolution and penetration in Spain (Source: CMT)

The concept of ladder of investment was originally proposed in [3]. The idea is to force incumbent operators to open several levels of access to their network in such a way that alternative operators may climb up the ladder using more of his own infrastructure, and thus decreasing their reliance on the wholesale products on the incumbent operator, once he has captured the appropriate number of customers to profit from the economies of scale of the investment.

However, even with the spectacular increase in wholesale broadband evolution, no progression to the last step of the ladder of investment took place, and as late as 2013, no ULL-based operator had deployed any direct access to provide services. None of the main operators providing broadband access based on ULL services in 2007 (Orange, ya.com, Tele2, Jazztel) had deployed any direct access on 2013, six years later.

ULL Regulation seems to have stifled the discovery market process, discouraging alternative operators to invest in new networks and inhibiting the discovery process of unknown sources.

3.1.3.3. Effect of FTTH bitstream regulation

In 2009, CMT decided against imposing a regulated wholesale access service to Telefonica FTTH Network for speeds above 30 Mbps. For several years this situation has caused alternative operators to abandon the strategy of "wait-and-see" hoping that CMT would force Telefonica to offer regulated wholesale services above 30 Mbps. The successful launch by Telefonica of the first 4-play products in Spain have also been a strong driver for them to act and not depend on favourable regulation. Not being able to imitate the Telefonica product by using regulated services, specifically for bundles with FTTH, they started to look for alternatives to serve the customer. This has sparked a dynamic competitive process of discovery that had been absent in the Spanish telecommunications market for most of the history of ULL.

Jazztel was the first to react, starting its own FTTH network for around 3 million households in cooperation with Telefonica. Vodafone and Orange initially reacted by signing a similar agreement. Vodafone eventually acquired ONO (a Spanish cable operator) in 2014 as a means to bundle its mobile services with fixed services of similar speeds to those of the Telefonica FTTH network, protecting the value of its mobile network and customer base.

The following figure shows the NGA (Next Generation Access) deployments evolution in Spain with the regulatory environment established in 2009. The FTTH evolution both for Telefonica and other FTTH operators is remarkable.

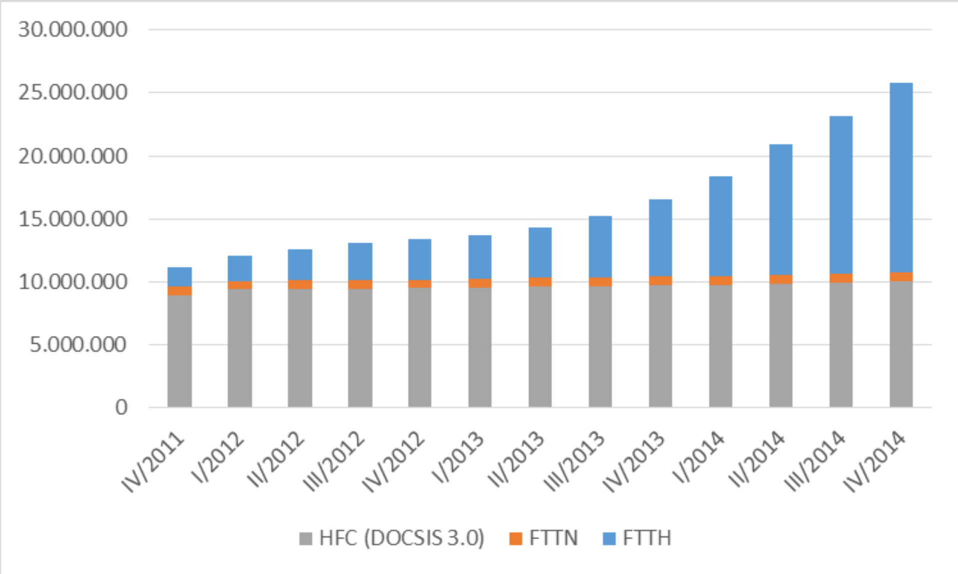

Figure 37 NGA accesses installed in Spain (source: CNMC)

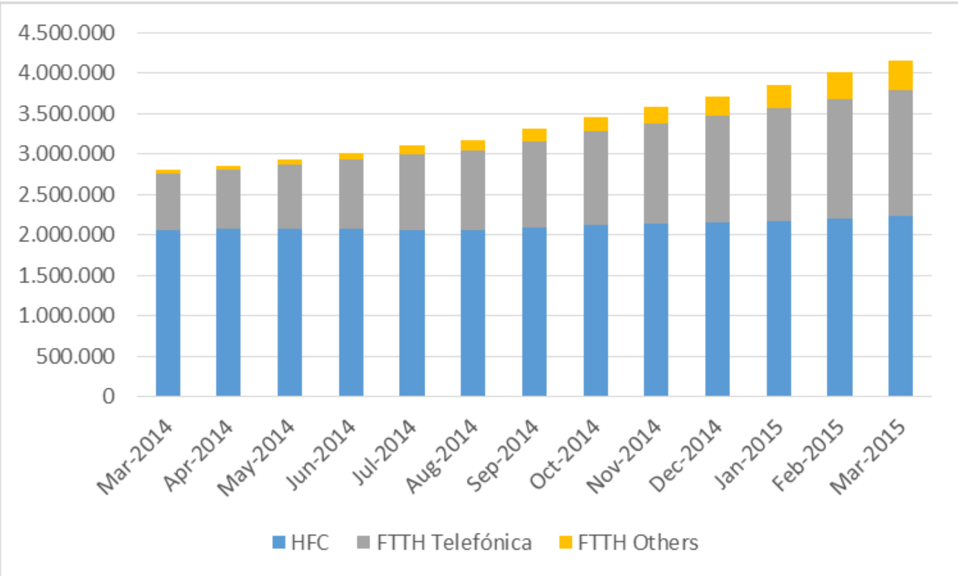

Figure 38 NGA subscriptions in Spain (source: CNMC)

Summing up, it has been shown that there seems to be a causal relationship between the lack of regulation on access to Telefonica FTTH network above 30 Mb/s, and the consequent investment by ULL-based operators after that regulatory decision. Before the FTTH deployment of Telefonica, deployment of infrastructure by alternative operators was not necessary because entrant operators could completely rely on the Telefonica network to provide ULL-based services.

The analysis of similar cases in other European countries can also be found in [6].

3.1.3.4. Effect of Virtual Unbundled Loop Access regulation

In 2013, the Spanish NRA re-organized internally and formed the CNMC, which in 2014 proposed a new regulation for residential broadband access.

In its recent analysis in December 2014, the CNMC confirmed that the previous analysis of the market for broadband access competition was still valid (Telefonica still losing broadband share even in the areas with significant competition). Nevertheless, the new CNMC regulation updated the criteria for significant market power analysis considering the new operator's consolidation (Vodafone-ONO and Orange-Jazztel) and included the deployment of Next Generation Access (NGA) in the analysis for its new regulation proposal.

In the new analysis, CNMC only found 9 cities (16% of the population in Spain) with relevant NGA competition between the incumbent and alternative operators. In the rest of the country, CNMC identified Telefonica as the operator with significant market power, and as a consequence it proposed the obligation on Telefonica of providing a Virtual Unbundled Loop Access to other operators for residential broadband access in the corresponding areas, avoiding the limitation of 30 Mb/s speed of the previous regulation scenario. On the other hand, CNMC proposed to eliminate the restriction to Telefonica of allowing closing central offices only if at least 25% of customers had connections different to copper. This new regulation proposal is currently in a period of comments and claims.

While the intention of the new regulation is trying to push a good competitive scenario, it seems from the historical evidence that the VULA obligation may have negative effects on good competition at the infrastructure level and the high levels of investment for FTTH deployments in Spain shown before this new regulatory analysis.

3.2. Case studies based on shared ownership models

The following sections report on a number of case studies from different countries around the world. While the list of countries and the examples reported inevitably address only a small number of case studies, they are indeed valuable to assess what type of deployment strategies have been adopted worldwide.

3.2.1. Europe

3.2.1.1. Sweden:

The main references for analysing case studies in Sweden were taken from [7]-[16]

Stockholm

Sweden and especially the city of Stockholm has been among the first to establish fibre access networks. Since the council of Stockholm had the firm conviction that access to broadband communication should be a public utility, the idea of "open access" has played a significant role with regard to the deployment of the network.

The Stockholm fibre network is owned by a company called Stokab which is fully owned by the city. Stokab's origin dates back as early as 1994. Originally only government and public organisations have been connected to the network. Then business users have been added and only in the last step private customers gained access to the fibre network. This allowed the company to expand the network using the cash gained from the early customers. Only these revenues and loans have been used to finance the network, without using any other state funds. Stokab has been profitable most of the time from the beginning until today.

Stokab provides access to dark fibre in a point-to-point (P2P) configuration to over 100 network operators and 700 service providers. Today all major telecom companies are among its customer base, including the incumbent TeliaSonera, Telenor and Tele2. All city-owned housing companies have connected their buildings to the Stokab network and even extended the fibre to single apartments. The fibre ends at demarcation points in separate communication rooms, e. g. in building cellars. Here network operators can establish their active equipment and connect to the home network and also to neighbouring MDUs. Homeowners are responsible for the in-house cabling. To attract private customers they have even been offered a small incentive of SEK 500 (≈ € 60) if they connect their properties to fibre.

Although the Stokab network is based on the idea of a fully separated structure all types of business models coexist.

Today, roughly 90% of all Stockholm's households and nearly all companies are connected by fibre with peak access speeds of up to 1 Gb/s. In Stockholm, these 90% of households live in multi-dwelling properties, and only these have been connected to the Stokab network. Up to now no single dwelling private residents have access to the network because that is still seen as too expensive.

Today in Sweden altogether more than 200 of the overall 290 municipalities have established local fibre access networks under the open access regime. Most of them are point-to-point fibre links (active Ethernet). Only a smaller part is realized using PON systems.

Västeras

Another well-known example of an open access network is the one in the city of Västeras 150km west to Stockholm. In 2000 the city tasked its power utility Mälarenergi with the responsibility of building and operating such a network. The utility created a subsidiary called Mälarenergi Stadsnät. This unit owns the fibre infrastructure and also acts as network operator selling wholesale services to separate service providers.

The architecture chosen is an active Ethernet topology. Data rates for customer connections are mainly 100 Mb/s.

The deployment started with business properties and then (beginning 2003) has been extended to residential homes. The early cash from businesses provided the necessary money for the extension of the network. But it has been realized that a return on investment would not be possible in a reasonable time frame from just wholesale fees. So another business model was set up where the property owner has to pay a significant amount (SEK 30,000 – about €3,200) for the physical connection to the network. Additional they have to buy services from the service providers. Nevertheless, this business model has been successful. Today, they count more than 35 service providers.

The Mälarenergi Stadsnät has evolved in 2014 to Stadsnät i Svealand AB which covers the three neighbouring municipalities of Arboga, Hallstahammar and Eskilstuna which are new shareholders.

3.2.1.2. Netherlands

The main references for analysing case studies in the Netherlands were taken from [17]-[28].

In the Netherlands there are examples of open access networks on a local level (Amsterdam, Rotterdam, Almere, Nuenen, etc.) as well as on a national level (Reggefiber/KPN).

A famous example is the city of Amsterdam. In 2006 the company "Glasvezelnet Amsterdam" (GNA) was founded to build the "Citynet Amsterdam". The owners of this company were the Amsterdam City Council, a conglomerate of several large Amsterdam housing companies and the ING Real Estate Investment Management/Reggefiber each holding one third of the capital on an equal basis. This project is realized as a public-private partnership (PPP). It has been confirmed by the European Commission in 2007 that the investment of the Amsterdam municipality has not been a forbidden state aid (according to European law) but has been undertaken according to the Market Economy Investor Principle (MEIP). That means the municipality acted in the same way as a private investor with the identical risks and obligations.

Glasvezelnet Amsterdam owns the passive infrastructure. It is leased to BBned (originally 100% ownership of Telecom Italia, today owned by Tele2) as a network operator who must provide access to service providers. They were originally granted exclusivity until 2009, but now there are multiple operators. KPN also acted as a service provider from 2009 onwards and started as network operator in 2010.

Citynet Amsterdam is realized in a point-to-point topology with two fibres to every home. This topology has been chosen because it allows for easy local-loop unbundling.

Other examples for local open access networks are the Almere UNet where the municipality owns the infrastructure and rents dark fibre to network operators and the city of Nuenen's OnsNet which was one of the very first networks.

On a national level a new entrant to the broadband market was the Reggefiber company whose intention was to establish FTTH networks under an open access regime. Reggefiber has been founded by Reggeborgh, a housing/construction company. Later it has become a joint-venture with KPN who took over a 49% share. Today Reggefiber is under 100% ownership of KPN.

The access network also is built with PtP topology to allow for easy local-loop unbundling. Two fibres per home have been deployed – one for broadband applications and one for analogue TV.

As a basic success factor it is seen (in the case of Amsterdam as well as on the national level) that deployment starts only if and when 30 – 40 % of the home owners have signed a subscription. This aspect is also seen in other countries as a basic requirement for commercial success. E.g. the Deutsche Telekom is also requiring a 30 – 40 % pre-deployment subscription ratio before starting a local rollout. In the US Google Fibre has a similar strategy. In this way it is secured there will be adequate cash flow right from the beginning.

3.2.1.3. Switzerland

The main references for analysing case studies in Switzerland were taken from [29]-[38].

In Switzerland there has already been very good broadband provisioning due to a strong competition between the incumbent telco Swisscom and the cable network providers. About ten years ago Swisscom wanted to establish fibre optic access networks in the country in order to withstand or even get an advantage over the competition. At the same time local utilities wanted to extend their business case and also invested in optical access networks in their respective area of activity. They intended to build a single fibre open access solution. In this situation the Swiss regulator ComCom arranged a round table group including Swisscom and the utilities to discuss a common solution. At the end, all agreed voluntarily on a 4-fibre approach which is unique worldwide up to now and which is being observed carefully on a global level.

According to the model Swisscom and the utilities will build a fibre-optic access network in cooperation in a number of cities (15 in 2012, among them Zurich, Basle, St Gall, Berne, Geneva). Either Swisscom or a utility will actually organize the construction work at any given location. The cooperation agreement then requires that 4 fibres per apartment are installed (plus further 4 fibres per MDU). This is done in a PtP-topology. One fibre is attributed to Swisscom and another fibre to the utility. The remaining two fibres are reserved for other competitors who can buy these fibres. That is possible for a complete area only and not for single buildings to avoid cherry picking.

The situation now can be seen as infrastructure competition with an open access regime. Special attention has been paid to the standardization of the access to the premises and the in-house cabling system especially with respect to proper handling of the four fibres.

In 2014 Swisscom announced that they will offer a 1 Gbps connection (PtP) to all connected subscribers.

3.2.1.4. France: Pau-Pyrenees

The main references for analysing case studies in France were taken from [39]-[42].

The very first FTTH deployment in France has been the network established by the city of Pau located on the northern edge of the Pyrénées. The project (also known as Pau Broadband Country) covers Pau and the surrounding area and has been started in 2003. The chosen technology is a PtP active Ethernet architecture. Network owner is the Agglomération of Pau-Pyrenees, a group of 14 neighbouring municipalities in the department of Pyrénées- Atlantiques. Axione operates the network, responsible for design, engineering, installation, operation, and maintenance. The network is open to competing service providers, amongst them e.g., SFR-Cegetel and Heliantis.

Due to the very early deployment the success in terms of connected homes has been very limited at the beginning when the benefit was not realized. Not until the potential internet services became better known the network attracted more and more customers. At the end of 2011 55,000 homes out of about 70,000 have been passed and 11,000 connected.

3.2.1.5. Spain: Asturcon

The main references for analysing case studies in Spain were taken from [43]-[49].

The Principality of Asturias is an autonomous community located at the Spanish north-west coast. This area has suffered from economic downturn in the past. To improve the situation and attract new businesses the government of the Principality of Asturias intended to invest in the telecommunication infrastructure which is seen as a public infrastructure. Other operators had not shown any interest in deploying an alternative broadband access network than the available DSL ULL connections. The new network should be an open access network open to all service providers and managed by a public operator.

This led to the birth of the first FTTH network in Spain. The deployment was financed in part by the Principality of Asturias and in part from the European Regional Development Fund and from a national fund. The neutral public operator is called GITPA (Gestión de Infraestructuras Públicas de Telecomunicación del Principado de Asturias). Originally all homes in towns with more than 1000 inhabitants (and with no or only one broadband access network) should be covered. The work started between 2005 and 2007. In 2011, the network (called ASTURCÓN) provided service to 45 towns representing approximately 9.5% of all homes in Asturias. It had about 11,000 customers with 52,000 homes passed. Also small enterprises and business parks are connected. The technology applied is mainly GPON with a 1/32 splitting.

GITPA offers wholesale services to retail service providers. They have access to Layer 2 bitstream services. There is a single point of interconnection for the entire network. At the end of 2011 three service providers offered services: Telecable, Adamo and Orange (internet, VoIP and TV). The public network operator charges per line provisioned. This includes an installation fee and a monthly charge.

3.2.2. Asia-Pacific

There are several countries which have established a national broadband plan based on the idea of an open access network: examples are Singapore, Australia, New Zealand and Malasia.

3.2.2.1. Singapore

The main references for analysing case studies in Singapore were taken from [50]-[56].

In Singapore a Next Generation National Broadband Network (NG-NBN) will be established under the Intelligent Nation 2015 (iN2015) master plan. That includes (mainly) GPON and optical Ethernet (PtP) connections to every physical address in Singapore. Broadband speeds of 100 Mbps scalable to 1 Gbps (and above) will be delivered.

This network is based on the principle of an open access network comprised of three distinct layers:

- An infrastructure or network owner called the Network company (NetCo) which is responsible for the design, build and operation of the passive infrastructure (such as dark fibre and ducts); this task has been attributed in 2008 to the OpenNet consortium (led by SingTel). Today it is called NetLink Trust. Its task is to provide dark fibre and interconnection offers, at regulated prices, for operators buying bitstream.
- A network operator or Operating Company (OpCo) who is committed to offering wholesale network services over the active infrastructure comprising switches and transmission equipment. This task has been attributed in 2009 to Nucleus Connect (wholly-owned StarHub subsidiary, Singapore's second largest carrier); from 2010 SingTel acts as a second operator. They are in charge of providing

universal service offers, based on bitstream, for broadband wholesale solutions at regulated prices. Structural separation with regard to the NetCo is required.

- Retail Service Providers (RSP) which will sell services to end users and industry on a fully competitive basis, covering markets like internet access and VoIP-telephony. At the end of 2012 there have been 17 service providers (SingTel, StarHub, M1, SuperInternet, …). Operational separation with regard to the OpCo is required.

Several companies are active in more than only one layer (StarHub, SingTel). But because of the separation requirements they have to operate with clearly separated subsidiaries and on the basis of fair and non-discriminatory conditions.

3.2.2.2. Australia

The main references for analysing case studies in Australia were taken from [57]-[66].

In 2009, the federal government announced a plan for a National Broadband Network (NBN). The goal of this plan was to build and operate a national, wholesale-only, FTTH network on the basis of a public-private partnership. The NBN would be an open access infrastructure available to other carriers. 93% of the premises should have access to this network.

NBN Co was founded as a wholly-owned Commonwealth company to design, build and operate Australia's new network. The chosen topology is GPON. Access is given to competitive service providers as a wholesale layer 2 bitstream called the nbn™ Ethernet Bitstream Service.

In 2013 the government changed the strategy of basically rolling out a FTTH only network to deploying an access network based on a multi-technology mix. This will result in the amount of pure FTTH connections reducing to only some 20% of all broadband connections. The rest will be served with FTTC/N, HFC, wireless and satellite. But it will remain an open access regime based on wholesale bitstream access.

3.2.2.3. New Zealand

The main references for analysing case studies in Australia were taken from [67]-[80].

In New Zealand the government 2010 has started a program to build a FTTH network by means of public-private partnership called the Ultra-Fast Broadband (UFB) initiative. It is expected to reach 75% of New Zealand's population in 2019/20. The government will invest $1.35 billion into this initiative. Significant amounts of private co-investment will come from UFB partners.

Crown Fibre Holdings (CFH) is a state-owned company which has been established to manage and monitor the project.

About 70% of the network will be built by Chorus. Chorus has been a part of the incumbent telco Telecom New Zealand (TNZ) which has been split off in separate companies. CFH has invested in Chorus. CFH also established joint ventures with three local electric utilities named Northpower Limited (1.6% UFB coverage), UltraFast Fibre (13.7%) and Enable Networks Limited (15.3%) to build the rest of the network. These are called local fibre companies (LFCs).

These companies make payments to CFH as soon as individual premises are connected to the network. On the other hand, Chorus and the LFCs sell wholesale services to retail service providers. At the moment there are more than 80 service providers selling UFB services. From them only a few offer nationwide services, while most only focus on a few areas.

The technology used is mainly GPON for residential access and PtP for large businesses. Also dark fibre is available.

3.2.3. North America

In the US there has always been a strong cable TV sector besides the incumbent telcos which covered the whole country. In the early days there have been considerations by the FCC (Federal Communications Commission) to open the telco networks by a kind of unbundling but this idea was dropped very soon. The coexistence of telephone and cable networks is now seen as the basis of infrastructure competition. The owners of the telephone networks are the former RBOCs (Regional Bell Operating Companies) which re-united mostly in the companies of Verizon and AT&T. They have their separate distinct service areas. There are also a lot of other (smaller) independent telephone companies. The cable network sector is represented by large companies like Comcast, TimeWarner, etc.

Fibre access networks have been established during the last years mainly by Verizon with their FiOS system (FTTH) and partly by AT&T with their U-verse system (FTTN). The cable sector has introduced the DOCSIS 3.0/3.1 standards. But the availability of real broadband or even fibre broadband is still limited to the metropolitan areas and larger cities.

This is the situation where a lot of municipalities with no or insufficient access to broadband connections have decided to start their own telecom business and establish a municipal fibre network in their communities. The vast majority of them are vertically integrated where the municipality owns and operates the network and offers its own telecom service. The incumbent telcos didn't like these municipal activities because they saw it as a kind of illegal and unfair competition with the private sector. Unfair in the sense that public entities could use taxpayer's money to lower end-user prices.

Therefore the incumbents have undertaken a lot of lobbying activities to influence the government/legislation in order to prevent the municipalities of establishing publicly owned networks. As a result, about 20 states in the US have passed laws that forbid municipalities to offer telecom services to the public. These laws may be different in the level of restrictions. E.g., in the state of Utah it is forbidden for municipalities to offer retail telecom services but it is allowed that they may own their networks. Under these conditions the cities are forced to establish open access networks if they want to improve their broadband connections.

Actually there are considerations inside the Obama administration to skip all these state laws and generally allow municipalities to run their own networks [81].

3.2.3.1. Utopia

References for the Utopia case study were taken from [82]-[99].

In 2002, 14 cities in Utah's Wasatch Valley joined in a consortium called "Utah Telecommunication Open Infrastructure Agency" (UTOPIA) to establish a fibre access network that should pass every home and business within their cities' borders. This would cover a population of about half a million. Because of the Utah state law they were forced to implement it as an open access network and to offer wholesale services to private retail service providers. The cities would finance the project through the issuance of bonds. On the other hand, the bonds would be repaid by the revenues earned from the private service providers.

Effectively, the Agency is the holding company that owns the passive network. Dynamic City, a company in Lindon, Utah, would operate and implement the network on behalf of UTOPIA. Dynamic City was bought by PacketFront of Sweden in later years. Also the Agency took over the network operation by itself later on.

Deployment and services started in 2005. The network architecture chosen was Active Ethernet.

UTOPIA has not been very successful during the years of operation. They had difficulties to attract service providers because of the very limited and patchwork-like deployment. Neither the goals for passed nor for connected homes have been met. In 2007, UTOPIA made service available to 37,160 addresses, less than one-third of its original goal. The take-rate was disappointing as well: 49,350 subscribers have been expected in 2007, but only 6,161 have been counted. In 2012 the number of premises had risen to 61,614, the number of subscribers to 9,596. In October 2013 UTOPIA had 11,269 subscribers. In January 2014 it is built to approximately 10% and passes approximately 40% of its intended 160,000 premises.

There was obviously no clear and detailed deployment plan. No city wanted to be put behind the others. Nevertheless several cities have seen little to no fibre deployment while others have had larger amounts of infrastructure installed. The service providers wanted scale which could not be delivered. Especially there was a lack of TV service providers.

Also the Agency ran out of capital and had to issue further bonds. In this way the debt increased but the revenues could not keep up mainly because of the low take-rate. Due to the financial trouble UTOPIA could then no longer continue to further grow the network. In 2010 nine UTOPIA cities formed another related entity called the "Utah Infrastructure Agency" (UIA). UIA contracted with UTOPIA to build and operate that portion of the network which should be funded through UIA financing.

In 2013 the situation had not improved significantly. The Agencies now had several alternatives:

- To sell the network
- To shut it down
- To establish a public-private partnership.

The shutdown would have been the worst alternative because the debt would remain. On the other hand, nobody wanted to buy the network. So they started to set up a public-private partnership (PPP) with Macquarie Capital, an Australian investment and management company which had already been engaged in such partnerships with respect to building airports, bridges, roads and other infrastructures projects.

Macquarie set up a milestone plan to overcome the difficulties with the UTOPIA/UIA network. According to it a PPP will be established between the Agencies and Macquarie in which the Agencies will retain ownership of the network. The PPP will be established with a 30-year duration. It will build the network on a fixed-price basis within 30 months after closing of contract. It will also operate, maintain and refresh the network for 30 years on a fixed price basis. After that period the network will be completely handed back to the cities. A separate wholesaler will manage the service provider relationships and help market the network. The service providers will be solely responsible for customer contacts.

The network is seen as a utility and every household (or address) has to pay a utility fee of about $18-20 per month whether the network will be used or not. The cities are responsible to collect this fee and transfer it to the PPP which will use it for building and operating the network. The service providers have to guarantee a basic Internet access with actually 5 Mb/s up and down (20GB monthly cap) for free. They can offer further premium services which they can charge their customers. A Gigabit service will be available. The take up rates are estimated to be in the 30-50% range. The service providers will then also be charged transport fees related to the provision of premium services. These revenues will then be split between the Agencies, the Wholesaler and the PPP, with the significant majority going to the Agencies. The original debt will remain with the Agencies.

The network is intended to be based on availability and will connect to every address in the cities. It will keep the original active Ethernet topology. It will extend to a network portal installed at the outside of every single family home and to telecommunication closets in MDUs and businesses. The Internet service providers are responsible for completing connections inside the premises. They will receive a subsidy of $50 from the PPP for this purpose.

The public-private partnership is not yet fixed. Four cities have already decided to opt-out. During 2015 the final decision will be prepared with a vote of the cities' inhabitants.

3.2.3.2. iProvo

References for the iProvo case study were taken from [100]-[102].

Provo is a city also located in Utah amidst the ones which created the UTOPIA network. But it didn't join that alliance, instead it created its own fibre network. It was one of the first community fibre networks in the US. They started in 2001 when the city built a backbone network consisting of three fibre rings, which connected public buildings, traffic signals, etc. Then the city wanted to extend this network directly to residents and businesses. But due to the influence of the incumbent service providers and following the state law the city was forced to shift the structure of its network model to a wholesale or open access system.

After a pilot phase in 2002 the city council decided to establish the network covering the whole town in 2003. Tax revenue bonds have been issued to finance the network called iProvo. It should have been completed in 2006 and generating a positive cash flow by 2008.

But the primary service provider of iProvo, HomeNet, has not been able to establish a significant subscriber base and generate enough revenues to cover the costs of building and maintaining the network. In 2005 HomeNet and iProvo began to run into trouble. Until then 2,400 customers in peak times had been connected to the network, but one third of them had been lost again in 2005. HomeNet ended its contract in July 2005 and filed for bankruptcy. This sent iProvo in a financial downward spiral and these troubles increased over the next years.

In May 2008 iProvo was sold to a private company called Broadweave Networks. Broadweave agreed to pay off the bonds that had been issued to build the network. Broadweave merged with another company to form Veracity Networks a year later. The new company realized they could not handle the liabilities and in 2011 defaulted on its purchase agreement with the result that the control of the network reverted back to the city. The city leased the network back to Veracity while it looked for a new buyer. Simultaneously the city began charging $5.35 per month on resident's power bills to pay for the bonds.

The network was operational then but only one-third of homes had been connected to it. At its peak, iProvo had about 11,000 subscribers, but with a high churn rate.

Provo had difficulties to find a buyer willing to pay a reasonable price. In April 2013, Provo finally found a buyer: the city sold the $40 million network to Google for just one dollar. The whole debt remained with the city, i.e., with the taxpayers.

3.2.3.3. nDanville

References for the nDanville case study were taken from [103]-[107].

The network in Danville, Virginia, started with a fibre-optic network that the local utility, the Danville Utilities Department, built in the early 2000s for communications purposes across its electric network. This network also connected municipal buildings and schools. In 2006, the utility intended to switch the network to an open access system where private service providers could offer services to residents and businesses. The network that emerged in 2007, called nDanville, was the first municipal open access network in the United States. It has a PtP active Ethernet topology.

The network has been built on a pay-as-you-go basis. The build-out depended on the utility's ability to fund the cost from reserves. This conservative strategy leads to the situation that end of 2012 nDanville was debt-free and can now contribute to the city's general fund (hundreds of thousands of dollar every year).

Current subscribers have the choice between currently three service providers – Gamewood Technology Group (internet, phone and TV), Sunset Digital (internet and phone) and Kinex Telecom (internet and phone).

3.2.4. General considerations

The reference for this section were taken from [108]-[145].

There are some general aspects regarding the success of open access networks which can be learned from the actual deployments. Some of them do not only apply for an open access regime but are applicable for the general acceptance of FTTH networks.

First of all, FTTH (whether it be open access or not) has mainly been successful where there has been no or very limited broadband offering available before. The problem arises if an alternative broadband technology exists, e.g. xDSL (FTTC/N) or cable network. Also, if the price for fibre is significantly higher than the competing technologies then the take rate is generally low. Furthermore, if the FTTH data rates are not competitive, e.g., only 10/1 Mbps DS/US which is still very common in many data plans, the success is also rather limited. So the answer to the question: "*Will the user pay a premium for fibre*?" is usually "*No*" (or very little). To maximize the success operators should charge only prices in the order of usual xDSL or cable offers or at a relatively small premium for a significantly higher speed offering. In some cases operators even offered a bonus to trigger potential customers to sign a contract.

The acceptance of a fibre connection or take rate is one of the fundamental success criteria for FTTH especially for open access networks. Here the available market share for any one operator is a priori smaller than for a vertically integrated operator scenario.

The two approaches of supply-driven deployment and demand-driven deployment strategies need to be distinguished. The supply-driven strategy starts the deployment independently of any guaranteed demand. The large national broadband networks in Singapore, Australia and New Zealand follow this strategy. This strategy is inevitably higher risk as there is no guaranteed revenue and in at least one case (New Zealand) people have been very reluctant to connect to the FTTH network. The main reason for such reluctance seemed to be the higher premium being charged for the service [145].

In case of a demand-driven strategy the deployment only starts if a certain number of pre-contracts are already signed. This is the case with Reggefiber in the Netherlands where about 30 – 40 % of households must sign such a contract before Reggefiber starts laying fibre at all. The same strategy holds for Deutsche Telekom in Germany in those cities where they planned to establish an FTTH network. This percentage is the minimum which is believed necessary to achieve a positive return on investment according to numerous techno-economic investigations. Stokab in Stockholm had a different but similar strategy as they first connected to public customers (government buildings, schools, hospitals, etc.) and established a secure revenue basis before the extension to private customers. The first private customers were the large housing companies which further secured the revenues. Because this strategy links investment directly to revenues they are much lower financial risk but suffer from the problem of potentially long delays before deployment can commence and maybe losing out to neighbouring areas that deploy earlier.

Related to this question of deployment strategy is the question: *how many network operators can a country or region afford and be run profitably*? Some investigations have studied this aspect and showed that the *number of potential operators is very limited – not more than two or three*.

Other studies investigated the question: *where are the limits of profitable private deployments?* According to them, *infrastructure based competition with several different networks is possible only in the most densely populated areas*. In rural areas with a low population density no private roll-out will ever be cash-flow positive, even more so if the market share is split in an open access regime. These calculations are based on some assumptions: a time frame for return-on-investment of about 5 – 7 years (which is quite a long time for typical business cases), and some assumptions about the achievable ARPU (average revenue per user). The maximum ARPU will be limited (for acceptance reasons and availability of disposable income) but the time horizon can be extended if the infrastructure investor is not a private company but a municipality/utility which has different commercial constraints compared to private enterprises. However unfair competition arguments based on tax payer subsidisation can be levied at such operators and in Europe can fall foul of state aid rules.

However municipalities, especially in rural areas/smaller towns, are often taking the initiative to trigger the deployment of FTTH networks. These municipalities see these networks as a kind of natural monopoly or public infrastructure which should be owned by public authorities. The networks then will be mostly open access based and since the municipalities often don't have enough funds to invest, a lot of the deployments are financed under a private-public partnership (PPP) agreement. Under EU law municipalities are only allowed to invest in telecommunication infrastructure if it is done under identical conditions a private investor would invest in the project. Often EU permission has to be granted (e.g., in the case of Amsterdam's Citynet or the Asturcon network). In the US very often municipalities are not allowed (by state law) to invest in or run telecommunication networks and there have been many legal proceedings against towns that wanted to establish a community network based on complaints of the telecom incumbents or the cable companies.

Utilities which are often owned by municipalities are already familiar with public networks (gas, water, electricity). They have rights of way, own ducts and want to expand their business case. So a lot of them have invested in telecom networks, i.e. fibre networks. This is the case especially in the Nordics, Germany, the US and Switzerland.

One interesting aspect in open access FTTH networks is the choice of network topology, either point-to-point or point-to-multipoint (e.g., GPON). Most of the incumbents worldwide have chosen a PON architecture for their deployments, which is the case also for the open access national broadband networks in Singapore, Australia and New Zealand. But most of the non-incumbent driven networks, especially in Europe, are established using a point-to-point topology. Even the incumbents KPN in the Netherlands and Swisscom are relying on this topology. The reasons for it are named as most future proof and most secure architecture and best-suited for open access, although we believe such arguments are less valid today as NG-PON2 systems already give the ability to use different wavelengths in the same fibre, making the much higher cost of point-to-point fibre systems difficult to justify.

In the case of GPON, competitive access to the network is possible today almost only via a bitstream access on layer 2 or 3. This type of access does not allow for significant differentiation in the competitive offer. An alternative would be a kind of sub-loop unbundling (SLU) at the last splitter location. The rest of the way to the customer premise then is practically a point-to-point connection. If the splitter is located in the field near the customer premise a competitor would then have to own his own fibre link to that location. A different scenario, which is also described in the literature, is to push the splitters back into the central office in order to make access to the fibre more convenient. This however this is effectively a point to point fibre infrastructure and increases the cost of FTTH deployment, which needs to be accounted for when considering the economics of deployment strategies.

In addition, recent advances on the use of Software Defined Network (SDN) and Network Function Virtualisation (NFV) approaches for access/metro networks (e.g., the CORD project by AT&T [142]) could change the scenarios within the next couple of years. Separating control plane and data plane in the access infrastructure, moving the control software in commodity servers through NFV could produce a new virtual OLT that is fully programmable and will allow different operators to take control of virtual slices of the PON. Indeed the use of SDN in the access network has recently been investigated by a number of other projects ([143],[144]).

Generally, the adoption of multiple wavelengths (WDM) into the network is seen as a final solution to all access problems (especially in the case of PONs). In PONs a separate wavelength could for example be assigned to a provider or a customer and create a direct virtual point-to-point link. However only very few discussions or investigations on the use of different wavelengths in such a future network have yet taken place, and the next section provides some updated discussions from a DISCUS project perspective.

4. Updated views on business and ownership models

In consideration of the feedback received from the stakeholders and the investigation of a number of case studies for open access networks in Europe and the rest of the world, we propose a review of the key principles expressed in the DISCUS deliverables titled: "Wavelength usage options in access networks" and "Business and ownership models for future broadband networks". The main points learnt through this process were the following:

- It is not realistic to expect one rigid architecture (intended in the broader sense as inclusive of technical, economical and usage aspects) could fit all possible scenarios. It is thus important that the proposed architecture is sufficiently flexible to implement a wide range of diverse requirements.

- While it is recognised that sharing wavelengths as flexibly as possible is the ultimate goal to achieve efficient sharing across multiple owners and services, this requires a level of access virtualisation that is currently not available. While, as seen with the AT&T ONOS-CORD project, things are moving in this direction and this may well become the most efficient and flexible solution, other wavelength assignment options such as wavelength to the SP or to the users need to be reconsidered as valid interim solutions to enable early open access options to be realised.

- PON technology is the preferred option for many large and incumbent operators allowing them to reduce FTTH deployment costs and to compete with other operators. These operators do not see fully open access as their major goal and provide competitor access only at a service level (e.g., through bitstream and VULA). Initial open access networks were often based on PtP fibre, which is generally a more expensive access technology and limits network restructuring which we believe is necessary for future low cost and affordable networks, however we have seen that later developments (such as in Singapore) are now also using PON technologies for open access. This leads us to believe that PONs will be the technology of choice for all operators in the future.

As a consequence we revise the main points we made in relation of the wavelength usage and ownership model for the DISCUS architecture.

Regarding the wavelength usage models, we previously proposed four different models:

1) Wavelengths assigned to service and network providers (WpSP)

2) Wavelengths assigned to the service type - Wavelength-per-Service-Type (WpST)

3) Wavelengths for bandwidth management are shared across service providers and carry all service types - Shared Wavelengths (SW)

4) Wavelength assigned to users - Wavelength per User (WpU)

Among these we concluded that option 3) was the preferred one, as it allowed better utilization of the available capacity, provided flexible bandwidth assignment over a very wide range of user demands and could expand the total capacity of the network in line with growing user demands. While we still consider option 3) as the ultimate goal of a future-proof flexible network architecture, we recognize that there are limitations current network control and management frameworks make it difficult to implement a fully open access architecture.

We considered that option 2) was likely to be unrealistic as it would require multiple transceivers and protocol implementations per ONU and multiple OLTs at the head-end (the metro-core node for the DISCUS architecture) to terminate the multiple instances of the PON protocol. This is believed not to be cost effective and power hungry as many of the transceivers protocol circuitry and OLTs would have to be operating for large proportions of the time that services are used. Although advances in optics integration means that building integrated laser and photodiode arrays in a common optical module with only a single fibre interface is possible and could enable ultra-fast switching among wavelengths, it remains to be seen if the additional complexity, compared to the limited benefits that such a model would bring, will reach economic viability. But it is a possibility that future ONUs could operate over multiple channels simultaneously.

Option 4) wavelengths assigned to users is the well-known way of implementing a virtual point-to-point topology model over a PON physical layer architecture and could be a way of implementing the point to point architecture that has so far been the preferred options for open access networks. The main drawback is that from an active network perspective it presents higher cost, energy consumption and footprint compared to TWDM PON, and limits the number of users per PON to the number of wavelengths available (i.e., around 40 in post NG-PON2 systems, unless early adoption of coherent technology is evoked). While this is OK considering current GPON split ratio of 32 or 64, it is much less than splits of 256 or higher envisaged by next generation systems and the DISCUS architecture. In addition, this method does not operate statistical multiplexing on the PON, thus wasting capacity that could instead be distributed to other users to deliver additional services. Finally, where the wavelength separation is achieved through passive wavelength filters (which is usually the case in WDM PONS), it will lock wavelength channels and thus capacity to the individual customer access fibres, with a risk of ossifying development of further business models. However, we do envisage that in a PON a number of wavelength will be used as logical point-to-point connections for dedicated services, such as for mobile base stations and ultra-high capacity services for businesses and enterprises customers.

Option 1) where wavelengths are assigned to service providers might in principle be an option until the control and management issues with option 3) are resolved (see below). By separating access, giving providers different wavelengths, it can provide reasonable statistical multiplexing of capacity, without limiting the number of users where PONs with high split ratios are deployed. From a physical implementation perspective however it cannot be assumed that different service providers will be able to deploy their own terminal equipment into the same fibre infrastructure through physical wavelength unbundling due to the potential interference between wavelengths when operated independently. Although it is possible to deploy more stable transmitters at the ONU to avoid interference due to wavelength tuning inaccuracies this could increase the cost at the ONU, which is typically a low-cost device for residential usage. However, if the physical layer is controlled by one entity, then different SPs can connect electrically to the OLT and be assigned an entire wavelength channel using today's technology. The main drawback of this approach remains that, besides not being as bandwidth efficient as option 3), it does not allow for multiplexing different providers into one ONU (unless the ONU has more than one transceiver) and therefore restricts simultaneous access to multiple providers.

Option 3) remains the most efficient in terms of capacity utilization and assignment flexibility by dynamically matching network resource to user demand and freely assigning capacity between users and providers. It however requires the presence of an entity owning and controlling the active infrastructure such as an incumbent operator. While this could be operated in conjunction with models such as bitstream and VULA, full open access operation will require more powerful virtualization mechanisms where multiple providers could operate over the same PON and be able to control every aspect of their PON virtual slice as if they were managing a separate physical system. This will require enhancements on the control and management of PONs, which could be provided by developments in the concept of Software Defined Access Networks. When combined with such a virtualization framework, option 3) could in principle give the exact same ability as the point-to-point model in terms of customer management from a provider perspective, with the added value for the end user to multiplex services from different providers at the same time, while being more cost effective and energy efficient.

There are however two intermediate steps that could be adopted in the meantime to enable multi-tenancy in the access [146]. The first is to reuse existing network equipment controlled by the infrastructure provider through their management system: virtual network operators could get access to the network through a standard sharing interface which can provide raw access to the management layer with optional monitoring and diagnostic functionalities (there are however serious network security issues to be addressed for this to become an acceptable solution for network operators). The next step involves the deployment of new hardware in the access node capable of resource virtualisation, so that the virtual network operators/service providers could be assigned a virtual network slice and get full control of the equipment. For this step however the interface might still be into the same network operator management system. The third and final step is the full SDN integration, where the virtual operators get access to their network slice through a flexible SDN framework with standardised APIs.

The second DISCUS white paper dealt with “Business and ownership models for future broadband networks”. The ownership model we suggested can be summarised by the graphic in Figure 41. While we believe the results still broadly apply to the architecture, and indeed were not challenged through the feedback received, we want to provide further comments to the architecture design criteria we proposed in the white paper.

Owner \ Equipment	Criteria	CPE	Passive Infrastructure	Active Infrastructure: Reach extender	Active Infrastructure: OLT	Active Infrastructure: Packet/Fibre switch	Active Infrastructure: Service routers
Infrastructure Provider	Infrastructure sharing	N/A	Fair	Infrastructure Provider becomes also Network Provider in active sharing model			
	End user benefit	N/A	Good				
Network Provider	Infrastr sharing	Good	Good	Good	Good	Good	Good
	End user benefit	Fair	Good	Good	Good	Good	Good
Service Provider	Infrastr sharing	Poor	Poor	Poor	Fair	Poor	Poor
	End user benefit	Poor	Poor	Poor	Fair	Poor	Fair
End User	Infrastr sharing	Good	N/A	N/A	N/A	N/A	N/A
	End user benefit	Good	N/A	N/A	N/A	N/A	N/A

Infrastructure Provider: Sub-optimal sharing leads to overprovisioning to support multiple network providers

Network Provider: Moves competition to the service layer, allowing maximum exploitation of resources.

Service Provider: This leads to the vertically integrated model.

Figure 41 Ownership model analysis suggested by DISCUS white paper "Business and ownership models for future broadband networks"

The proposed design principles were as follow.

1) There is **no duplication of passive network infrastructure** used to provide basic network services: that is there is only one fibre network for each customer premises for the mass of customers – (if it is difficult to economically provide one fibre network, it is probably impossible to provide more than one)

This principle is still of paramount importance and should be taken into consideration in access network deployment. Indeed open access networks are based on this principle. There are however cases where this principle is not respected, i.e. where an incumbent is not required to open up its network. In a number of such cases this has led competitors to organise and deploy a separate infrastructure from the incumbent. So although not optimal from a network efficiency perspective, market forces can lead to the deployment of overlapping optical access networks.

2) As much as possible of the **fibre infrastructure (and network equipment) should be shared by as many customers as possible**.

What this principle really states is that the number of providers and their mode of operations shouldn't get in the way of maximising sharing of infrastructure among users. While this is achievable with wavelength usage model 3), as stated above it would require full access virtualisation to enable a fully open access model that goes beyond bitstream and VULA overlay models. This requires updating the OLTs as well as the development of an agreed and standardised control and management framework. Until this can be achieved there are possible intermediate steps using virtualisation of current network management systems, and different wavelength assignment mechanisms such as wavelength to service providers.

3) **Customers should have the option to access to multiple providers simultaneously** and be able to change providers "on the fly".

4) Customers should have the option of bundled and fixed term contracts or have all **services provided from any provider at any time on a pay as you go basis** if desired

Option 3) and 4) are both variants of a fully accessible or "open access" scenario service provisioning market. While this is the preferred option to achieve full competition at the service level, it works with wavelength usage model 3), but not with usage model 1), which might be used for expediency in the near term. A few stakeholders believe that the benefits that could occur from such a high degree of flexibility in the service provisioning is over-rated, as they believe that service bundling provides a better option for both users and providers. We believe this is still debatable and cannot be tested until such flexible service level architecture is made available in the market. There are certainly significant limitations in the service bundling models used today such as: most bundles are pre-structured and customers may need to buy into bundles that have services they do not use, or they do not get the all the services they would prefer because they are in a different bundle package, or possible all the services they want are not available from a single supplier. The customer cannot get access to best of breed for all the services he/she uses but will have to compromise on some of the services within the bundled package. The customer gets locked into a contract for a fixed term and there is often a penalty for leaving the contract early (at best not all of the remaining term will be refunded).
If wavelength option 1) is to be considered however, there is still the option for a new category of brokers to emerge in the market, offering bundles that are a selected mix from the services offered by different SPs. However, whether SPs would enable brokers access to such service bundles without regulation to force them into "open access" remains to be seen.

5) There should be **no lock-in to single providers**.

From a technical perspective there is no reason why change of providers could not be done on demand, although in many cases, where part of the installation cost is subsidised by the provider (e.g., for the fibre connection or for the ONU), temporary lock-in might be required.

6) There should be **no physical hardware reconfiguration of network equipment, or infrastructure, required to change service provider -** all reconfiguration would be via software control of network equipment.

From a technological perspective there are no major issues. With wavelength option 1) this could be done by tuning the ONU to a different channel, while with option 3) only network PseudoWire rearrangement might be required. The requirement is that of a standardized network control and management framework (e.g., a Software Defined Access Network) allowing infrastructure, network and service providers to coordinate their actions following a user request. This type of interaction is what DISCUS has implemented in its control plane deliverables and demonstrations and is a key feature of the DISCUS architecture proposal.

5. The DISCUS architecture and equipment ownership

From the case studies examined and as emphasised in the previous discussion, it is of paramount important for next a generation broadband architecture to satisfy a number of requirements, such as:

1) Ability to support multi-ownership model with efficient infrastructure sharing.

2) Ability to improve the energy efficiency and economic viability,

3) Ability to provide a seamless deployment model that is effective both in sparsely and densely populated areas.

In the DISCUS architecture, which by-passes the vast majority of Local exchanges and instead terminates network traffic on a small number of Metro-core nodes (MC nodes), the majority of the packet processing equipment will be housed in the MC node buildings. The access and core physical infrastructure consisting of the cables, splitters, remote amplifier nodes etc., will largely remain the same for all business and ownership models except possibly for the case of the multiple competing infrastructure owners that arises with a full separation of providers. The MC node is therefore the node where the different wavelength usage and equipment ownership models will have greatest impact on equipment utilisation efficiencies, power consumption and cost per customer.

The simplified structure for the MC-node in the DISCUS architecture is shown in figure

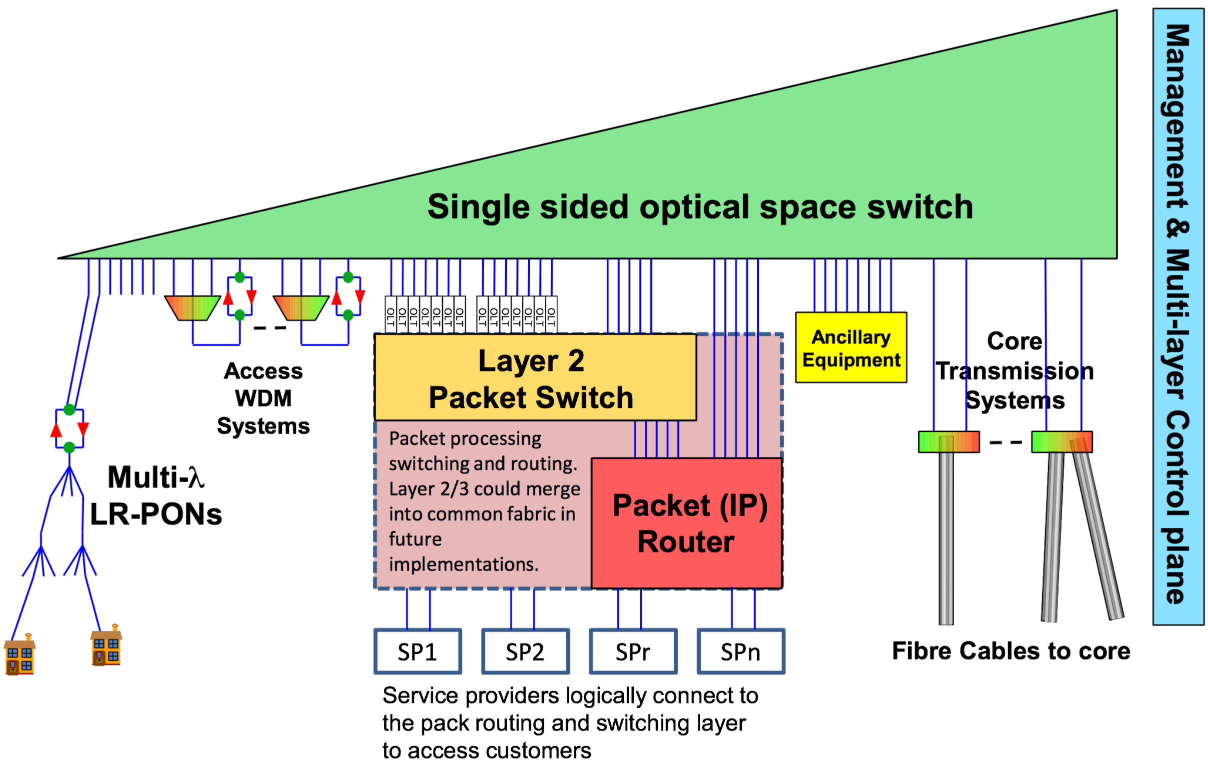

Figure 5.10 MC-node structure for the DISCUS architecture

5.10. Key features of this architecture are the optical switching layer which enables fibre layer interconnect between access and core network fibres and the optical interfaces of electronic packet processing equipment. Service providers regardless of ownership and business models will need to get access to the packet processing layers within the MC node in order to access customers. The nature of that access will determine the range of customers accessible to any one SP.

In practice service providers could gain access to the packet switch via access fibres and the associated transmission systems, core fibres and those transmission systems or by having owned equipment within the MC-node which is either a subset of the packet layers or interconnects to the packet switching and routing layer via the optical switch. The optical switch would also enable interconnect at either layer 2 or 3 or both if a provider required it.

Considering the wavelength usage models described in Chapter 4, option 3), where we have an infrastructure and network equipment operator that provides open access to the MC node to service providers, is the most efficient because all the equipment can be consolidated into the minimum set required to services the user demand. With full network service virtualisation, the packet processing fabric can be partitioned logically with control and management plane instances so that service providers can effectively operate and control their portion of the network as if they owned the equipment. However instead of owning the equipment, a leasing or rental model would apply with payments going to the network operator.

The optical switching layer does however also support ownership of the physical packet processing equipment by the service providers or multiple competing network operators. The disadvantage with this would be the separation of the equipment into distinct pieces which would inevitably lead to underutilisation of that equipment. Another problem is access to the customer base: unless there is a main operator that owns the access switch that the competing providers can connect to and gain access to the full customer base, there would inevitably some partitioning of the customer base across service providers. This would depend on the number of service providers and the number of wavelengths available, but if the number of service provider exceeds the number of wavelengths on any one PON, then restrictions of access would be incurred. In addition, service providers could run into capacity constraints as spare capacity of underutilised wavelengths owned or allocated to competing providers would not be available to their competitors.

Although the optical switch provides some level of shared access across customers, those customers connected to the same physical PON would also be connected to the same service providers, which could limit freedom of choice for those customers. If indeed there was a common single operator that owned the access switch that is partitioned across the competing providers, using VNF, then all service providers could access all customers and all customers could individually choose their providers of services. It also begs the questions that if network virtualisation is used for the access switch then why not use it for all packet processing equipment, so that all providers of services could also be virtual network operators?

6. Conclusions

One of the driving concepts behind the DISCUS architecture is the need for shared infrastructure and equipment models to minimise power consumption and cost for end users. Maximum sharing also is fully compatible with open access principles but will require further development of access network virtualisation combined with SDN and SDAN. With that additional functionality which is being developed by some of the major players in the industry, the preferred model of a single shared network within a geographical region becomes a viable option for future networks.

In this model, wavelengths are used primarily for capacity management, although some wavelengths can also be allocated to specific users and functions (such as mobile base stations and physical private infrastructure services). The DISCUS architecture also supports other business models although there would be some efficiency and functional impairments to be considered. For example, the option of providing wavelengths per service provider will lead to some inefficiencies and also could restrict full freedom of access for customers to their providers of choice and would make access to multiple service providers at a single ONU more difficult and expensive (a multi-wavelength ONU wold be required).

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Abbreviations

ADSL	Asynchronous Digital Subscriber Line.
API	Application Program Interface.
ARPU	Average Revenue per User.
BSA	Bitstream Access.
CO	Central Office.
CoS	Classes of Service.
CPE	Customer Premises Equipment.
DOCSIS	Data Over Cable Service Interface Specification.
DSL	Digital Subscriber Line.
EoI	Equivalence of Input
FTTCab	Fiber to the Cabinet
FTTC/N	Fiber to the Cabinet/Node.
FTTX	Fiber to the X.
GigADSL	Gigabit Asynchronous Digital Subscriber Line.
GPON	Gigabit Passive Optical Network.
HFC	Hybrid fiber-coaxial .
ICT	Information and Communication Technology.
IP	Internet Protocol
IP-TV	Internet Protocol Television.
ISDN	Integrated Services for Digital Network.
LLU	Local Loop Unbundling.
MC	Metro/Core.
MDU	Multiple Dwelling Unit.

MEIP	Market Economy Investor Principle.
NetCo	Network Company.
NFV	Network Function Virtualisation.
NGA	New Generation Access.
NG-NBN	Next Generation National Broadband Network.
NG-PON	Next-Generation Passive Optical Network.
NT	Network Termination.
ODF	Optical Distribution Frame.
OLO	Other Licensed Operators.
OLT	Optical Line Terminal.
ONU	Optical Network Unit.
OpCo	Operating Company.
P2P	Point to Point.
PON	Passive Optical Network.
PPP	Public Private Partnership.
PSTN	Public Switched Telephone Network.
PtMP	Point to Multi-Point.
PtP	Point to Point.
RSP	Retail Service Providers.
SDN	Software Defined Networks.
SLU	Sub-loop Unbundling.
SMP	Significant Market Operators.
SP	Service Provider.
STB	Set-Top Box.

SW	Shared Wavelengths.
TWDM	Time and Wavelength Division Multiplexed.
UFB	Ultra-Fast Broadband.
ULL	Unbundled Local Loop.
VDSL	Very-high-bit-rate Digital Subscriber Line.
VI	Vertical Integration.
VLAN	Virtual Local Area Network.
VULA	Virtual Unbundling Line Access.
WDM	Wavelength Division Multiplexing.
WLR	Wholesale Line Rental.
WpSP	Wavelength assigned to Service and Network Providers.
WpST	Wavelength-per-Service-Type.
WpU	Wavelength per User.
xDSL	x Digital Subscriber Line.

Document versions

Version[2]	Date submitted	Comments
V1.0	25/01/2016	First version sent to the EU.

[2] Last row represents the current document version