D3.2

Initial white papers on regulation/policy and multi-business model support

Dissemination Level: PU

- **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 composed of two white papers: the first on wavelength usage options in access networks; and the second on business and ownership models for future broadband networks.

The first paper explores what possibilities are available for wavelength usage in the access, emphasizing pros and cons of the different models introduced.

The second paper describes ownership models for the different parts of the access network, again emphasizing advantages and disadvantages of the different approaches.

Both papers focus on the benefit to the end users, as this should be the main scope of a large-scale communication network. However fair return on investment to network and service providers are also taken into consideration.

The white papers will be disseminated though the DISCUS website, as well as the standard communication channels of the partners involved in the work.

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1 Introduction

In an earlier deliverable (D2.1) which describes the proposed DISCUS architecture for future ubiquitous broadband provision it was stated that a major objective of the DISCUS project is to enable a future network that would tackle the three major problems facing today's network as it tries to respond to the huge growth required in network capacity that could arise over the next decade. These problems are: the cost of network provision and financial viability of the telecoms sector, the huge growth in power used by the worlds telecommunications networks and 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.

DISCUS is proposing a radical simplification of the network architecture with rebalancing of costs from core and metro to access combined with large scale infrastructure and equipment sharing so that all three problems are addressed with a single general solution. However it is recognised that the DISCUS solution not only requires technical and design solutions but also a fresh look at the regulatory and business model environment that network providers, network operators and service providers need to operate within.

DISCUS also considers the business model and regulatory environment from a customer/end user perspective so that the major benefits of a new network architecture should go to the customers and users of the network while giving a fair return on investment to the network and service providers so that encouragement for network investment is provided. One aspect of this is to provide much greater availability of competitive service provision to customers without the long period contractual lock-in that happens too often today.

This 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.

The history of regulation in the wake of opening the incumbent dominated telecommunications network sector to competition was to focus on physical layer competition, particularly in the access network where the policy of Local Loop Unbundling (LLU) has been widely implemented. This was a very successful policy during that early era and because most of the network infrastructure, particularly the copper pair access network, was built from public funds, it was perfectly reasonable that other operators and service providers should get equal access to that existing infrastructure resource and avoid the need to build a parallel network at huge capital cost.

Despite the success of LLU in creating competition in the telecoms sector, from a customer or end user perspective the main benefit has been lower prices as the incumbents responded to the leaner competitors and became slimmer, leaner and much more commercial in their own operations and structure. However the ability to change provider, avoid contractual lock-in and select different services from multiple different providers at the same time has not occurred in the competitive market that has been created.

A major question that we wish to address within DISCUS is how we now ensure that the future network being proposed enables the next stage of competition which will focus on empowering and providing much greater choice for the user rather than competition just for its own sake.

From a user perspective the ultimate solution should provide the ability to select, on the fly, any service provider for any service and have multiple service providers at the same time so that the users have the choice of avoiding contractual lock-in and can select the best offerings for their needs. They should have the option of only paying for what they use on a "pay as you go" basis" if this is desired. This would also enable a single network termination to provide multiple users in the same household, or office, the ability to have different service providers, even for the same services, if they wish to do so.

This does not rule out single service providers with bundled fixed term contracts but rather expands the competitive market to also include a pick and mix capability for those customers that want to get the best deals for any service at any time.

Another aspect of the DISCUS objectives is the "principle of equivalence" where the capability of the optical network termination is the same regardless of geographical location. The actual capability at the customer premises would depend only on the capability of the terminal equipment not the network serving the terminal. The network should be capable of delivering all services and capacities regardless of location of the customer. This would also allow service providers to locate and connect any where in the network and grow capability at that location, to 100Gb/s or greater capacity if they wish to. This would help stimulate service entrepreneurship, innovation and a much more competitive and dynamic service provision environment.

The aim of this deliverable is to produce two white papers to encourage and stimulate wider discussion and debate about the regulatory and business environment for a future ubiquitous superfast broadband network. This deliverable contains the two white papers in the main body of the report. The first white paper is a discussion of wavelength usage options and models and the second is a discussion of network resource ownership options and the business models that could be supported. To provide further background to the white papers there are two appendices which give an overview of the European regulatory policy and processes and some background to possible "open access" concepts.

2 White paper on wavelength usage options in access networks

The following is the white paper on wavelength usage options and models; it is intended to initially disseminate the paper via partner channels and contacts and the DISCUS project web site.

Wavelength usage options in access networks

2.1 Introduction

Future networks will have to cope with a huge demand for growth in user bandwidths, maybe as much as three orders of magnitude or more compared to today. The use of wavelength division multiplexing (WDM) over fibre access networks will be one of the optical technologies to be exploited to meet this challenge. However the way wavelengths are used can affect the economic viability, the competitive environment and the regulatory framework required to ensure open and fair access to network resources by all customers and service providers. This white paper discusses wavelength usage models and the implications for regulation with the aim of fostering a wider debate that can help shape requirements for a future architecture.

Three major problems need to be tackled as networks try to grow to respond to this huge demand for network capacity. These problems are: the cost of network provision and the long term financial viability of the telecoms sector, the huge growth in electrical power used by the worlds telecommunications networks, and 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 for those areas.

The FP7 project DISCUS [1] is proposing a radical simplification of the network architecture with rebalancing of investment from core and metro towards the access, (by reducing the number of core nodes, reducing the opto-electronic ports required and the amount of electronic traffic processing switches and routers). This is combined with large-scale infrastructure and equipment sharing so that all three problems are addressed with a single general solution. However it is recognised that the DISCUS solution not only requires technical and design innovations but also a fresh look at the regulatory and business model environment that network providers, network operators and service providers need to operate within.

DISCUS considers the business model and regulatory environment from a customer/end user perspective so that the major benefits of a new network architecture would go to the customers and users of the network while at the same time giving a fair return on investment to the network and service providers to encourage network investment. One aspect of this is to provide much greater availability of competitive service provision to customers without the long period contractual lock-in that happens too often today.

DISCUS is aiming for an evolvable solution that can gracefully grow network capacity as it is expected that customer demands for bandwidth could grow by three orders of magnitude or more from today's values [2], [3]. To enable such large increases in capacity wavelength division multiplexing (WDM) will be exploited in the access network. WDM technologies in optical networks have been applied to the core network for many years, the major use being to increase the capacity of the installed fibre base. In the last few years there has also been increasing use of the ability to route traffic flows within the wavelength domain using reconfigurable optical add drop multiplexing technology.

When WDM is applied to the access network there are additional uses that could be applied to the wavelength domain, particularly when shared passive optical access networks are considered. Bandwidth expansion in a managed and graceful way becomes one of the major uses for wavelength multiplexing in access networks (cf. NGPON2 standard). However wavelengths could also be used to provide the equivalence of unbundled access to different network and service providers or could be used for different types or classes of services that could be handled differently in the terminating node.

Wavelength routing can also be used within the access network. Wavelengths can be routed through the access network in two ways: one is in a static or fixed way where a wavelength routing element such as a WDM device is placed within the access network infrastructure. This method assigns fixed wavelength paths between the network terminating node and the customer premises. The alternative method is fully flexible wavelength routing where the access network is wavelength transparent and wavelength routing is achieved by selecting the transmitter and receiver wavelengths at the customer premises and network terminating node.

The DISCUS architecture, which is based on long reach passive optical networks with large splitting ratio in the access and metro networks and a flat wavelength switched core network interconnecting a relatively small number of traffic processing and switching nodes, can exploit the wavelength domain in all the ways mentioned above. The DISCUS LR-PON architecture is based on power splitters and uses optical amplifiers to overcome the power budget limitations. The use of power splitters provides the greatest transparency of the optical path between the metro-node where the LR-PON terminates and the customer premises termination and will also provide the greatest flexibility when WDM is used over the optical distribution network (ODN). This is the case we consider in this white paper.

The wavelength usage options discussed in this paper are therefore:

- Wavelengths assigned to service and network providers (WpSP)

- Wavelengths assigned to the service type - Wavelength-per-Service-Type (WpST)
- Wavelengths for bandwidth management are shared across service providers and carry all service types - Shared Wavelengths (SW)
- Wavelength assigned to users - Wavelength per User (WpU)

The options are shown in Figure 1

These usage options will be compared against the following topics.

- Description of wavelength usage option
- Issues from business model perspective
- Technical and techno economic issues

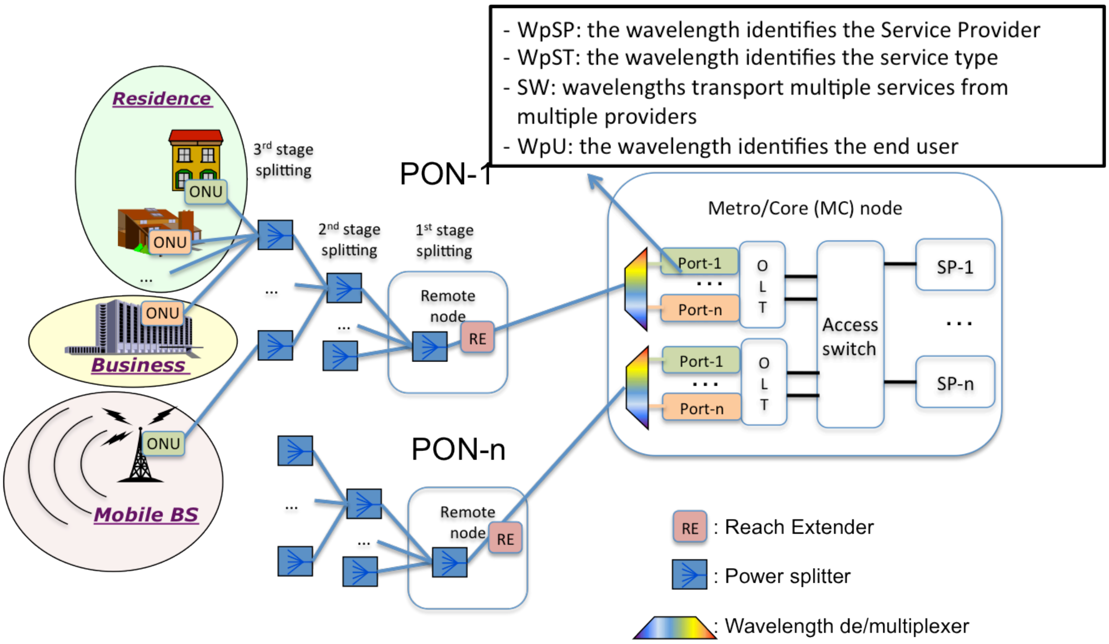

Figure 1 Wavelength Usage options over the DISCUS LR-PON architecture

2.2 Wavelength usage options

In this section we briefly describe the main features of the four wavelength usage options listed above. In this paper we use the term user to mean all types of user residential, business and even service providers. Where the different types of user need to be differentiated they will be mentioned specifically.

2.2.1 Wavelength assigned to Service Providers (Wavelength-per-SP – WpSP)

Assigning wavelengths passing over the PON infrastructure to individual SPs is equivalent to unbundling the PON infrastructure. In practice two wavelengths are assigned to each service provider, one for the upstream and one for the downstream direction. Any customer can connect to any SP by ensuring their ONU (the Optical Network Unit) selects the appropriate pair of wavelengths assigned to the SP for the up and down stream transmission paths. Because the ODN is based on a power splitter architecture all wavelengths channels are present at all ONUs and by using an appropriate wavelength selective filter and tuneable optical transmitter any SP can be selected by any customer. Typically it would be assumed that to keep the ONU low cost only one pair of wavelengths would be selected at any one time and the usual model would be that the customer will receive all services (i.e., telephone, broadband, Video-on-Demand etc.) from the same SP.

This model enables current local-loop unbundling regulations to be compatible and may be preferred by regulators if point to point fibre is not available.

2.2.2 Wavelengths assigned to service type – (WpST)

In this application of wavelength usage over the PON different services are assigned to different wavelengths, for example (VoIP, VoD, etc.). All SPs share access to customers on each wavelength or service using electrical multiplexing (usually TDM) via the PON protocol. This implies that each OLT delivers a particular service type, and the SPs access their portion of customers by sharing the PON channel capacity in a way that is proportional to the number of customers they service.

2.2.3 Wavelength for bandwidth management (Shared Wavelengths - SW)

An alternative option to both WpSP and WpST is to use wavelength purely for bandwidth management so that a wavelength is not assigned to a particular SP or service but will provide access to a number of SPs and all services from those SPs. Additional wavelengths are therefore only added to the system to expand capacity for increased service usage, and therefore the number of wavelengths is determined by the traffic requirements.

In this wavelength usage option there is no static association of wavelengths to a SP or a service type, but capacity is assigned to SPs as a form of bit-stream unbundling. There are two ways this capacity to SPs could be assigned: statically where each service provider has access to a fixed capacity bandwidth pipe within each wavelength (the usual way bit stream unbundling would be implemented today) or dynamically where the amount of bandwidth within each wavelength allocated to an SP will be proportional to their customer base and the use those customer make of the SP's services (in this case SPs only get capacity allocated if customers are actively using their services).

Wavelengths are added to the PON to increase capacity and to balance the traffic load across the wavelengths channels so that overloading is avoided. Customer ONUs would then be tuned to the appropriate wavelength/s.

For the majority of customers the ONU will only need a single transceiver. Initially this transceiver could be fixed-wavelength and will only require upgrading when the PON single wavelength capacity is exhausted and an additional wavelength is added. Even then, while the wavelength count is small, fixed-wavelength ONUs could be used to share customers across the wavelengths operating on any particular PON, increasing the average bandwidth per customer. Tuneable transceivers would be an upgrade option that would enable full dynamic traffic and capacity management but is not essential at day one.

Tuneable ONUs do have additional operational advantages compared to fixed-wavelength ONUs; there are no sparing/maintenance issues for ensuring the correct transceiver is in the correct customer ONU, and the network can be rebalanced/reconfigured remotely by the network operator without the need for changing out customer ONUs.

2.2.4 Wavelengths to individual users (Wavelength-per-User – WpU)

The original WDM PON replaced the passive power splitter with a wavelength multiplexer to route a specific wavelength to each user ONU connected to the PON. The advantage of this WDM-PON is that the WDM device has lower optical loss than the power splitter and enables lower power optical transmitters to be used. From a regulatory perspective this solution is a point-to-point topology with some of the advantages of the shared fibre solution of the TDM PON.

The point-to-point nature of the technology enables a carry over of LLU type unbundling into optical access networks. However there are a number of disadvantages with this solution the main one being the lack of flexible assignment of capacity to customers and the inefficient use of the PON capacity.

Wavelength per user can also be supported over power split PONs providing the same wavelength unbundled access but with the advantage of greater wavelength flexibility and the ability to randomly assign multiple wavelengths to those larger customers that may need multi-wavelength access.

2.3 Wavelength Usage options from a business model perspective

All the options have pros and cons from a regulatory and business model perspective and these issues will be discussed below under the headings of the four wavelength usage options being considered.

2.3.1 Wavelengths per SP (WpSP)

This use of wavelengths is at first sight very attractive, particularly as it gives a clear demarcation between service providers, but there are a number of issues that need to be considered.

One is scalability: the number of SPs available to customers is limited by the number of wavelengths that can be transmitted from the OLT and ONU over the PON infrastructure. The actual number is dependent on the PON architecture and the capabilities of the technology deployed. The DISCUS LR-PON architecture may use EDFA amplifiers within the PON, in which case the wavelength range would be the C-band (and maybe L-band). The maximum number of wavelengths for the C-band with current technology would be about 100, which could service 50 SPs (two wavelengths required per SP). SOA amplifiers could be an alternative technology which could increase the wavelength range; another possibility is coherent technology which could further increase the number of channels, however there will always be a limited number of wavelengths available.

For each pair of wavelengths used an opto-electronic terminating port is required at the head end of the PON (this is the metro-core node in the DISCUS architecture). The number of ports required at the metro-core nodes can therefore become quite large, being proportional to the number of PONs multiplied by the number of SPs (rather than being proportional to the overall access capacity required). Terminating port sharing is also reduced increasing the cost per customer of the head end equipment.

Another issue is the efficiency of wavelength usage. SPs will have a minimum of one wavelength allocated to them: depending on the number of customers and the popularity of their services some wavelengths will be under utilised because this spare capacity cannot be allocated to more popular or heavily used SPs. There is no statistical multiplexing gain from capacity sharing between SPs.

The same problem of SPs being locked to wavelengths also impedes end users from accessing services from different SPs simultaneously. This would be possible by adopting multi-channel ONUs, but it will incur higher cost for the user (at least due to a more complex and expensive ONU). From an SP perspective, physical channel separation is probably seen as an advantage, as each SP can easily separate their user base from other providers and directly control quality of service requirements on the PON. However from the end user perspective it will probably mean that SPs will lock their customers into 1-year term, or longer, contracts, similar to current DSL or cable contracts.

Another issue with wavelengths assigned to SPs is that in order to access a large number of customers an SP will need a wavelength pair on, possibly, all the LR-PONs connected to the metro-node. A large SP may be able to afford the cost associated with connection to many wavelengths via dedicated LR-PON OLT head ends, but this cost will be a barrier to a small start-up SPs that might want to connect via an ONU on one of the LR-PONs and try new and experimental services. Their customer base could initially be quite small and also scattered across many of the LR-PONs connected to the metro-node. These small SPs would prefer instead to use capacity on shared wavelengths that go to all LR-PONs and reach all potential customers on the metro-node, and quite possibly all customers on all metro-nodes in the network.

2.3.2 Wavelengths assigned to service type – (WpST)

This option where multiple SPs share the same wavelength for each service type provided would allow end users to dynamically switch between different SPs without tuning the ONU to different wavelengths. So within one channel an end user can choose among a large number of providers, thus increasing competition for each.

This approach also enables SPs to specialise in specific services: it could enable small SPs to enter specific service markets where they offer only one or a small number of service types. Small providers will not need to sustain the cost of providing entire wavelengths, but would share the cost of the channel with other providers, which could be in proportion to their usage of the channel. Larger, more popular SPs that use more of the channel capacity would pay proportionately more to the network provider.

Although it is still possible for SPs to offer multiple bundled services, the ONU would need to have multi-wavelength capability to gain access multiple service types simultaneously. Such a multi-wavelength ONU enables mixing services from multiple different providers including different bundles of services to the different users of the ONU terminal at the customers premises, but of course at the cost of a much more complex and expensive ONU.

The wavelength channels could be shared using the TDMA PON protocol and provide a form of bit-stream unbundling. As with the WpSP option, wavelength utilisation will not be high because spare bandwidth on wavelengths transporting services with relatively low traffic demand is not shared across wavelengths that carry popular high demand services.

2.3.3 Wavelength used for bandwidth management or shared wavelengths (SW)

This option does not assign wavelengths either to service providers or services but instead each wavelength is shared by service providers who would use the wavelength channel to deliver all their services to the customer. Because this is not wavelength or bit-stream unbundling in the commonly accepted sense, this mechanism requires changes to current regulatory and business model thinking, which are mainly predicated on physical separation of access infrastructure to provide access to different service providers.

With shared use of wavelength the physical infrastructure is necessarily also shared and access to SPs is either via static bit-stream separation or a dynamic assignment mechanism. The latter would provide greater usage efficiency of network resource, minimising the number of OLTs, access switch ports and energy requirements as well as cost, and also would be the best way to avoid bandwidth hogging by large wealthy SPs. In addition it would create a fairer environment for encouraging a greater entrepreneurial, innovative and competitive spirit for service provision.

Sharing wavelengths across services and service providers is only one of the many possibilities of using shared wavelength access. For example a new wavelength could be allocated to give a larger increase in capacity to a smaller number of heavy users or could even be assigned to one individual user, as a dedicated virtual point-to-point high-speed link across the PON. Indeed these high speed paths can be set up very quickly and dynamically, so users could have access on a "pay as you go" basis if desired.

Such capability leads to the ideas of capacity brokering for those users that need very high capacities for relatively short durations. It can also service a private circuit market at a granularity from Mb/s to 100Gb/s (possibly higher if flex-grid technologies can be applied in the future).

Capacity auctions could be employed, this however could lead to scenarios where some large SP could overbook their capacity, even bearing financial loss for a certain period of time, in order to eliminate its competition (as it indeed occurs in the allocation of mobile frequencies). In order to avoid this, such auctions may require regulation and policing so that anti-competitive behaviour can be curtailed while not stifling innovative use of dynamic resource allocation and new business opportunities.

2.3.4 Wavelengths per User – WpU

As mentioned previously there are two ways of assigning wavelengths to users; either statically with a WDM component within network or dynamically when the passive optical network uses wavelength transparent optical power splitters.

If the WDM components are in the network and provide the routing function to route the wavelength channels to the customers, then it is not possible to separate SPs or services by wavelength assignment because the customer ONUs can only receive one wavelength channel, while all others are blocked by the network embedded WDM component. Bit stream unbundling could be used to provide access to a number of service providers but this would be via layer-2 VLANs or VCs routed via the layer-2 access switch. Because the wavelength capacity cannot be shared over other users (by definition for this option – wavelength assigned per user) unused capacity is wasted and average efficiency will be low compared to the dynamically assigned capacity of the shared wavelength.

The scalability problems of WpSP also apply to WpU as the number of wavelengths available, dependent on the technology deployed, limits the degree of sharing on the passive optical network.

Because all SPs and all services need to be transmitted over a single wavelength to the customer using a bit-stream method, if the configuration of the bit stream pipes are via a slow management systems, it is more likely that service provision will be via longer term contracts. However if a fast flexible bandwidth assignment system is available, as described in the SW scenario, then a more flexible and dynamic service provision market is also possible.

Finally, the scenario where customers can obtain access to capacity via multiple wavelengths would only be possible if the network uses passive power splitters. This is the option proposed for the DISCUS architecture.

2.4 Technical and Techno-economic issues

The four wavelength usage options being considered also have technical and techno-economic advantages and disadvantages, which are discussed in this section.

2.4.1 Wavelengths per SP and wavelength per service options (WpSP & WpST)

Both the technical and economic challenges of these two wavelength usage options arise because of the need to change wavelength in order to change service provider or service type. To have flexible access to service providers and services will require the ONU to use tuneable components from day 1. There are technical challenges with the operation of the tuneable components and the interaction with the PON protocols and management systems. For example when a tuneable ONU cold starts it is not registered to any OLT and hence they cannot exchange information. The ONU needs to tune to the wavelength of an OLT and then start the ranging process and then finally register with the OLT. It is only after the ONU is correctly tuned, and the OLT has ranged and registered the ONU, that information about wavelength availability and assignment to SPs or services can be exchanged.

Therefore the well known problem for wavelength tuneable ONUs, to tune to an operating wavelength on the PON in order to identify itself and register and then be directed to the correct wavelength (in this case for the chosen SP), must be addressed. This problem also relates to the ownership of the wavelength: if the wavelength is wholly owned by an SP there may be no way to provide registration of ONUs not destined for that SP, that is, there may not be any management channel provided that can be used to direct the ONU to the correct wavelength for its service provider and service (Ownership models for future broadband networks are discussed in the companion white paper [13])

Alternatively the ONU would need to implement a mechanism that can tune it to the correct wavelength before it registers itself on the network. This would require implementing an absolute wavelength referencing inside both the tunable filter and tunable laser, which would impact considerably the cost of the ONU. Moreover, this implies that the customer has already decided to which SP to connect and that the ONU has knowledge of the assigned wavelengths. It is also quite likely that the customer using the ONU will not know the choices available for SPs before the ONU is registered and communicates with an OLT, only then can the SP options/choice information be passed to the customer.

Another related issue is the simultaneous access to multiple service providers and services. This could be provided by an ONU capable of multi-wavelength selection but that has significant cost and technical challenges associated with it. Multi-wavelength channel ONUs can be implemented in two ways: one is by fast-tuning the transceivers so that the ONU can time-division multiplex between the different wavelength channels. The other is by having multiple transceivers at the ONU, so that it can simultaneously operate over more than one wavelength channel. To use fast tuneable components would also require the protocols on the LR-PON wavelengths to be precisely synchronised and scheduled collectively. This would require either cooperation between SPs (or at least a well defined and enforced standard to ensure multi-wavelength TDM can be implemented), or ownership of the wavelengths by the network operator who would lease the wavelengths to the service providers but provide overall control and synchronisation.

Possible solutions to these issues:

For the WpSP case the ONU could be provided with a fixed wavelength transceiver. This would require a new ONU to be provided in order to change SP, or at least the ONU optical transceiver module would need to be changed, so that a different pair of wavelength channels is selected. This could be a cost barrier to changing providers and even if providers supply the ONUs there is greater cost and potential wasted resource as ONUs are changed out. Thus this mechanism would tend to lock customers to SPs. Fixed wavelength ONUs however cannot work for the WpST case as customers will generally want access to multiple services. Thus WpST requires random access to multiple wavelengths simultaneously. Of course if all wavelengths are demultiplexed and received at the ONU then multi-service access could be provided, but at considerable cost.

Another possible solution which could be applied to both WpSP and WpST would be for the ONU to have a tuneable optical transmitter and receiver module. With a tuneable transceiver the ONU can scan the LR-PON for active wavelength channels in a listen only mode. For this to work each wavelength must transmit an SP identification messages so that a map of SPs and corresponding wavelength can be built up by the ONU. The ONU would have a process of communicating to the customer the available SPs and the customer would be able inform the ONU of their SP selection. The ONU then tunes its transmitter and receiver to the appropriate wavelengths and ranges and registers under instruction of the OLT. An alternative method would be for the ONU to find any available wavelength and tune its receiver to it. Once the ONU can receive one of the wavelength channels it can receive information about all the wavelengths and SP assignments (assuming this is available on all wavelengths). At present it is uncertain what the additional cost of a tuneable transceiver over a fixed wavelength transceiver will be but it is likely there will be a cost penalty. An additional problem for the single tuneable transceiver ONU for the WpST option is that the ONU is required to be fast-tuning, so that one transceiver can be used in a TDM fashion to hop between different wavelengths to access the required services.

If transceivers are sufficiently low cost the ONU could be fitted with two transceivers, one at a fixed wavelength the other tuneable, however there will inevitably be a cost penalty compared to single channel ONUs. The fixed wavelength is always available and is used as a control channel, managed by the network operator. The other tuneable transceiver is used to connect to a service provider for services. ONU ranging and registration is initially done over the fixed wavelength channel and once established provides a permanent communication link for control and management of the ONU. Information about the available wavelengths and the assignments to SPs would be transferred to the ONU via this fixed wavelength channel. The SP selection process would then be the same as previously described.

The ONU could of course have multiple tuneable transceivers rather than one tuneable and one fixed wavelength transceiver. This solution would enable the simultaneous access to a number of SPs for the WpSP case, while for the WpST case it would enable simultaneous multi-service selection, an essential requirement for this option. However this is almost equivalent to multiple fixed wavelength ONUs where each wavelength will need to be terminated in an opto-electronic transceiver with electronic circuitry. Such functionality will almost certainly produce a significant cost penalty associated with this option. As a result it may be difficult for the WpST option to be an initial entry strategy as minimising upfront costs will be essential for high penetration and take-up of the fibre to the premises (FTTP) solution that will be required for a future ultra-fast and ubiquitous broadband network .

The main difference between the WpSP and WpST options is that for WpSP the number of different channels is proportional to the number of SPs used simultaneously, while for WpST it depends on the number of services used simultaneously. Thus the relative complexity of the ONU depends on whether the average user is more likely to use more SPs or more service types simultaneously. However, the economic challenges of WpST are more severe than WpSP as the former requires a multi-channel ONU to receive multiple services simultaneously.

2.4.2 Shared wavelengths used for bandwidth management (SW)

Since the shared wavelength option does not lock wavelengths to SP or services, it has the best statistical multiplexing gain, particularly for the dynamically assigned bandwidth case and therefore assures the highest PON utilization of all the scenarios discussed. The higher PON utilization also reduces the number of OLTs required at the metro-core node, reducing costs, power consumption and footprint of the node.

This scenario also reduces the cost of customer ONU equipment and also the initial cost of entry as low-cost single-wavelength non-tuneable ONTs could in fact be used at day 1, while leaving end users still free to switch between SPs and receive services from multiple SPs simultaneously using the capability of the TDMA PON protocol. However, tuneable ONTs would still remain a preferred option for future capacity upgrades, enabling the Network Operator to add wavelength channels to the PON without needing to change end user equipment, as well as manging bandwidth demands across all the available wavelengths. Certainly, an important advantage of SW over WpSP and WpST is that fast tuning or multi-channel ONTs is not required, as all the required flexibility can be achieved within any one channel. The only requirement for multi-wavelength ONUs will be for those large users requiring large amounts of bandwidth that cannot be accommodated on a single wavelength.

The disadvantage of the shared wavelength usage option is that conventional unbundling regulation cannot be carried over to this option. This is a sharing economy model where infrastructure and network resources are shared across users and service providers. Although bit stream unbundling could be applied to each wavelength operating over the optical network this would represent a less efficient use of capacity as unused capacity allocated to a bit-stream channel could not be used by other providers. What are needed are flexible bandwidth service and network products or bandwidth on demand products that only assign bandwidth to customers and service providers when customers request services from those providers. This may require new regulation to ensure full and fair open access for all service providers and customers.

2.4.3 Wavelength-per-User – WpU

For the original WDM PON, with the WDM component within the network, the ONU and OLT can be simpler than for the TWDM case, as both ends can use lower-cost and lower speed point-to-point transceivers (today these would be typically based on legacy 1GE technology). The main issues however is that the OLTs are not shared among different users, thus, although less expensive, their number is much larger. This also leads to increased overall energy consumption and equipment footprint. One additional issue is that, due to the large number of wavelengths in use it might not be practical to use fixed transceivers, mainly due to inventory issues (although from a CAPEX perspective this would be the ideal case, due to its lower cost). The limited number of wavelengths per PON also limits the maximum number of users able to share the feeder fibre of the PON so that typically more feeder fibres are required in the ODN compared to the SW TWDM solutions.

The use of coherent technology, when used with passive splitters in the ODN, allows for more flexibility in WpU, as a higher number of wavelength channels is available (in the order of 1000) which are broadcast to all users. Thus for example a business user with high capacity requirement could be assigned more than one wavelength channel on-demand. The main drawback of coherent transmission is that it is still too expensive as a large-scale start-up solution but could be a future upgrade for all wavelength usage options.

From a capacity efficiency perspective, WpU is probably the least efficient mechanism for providing broadband as it locks capacity to users independently of their actual usage or needs. In addition, in principle, it allows a peak rate that is the same as the average sustained rate, which basic traffic theory shows is highly inefficient.

2.5 Summary of wavelength usage options

Future optical access networks will need to use the multi-wavelength capabilities of optical fibre technology to grow 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 this white paper four wavelength usage options have been discussed: wavelengths assigned to service providers, wavelengths assigned to services, wavelength used flexibly for bandwidth management and wavelengths assigned to users. The FP7 DISCUS project is proposing a new flexible network architecture for future networks which could support all four options. Indeed because of the flexibility of the architecture the options need not be mutually exclusive.

However the favoured option is the fully flexible bandwidth management option (SW) which provides the potential for lowest upfront costs, the most efficient usage of network resources and the greatest opportunity for creating a fairer competitive environment while encouraging a greater entrepreneurial, innovative and competitive spirit for service provision. The wavelength for bandwidth management option does not exclude other uses of wavelengths but would be the most economical solution for mass market FTTP provision as it can start with a single wavelength using fixed wavelength technology and then gracefully evolve to the fully flexible solution as demand for bandwidth grows.

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. 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 discussed in this white paper.

3 White paper on Business and ownership models for future broadband networks

The following is the white paper on business and ownership models; it is intended to disseminate the paper via partner channels and contacts and the DISCUS project web site

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Business and ownership models for future broadband networks

3.1 Introduction

This white paper and a companion paper on wavelength usage models are aimed at starting a discussion and debate on the regulatory and business environment that a future ubiquitous access broadband network should operate within.

There are three major problems that future networks must solve as they respond to the huge demand for network capacity that could arise over the next decade. These three problems are:

- The cost of network provision and the long term financial viability for the telecoms sector.
- The huge growth in electrical power used by the world's telecommunications networks.
- The need to avoid a "digital divide" being created between those customers in dense urban areas and those in the sparser rural communities, while minimising the need for government subsidies.

The FP7 project DISCUS [1] is proposing to tackle these problems with a network architecture that radically simplifies the network structure, rebalances costs from core and metro networks towards the access (by reducing network nodes - switching and routing centres - electronic traffic processing and port cards) and promotes sharing of large scale infrastructure and equipment to reduce per user costs. In addition to technical and network design solutions the DISCUS project also takes a fresh look at the regulatory and business model environment that network providers, network operators and service providers need to operate within as the network evolves.

In considering the business model and regulatory environment DISCUS focuses on the benefits from the customer/end user perspective while giving a fair return on investment to the network and service providers (SP) to encourage network investment. One aspect of this is to provide much greater availability of competitive service provision to customers without the long period contractual lock-in that happens too often today.

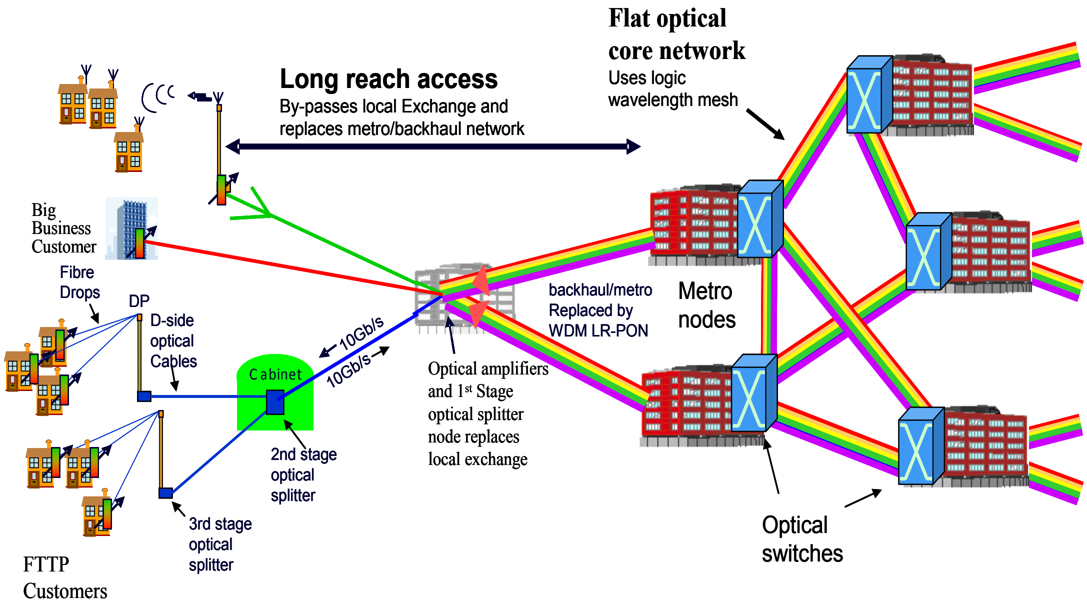

Figure 2 The end-to-end DISCUS architecture with LR-PON and flat optical core network

The DISCUS architecture, shown in Fig. 2, [2], [3] is based on large split and long reach passive optical networks in the access and metro networks and a flat wavelength switched core network interconnecting a relatively small number of traffic processing and switching nodes. The DISCUS Long-Reach Passive Optical Network (LR-PON) architecture is based on power splitters and uses optical amplifiers to overcome the power budget limitations. The use of power splitters provides the greatest transparency of the optical path between the metro-node where the LR-PON terminates and the customer premises termination and will also provide the greatest flexibility when wavelength division multiplexing (WDM) is used over the optical distribution network (ODN). The ownership and business models discussed in this paper are in the context of this network architecture.

In the companion white paper [4] the usage and ownership of optical wavelength channels is discussed. WDM will be an important technology to grow and enhance network capacity enabling more providers and content rich broadband services in the future. The use and ownership of the wavelength domain has major impact on the competitive, business and regulatory environments that the network needs to operate within. In this paper the complimentary ownership of network infrastructure and equipment and the effect on business models that can be supported as well as regulatory issues are discussed.

For this white paper the entities we are considering as potential owners of network resource, equipment and infrastructure are:

- **Network provider/operator:** The network provider would own and usually operate network equipment which is used to deliver connectivity to users and network services passing through that equipment. The network provider is therefore usually also a network operator (a provider could just be an owner of network equipment and lease this to a network operator if complete separation of the businesses id required). The operator would either be the incumbent operator or some other licensed operator (OLO). In the white paper we refer to "network provider" but it will usually means also a network operator.

- **The infrastructure owner (or provider):** We distinguish the infrastructure owner from the network provider by defining the infrastructure owner as only owning passive infrastructure, such as manholes, duct, street furniture, cables, fibre etc. They do not own network equipment including any electronic equipment housed in intermediate street furniture between the customer and the access network terminating node (the metro-core node in the DISCUS architecture or the local exchange/central office in today's networks). Of course a network provider could also own infrastructure but when we refer to an infrastructure owner/provider we are assuming a separated business.
- **The service provider:** These are users of the network that provide services to end user/customers (in this white paper when we refer to end users/customers we include all customer types, business and residential; even service providers - particularly small ones - are treated as customers in some business models). They can just offer content using network resources from the network providers, or they could offer additional services to support content distribution or other services e.g. a brokering service, authentication, billing etc. Although service providers can also own network resources, in this document we assume that they are not network providers unless we are specifically discussing issues of service provider ownership of network equipment and resources.
- **The end user or customer:** These generally would not own network equipment or network resources but they could own terminal equipment and this is discussed where it impacts on ownership models.

3.2 Network ownership models

This section discusses network infrastructure and equipment ownership models from the perspective of network provider/operator, network infrastructure owner, service and content provider and, where appropriate, the customer. In addition we will open a discussion on regulatory and competition issues. While it is obvious that these ownership models can be expanded by considering the permutations and combinations of these four business perspectives, we will only discuss those combinations that are more likely to occur and might affect the regulatory requirements of business models.

We consider the ownership options by starting with the customer premises equipment (CPE) and working deeper into the network comparing the pros and cons of different ownership and business models. To provide criteria for comparison we consider the ownership options from the perspective of the DISCUS architecture, which is predicated on:

- Infrastructure and network **resource sharing** (to reduce per customer cost)
- Equality of access so that any customer has access to the full range of network capability and services regardless of location: that is all services are ubiquitously available and **there is no digital divide**.
- The architecture should **foster an entrepreneurial spirit** and **encourage small start-up players to enter the market**. The aim is to enable new entrants to provide innovative experimental services, on a small scale initially, without requiring significant upfront investment for connectivity and capacity. If successful and the demand for these new services grows, bandwidth can be allocated in line with the demand and should only be limited by the capabilities of the CPE used by the new entrant.

Our basic criteria are therefore:

- There is **no duplication of network infrastructure and equipment** 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 that one)
- As much as possible of the **fibre infrastructure (and network equipment) should be shared by as many customers as possible**.
- **Customers should have the option to access to multiple providers simultaneously** and be able to change providers "on the fly".
- 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
- There should be **no lock-in to single providers**.
- 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.

3.2.1 *Customer premises equipment (CPE): the Optical Network Unit (ONU)*

The network CPE which will be the ONU for Fibre-to-the-Premises (FTTP) networks could be owned by the customer, the network provider, or the service provider. It could also be owned by the infrastructure provider if that provider was also the network provider.

3.2.1.1 CPE owned by network provider

The usually assumed model for the CPE or ONU for optical networks is that the network provider will own the equipment. Reasons for this include:

- Interworking between different ONUs and Optical Line Terminals (OLTs – i.e., the equipment on the network end which terminates the optical signal from the ONU) for all service configurations is not always reliable and although standards bodies such as FSAN and BBF have tried to ensure interoperability between ONUs and OLTs from different suppliers it cannot be guaranteed that all ONUs from one manufacturer will work seamlessly with the OLTs from another for all service configurations. Therefore the sourcing of ONUs is often controlled by the network provider or operator.

- There is currently (2013) not a standard for an optical Network Termination Equipment (NTE) into which a generic and adaptable ONU could be plugged by the end user (the NTE defines the edge of the operator's network and the edge of the customer's network. It is often a legal demarcation point defining the boundary of responsibilities). The ONU can perform this function when owned by the network provider.

The advantages of the network provider owning the ONU is that it removes a financial barrier to take up of FTTP provisioning as the upfront cost of the ONU is borne by the provider. The network provider will ensure compatibility with network equipment and operations, as well as being responsible for maintenance issues.

If the network provider delivers open access connectivity [5] (i.e., allows fair access to the network for customers and service providers) then ownership of the ONU should not limit service provider competition. While future access networks will invariably evolve to operating with multiple wavelengths [6], the protocol running over the PON can deliver all services from all providers through a low cost single wavelength ONU fixed wavelength transceiver. This will help to minimise entry costs. As requirements grow the ONU can be upgraded to a tuneable or even a multi-wavelength capable device at a later stage.

Disadvantages of ownership by the network provider or operator include:

- The network provider will wish to minimise changes and upgrades so evolution of ONU functionality may be slower.
- The network provider or operator has to recover the cost of the ONU which will make the business case for FTTP more difficult. However the ONU (and the final optical drop) is a "just in time" (JIT) expenditure and is only incurred when a customer requests service and revenues are generated. Thus, unlike upfront infrastructure and network equipment cost, it is lower risk and has minimal negative impact on return on investment or time to positive cash flow.
- Depending on regulation for telephony and emergency access, the network provider will be responsible for battery back-up of the ONU and also maintenance which increases operational cost.

3.2.1.2 CPE owned by service provider

Here we assume the service provider is separate from the network provider or operator. Where the service provider is also the network operator the previous discussion applies. However the case of ownership of the ONU by the service provider may restrict open access to other service providers and would not be a preferred model.

The issues associated with the ownership of the ONU by the service provider depend heavily on the wavelength usage model for a shared multi-wavelength PON solution as proposed within the DISCUS architecture [4]. If the wavelength usage model is a wavelength per service provider model, then an ONU offered to a customer by a service provider would almost certainly be part of a bundled contract. The service provider would probably provide a fairly basic low-cost ONU with a fixed transceiver operating at its assigned wavelength, as it would have no incentive in offering an ONU able to work with other providers. This would lead to contractual lock-in and a less competitive broadband market, as moving to a different SP will likely incur penalty costs and longer delays because the user will need to replace its CPE.

If however wavelengths carry services form any service provider and also all service types then an ONU can in principle receive services from any service provider. In this case the service provider would use ownership of the ONU as part of a contractual bundle for a fixed period contract for services. It may place restrictions on the ability of the ONU to deliver services from other service providers, that is it would be locked in a way analogous to mobile phone locking. However it is assumed the ONU could be unlocked at the end of the contract period and the ONU used to connect to services from other providers.

There are indeed operational issues with the service provider owning the ONU. For example, will the service provider be responsible for maintenance; will they be responsible for emergency service provision, battery back-up? It is probable that the ONU ownership model would be more like the mobile phone model and although the phone is provided by the service provider the owner effectively is the customer and the customer will be responsible for maintenance, battery back-up etc.

ONUs with tuneable transceivers would be advantageous even in a wavelength usage model where the service provider "owns" or is assigned a wavelength for sole use. The actual wavelength can then be assigned to the SP by the network provider and a service provider might be assigned different wavelengths in different PONs or metro-core nodes. Tuneable ONUs would mean that any ONU could be used on any wavelength by any service provider by just tuning it to the appropriate wavelengths during installation and registration. It is unlikely that SPs will have interest in providing a multi-wavelength ONU unless a wavelength usage model where wavelengths are assigned to services is implemented (i.e., service providers operating simultaneously on multiple wavelength channels, see companion white paper [4]), for other wavelength usage options any additional channel would probably be used for services from other competitor providers.

To summarise, if the service provider owns the ONU, it is likely that contractual lock-in will occur and competition will be poorer. The ONU will also probably be locked for some time to the original service provider making it difficult for the user to change provider. To stop such restrictive practices a strong regulation would be needed to ensure customers can access competing providers.

3.2.1.3 Customer-owned CPE

The option where the customer owns its CPE would have the least restrictions on competition. The main economic issue with customer-owned ONU is the additional cost that has to be borne and may constitute an entry barrier for some customers, thus reducing take-up. The customer will also be responsible for maintenance and any battery back-up capability if required. In addition a standardised network termination is required, into which the ONU can be plugged by the user. The cost of the ONU will depend on the functionality required, which in turn will depend on the wavelength usage model being used over the PON. For example if wavelengths are assigned to the service provider then the customer would need a tuneable transceiver in the ONU to change provider. Similarly if wavelengths are assigned to service type then a multi-channel tuneable ONU would be required. If instead the wavelengths are shared by service providers and carry all service types then the customer could buy a simple fixed-wavelength ONU and still get access to any service provider and service at any one time.

A disadvantage of customer ownership might occur in some cases as the network grows and evolves and new wavelengths are added to the PON. The network operator may need to move customers from highly loaded wavelengths to new wavelengths to balance the load across wavelengths and OLTs. Those customers owning a fixed-wavelength ONU may incur lower service quality (unless they purchase a new tuneable ONU) as the operator will not be able to reconfigure their ONU to work with a different OLT or wavelength. Another issue with customer-owned equipment is that ONUs will need to have a certification of interoperability, which could be expensive and problematic due to multi-vendor competition. In addition this will make it easier for un-certified CPEs to be connected to the PON, possibly interfering with or even interrupting the service of other ONUs.

On the other hand, customer ownership of ONU may stimulate a more dynamic market place for combining other CPE functions and ONU development with a varying range of features and capabilities. This will also minimise the issue mentioned above, as it will incentivise periodic upgrade of the ONU. Finally, customers requiring very high capacities, such as large business customers or service providers connecting to the core via the PON network, could purchase multi-wavelength ONUs with the appropriate capability (i.e., working at rates of 40 or 100Gbps, where allowed by the PON architecture).

3.2.2 Passive network access infrastructure

Passive network infrastructure includes ducts, fibre cables, casing splitters and wavelength multiplexers, if placed within the network (in this white paper we have assigned ownership of active equipment within the access network such as reach extenders or optical amplifiers to the network provider/operator). Network placement of WDM multiplexing devices is not preferred in the DISCUS architecture as it restricts the allocation of wavelength channels across the customer base, although it is an option to be considered for some wavelength bands.

The passive network infrastructure could be a separate business from the network provider or operator. One scenario of an architecture providing full separation would see the network provider leasing infrastructure from the infrastructure provider to build and configure its required network. Service providers would provide their services to the end users by leasing or having capacity assigned to them via the network providers. Separation of the infrastructure from the network provider is seen as a way of encouraging new entrants and competition into the access network provision market.

However there are problems in opening up this sector of the market: fibre to the premises is financially challenging and needs to gather revenue from as many users as possible to speed up the Return on Investment (RoI) on the infrastructure. Opening up the infrastructure to a number of competing network providers at the physical layer, installing their own competing infrastructure, will fragment those revenue streams making it even more difficult to get a financial RoI. This problem is being tackled within the DISCUS project by designing an architecture that maximises sharing of a single infrastructure over as many customers as possible by using a high-split LR-PON that has a fibre lean optical distribution network that minimises fibre cable and infrastructure investment.

An infrastructure provider would however need to pre-provide infrastructure and estimate the size of fibre cables without a detailed knowledge of the topology and architecture to be built for prospective network providers. This would almost certainly result in over provisioning of infrastructure in order to service potential parallel competitive networks, which would mean higher cost and therefore higher leasing prices to network providers. A further problem arising from multiple network providers and operators having parallel infrastructure leased from an infrastructure provider is that there would also invariably be an over provisioning of network equipment and unnecessarily higher costs and energy consumption.

However even if the competition model continues to be based on physical layer competition, the idea of allowing only one infrastructure provider would have the advantage that only one entity (i.e., the infrastructure provider) would handle the physical infrastructure. This would minimise intervention faults introduced by multiple-parties entering manholes, opening splice housings and generally disturbing other operators' fibre systems.

Infrastructure ownership by the service provider is the equivalent of today's typical scenario with vertically integrated incumbents owning both access infrastructure and service provisioning. This would require strong regulation, much beyond the principles of local loop unbundling used today for the copper network, if a truly open-access and competitive model without customers locked into long contracts is to be realised.

Infrastructure ownership by the network provider or operator may be more likely to realise the most efficient infrastructure as the fibre and cable build would be optimised to minimise first installed costs. This however will require strong and clear regulation to ensure full open access and sharing of the infrastructure over all service providers and services.

The case where the end user owns fibre infrastructure external to their premises or campus is not applicable to fibre architectures. If for example the customer installed and owned the fibre drop into their premises it would simply move the legal demarcation point between the customer's network and the operator's network from a point in his premises to a point outside. There would also be issues about ownership of infrastructure that goes beyond their property boundaries. These issues effectively rule out customer ownership of external infrastructure.

To summarise: the DISCUS architecture can support all the infrastructure ownership models discussed above but the most efficient, at least for first installed costs, would probably be ownership by the network provider as that would lead to the leanest and lowest up front cost infrastructure provision. However it is recognised that a strong regulatory environment would be required to ensure full open access.

3.2.3 Active network access equipment

The active equipment in the access network and terminating network node (the metro-core node in the DISCUS architecture) would typically be owned by the network provider. However there could also be options for some elements of network equipment to be owned by service providers.

Ownership by the network infrastructure provider is a contradiction in terms as once the infrastructure provider begins to own the network equipment they would become a more vertically integrated network provider.

Ownership by the end user is also unlikely as there is no reason for the customer to own network equipment that other users would utilise. It might be possible for large business customers to own equipment for private networks, however this would be unusual as private networking is more likely to be provided by leased capacity or by software defined and virtual networks in the future – such networks could be defined both by a full wavelength channel or capacity assigned with a wavelength to a virtual network link.

We now examine the pros and cons of ownership of some network equipment by the network provider/operator and the alternative of the service provider ownership. Again for this paper we discuss the ownership aspects from the point of view of the DISCUS architecture and to aid the discussion an example of the LR-PON access network connected to a DISCUS metro-core node is shown in Figure 3.

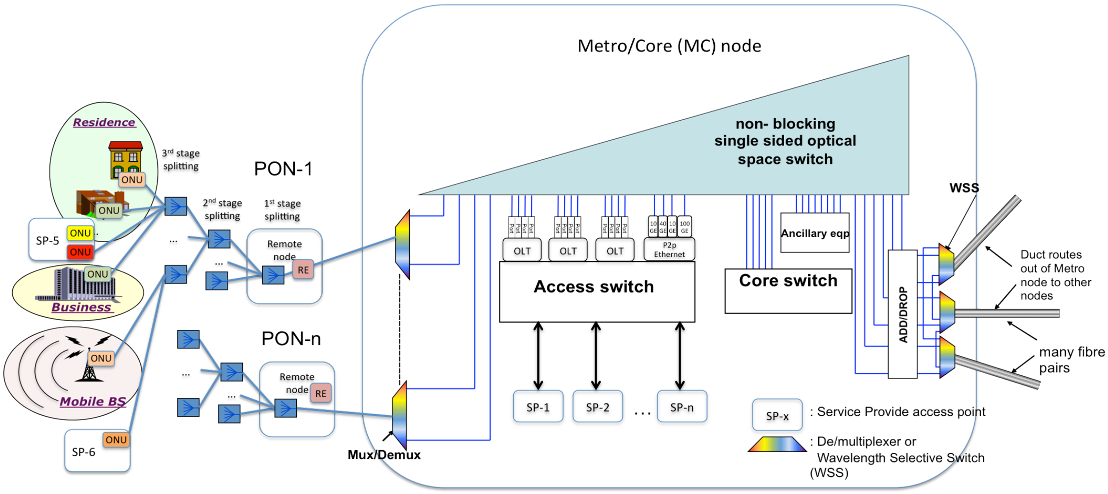

Figure 3 Example of Metro/Core node considered in the LR-PON DISCUS architecture

3.2.3.1 Reach Extenders (RE) ownership

For the LR-PON architecture a reach/optical split extender is usually required within the access network. This would usually be placed at the old local exchange site, which is by-passed in the DISCUS LR-PON architecture. Generally an optical amplifier is used, although in some cases it could include a regenerator.

The reach extender (RE) would usually be owned by the network provider. This solution makes the RE a transparent node that does not restrict open access and can be shared by all customers and service providers using that network provider. Competing network providers would provide their own REs, making this scenario compatible with all wavelength ownership and business models described.

Ownership by the service provider only works when single-wavelength amplifiers are used and wavelengths are assigned for the sole use of a service provider. However this only makes sense if the service provider also owns the transmission infrastructure at the network termination (i.e., the OLTs). The problem here is one of wavelengths management since the operation of each amplifier could disturb other channels in a WDM system. This ownership model is also incompatible with the more open and efficient wavelength sharing option where service providers share access wavelength capacity. Indeed, if the Service provider owns such network equipment this makes it a vertically integrated network provider as well as service providers and a regulatory framework would be required to ensure open access and prevent restrictive practices. Single wavelength amplifiers would also have higher power consumption and cost.

3.2.3.2 OLT

OLTs are normally designed into blade cards containing between 8 and 16 transceivers (depending on their rates). The cards plug into a shelf which provides a switching backplane and data aggregation point. Such shelves can in some cases also function as the access switch. We often use the term OLT when referring to a single PON head end terminating port, which consists of a single transceiver and the associated protocol circuitry and back plane or network interfaces.

Where wavelengths are assigned to service providers, single-PON OLTs are used solely by a service provider and therefore could be owned by them. However ownership of one PON OLT on an OLT blade would be problematic and a much better option would be for the service provider to lease it from the network provider, which will own and maintain the OLT shelf (although a large service provider might indeed own an entire shelf). Owning an OLT allows the service provider to have full control over the capacity allocation to its customers. If the customer has a fixed-wavelength ONU then the customer would be locked to the service provider that owns or leases the OLT corresponding to the customer's wavelength.

The case where the OLT is owned by the network provider is instead compatible with all business and wavelength usage models. Indeed the ability to lease capacity to all available services and service providers constitutes a more competitive business model, leading to open access and wider competition.

An additional reason in favour of network provider ownership is that of network protection. LR-PONs used in the DISCUS architecture are dual parented onto two metro-nodes. The protection mechanisms would struggle to operate correctly if the management and control of the OLTs becomes fragmented due to ownership by different service providers. Finally, the network provider ownership model can also be more efficient, as it can avoid full duplication of active OLTs and use a share protection mechanism for OLT protection rather than a 1+1 protection, which would reduce both cost and energy consumption.

3.2.3.3 Fibre and access switch

The optical circuit switch and the electronic access switch are shared between multiple OLTs and service providers and therefore would be owned by the network operator. This would ensure equality of access to network resources and minimise restrictive practices, although it may be necessary to have appropriate regulation to ensure that network providers will offer fair and open access products and services. Service provider ownership of the switching equipment would lead back to the vertical integrated operator scenario and offers no competitive advantage.

3.2.3.4 Service provider and other network operator access points

A number of different options are available for service providers to access the metro core node, which lead to different ownership models for the service router infrastructure. Some service providers may only be interested in providing content to the users, without regulating and authorizing their access to the Internet. These service providers could locate content at each metro node or else distribute it from a centralized location, and enter the metro-core node through a core network fibre link. In this case service routers are owned by the network provider, together with the access switch (they might even be embedded in the switch).

Another possibility is for the service providers, or indeed other network providers, to own service routers. These could be located at each metro node, placed at a large centrally located data centre or at a remote location. Hybrid models are also possible where larger service providers might own their own service router, while other smaller providers might share capacity on a shared router owned by the network provider/operator.

A further possibility that could be used to stimulate some competition in the network provider domain could be to have franchised areas where an operator would for example run a metro-core node area owning the access equipment, optical switch and layer 2 access switch but would also have other providers equipment such as service routers and/or core network equipment within the metro node connecting to the layer 2 access switch.

Another interesting option, valid especially for the more flexible shared wavelength business models, is that service providers could access their users directly from the ODN side of the PON via an ONU. Instead of renting dedicated fibre to reach the MC node, they could share the ODN access fibre with other broadband users, and, depending on their requirements, either be assigned a certain capacity over an existing PON wavelength, or else avail of a dedicated wavelength channel. This is illustrated in Figure 3 on the left-hand side by SP-5 which has been allocated two dedicated wavelengths, and by a smaller SP-6 which instead has been assigned capacity (for example a 1Gb/s assured rate) over a shared PON channel.

3.3 Summary of ownership and business model comparison

This section summarizes our discussions for the different ownership and business models. Essentially there a three general business model structures discussed:

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 own 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.

As mentioned in the introduction the objective of the DISCUS project is to devise an architecture that tackles the three major problems facing future ultra fast broadband 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 by minimising equipment and infrastructure build, while 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 be implemented 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.

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 start-up service providers could play a major role for the development of novel future 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, as new service providers can share capacity and access cost with other users, keeping initial investment costs low and enabling a “pay as you grow” business model for start-ups.

In conclusion we would propose 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 and also to minimise the cost for innovative new start-up service providers to obtain access to network capacity and services and an extended customer base.

4 Document Summary

The white papers in section 2 and section 3 on wavelength usage options and ownership and business models for access networks respectively are aimed at stimulating debate on how we should regulate and operate communications networks as we evolve towards ultra-fast broadband networks in the future with fibre to customer premises.

As the network evolves and user bandwidth grows, optical access networks will need to use the multi-wavelength capabilities of fibre technology to grow 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 creation of new services.

Four wavelength usage options have been considered: wavelengths assigned to service providers, wavelengths assigned to services, wavelength used flexibly for bandwidth management and wavelengths assigned to users. The FP7 DISCUS project is proposing a new network architecture for future networks that could support all four options: indeed because of the flexibility of the architecture the options need not be mutually exclusive.

However, the favoured option is the fully flexible bandwidth management option which provides the potential for lowest upfront costs, the most efficient usage of network resources and the greatest opportunity for creating a fairer competitive environment while encouraging a greater entrepreneurial, innovative and competitive spirit for service provision. The wavelength for bandwidth management option does not exclude other uses of wavelengths but would be the most economical solution for mass market FTTP provision as it can start with a low cost single wavelength ONU and then gracefully evolve to the fully flexible wavelength solution as demand for bandwidth grows.

One of the driving philosophies of the DISCUS architecture is also to share 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 maximises the resource sharing potential and minimises cost per user. However the regulation for competition needs to be reconsidered from a shared network perspective rather than continuing with the simple unbundling strategies of the past.

The second white paper discussed the different ownership and business models that could be applied to future networks. Essentially there are three general business model structures discussed:

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 own 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.

As mentioned in the introduction the objective of the DISCUS project is to devise an architecture that tackles the three major problems facing future ultra fast broadband 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 by minimising equipment and infrastructure build, while 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 services at any time: that is using the time domain for dynamic bandwidth assignment and the wavelength domain for capacity management. It is recognised however that this level of vertical integration would need strong regulation to ensure restrictive practices do not impede open access and that all service providers get fair access to customers and capacity.

Ownership of the ONU by the end-user or the network provider are most compatible with open access and service competition, while service provider ownership is more likely to lead to less competition as it enables locking of the ONU to the specific service providers.

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 better protection against failures. Multiple operators competing in the access network and optical and layer 2 switching space comes at the expense of a less efficient network, due to duplication of equipment from different providers which is likely to lead to higher costs and higher energy requirements. A better economic solution is to have a single network operator ownership, at least in a given geographical area, but with a strong and knowledgeable regulatory environment to ensure fairness and value for money pricing. A level of competition at the network provider level can be implemented via a franchising system where a network provider operates the access and metro-core node in a given geographical regions, similar to the way cable operators have had franchise arrangements.

Finally, ownership of service routers is both viable for service providers and other competing network providers. 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 but would lease capacity on a shared router. This would lower the entry cost barrier for small start-up service providers and could play a major role in the development of novel future 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, as new service providers can share capacity and access cost with other users, keeping initial investment costs to a minimum and enabling a "pay as you grow" business model for start-ups.

In conclusion we would propose 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 and also the cost for innovative new start-up service providers.

Appendices

5 Appendix I: A review of European regulation policy and structure today

5.1 General concepts

The European Community defined the European Digital Agenda that represents the roadmap for conveying the benefits of a digital society and economy to European citizens. With regards to telecommunications access, the main target has been defined as follows: By 2020, all Europeans should have access to internet of above 30 Megabits per second (Mbit/s) and 50% or more of European households have subscriptions above 100Mbit/s.

According to European Commission, there are 4 major challenges towards achieving the Digital Agenda:

- High-speed internet is considered as a key infrastructure, but Europe falls far short of the necessary investments, leaving potential for growth and societal benefits untapped;
- There is currently no adequate strategy to publicly support the rollout of broadband
- There is a too little competitive pressure on incumbents for investing in modern broadband networks. Even where projects could be financially viable, alternative public and private investors (including local administrations and public utilities) are held back by high capital costs (interest rates) and the lack of long-term funding.
- Networks in areas where there is no immediate business benefit. Current levels of European support are sub-critical and are hampered by a lack of planning and captivation capacity at the regional level.

In order to overcome these highlighted deficiencies, segments of the network that are uneconomic for competitors to duplicate such as the fibre access network should be properly regulated. The current guidelines which govern the telecoms sector in the EU were first agreed in 2002 but in this fast-developing sector, the regulatory framework needed to be revised, to ensure it continued to serve the best interests of consumers and industry in today's marketplace. An updated agreement on the EU Telecoms Reform was reached by the European Parliament and Council of Ministers on 4 November 2009, after two years of discussion during the legislative process. The new rules were transposed into national laws of the 27 Member States by May 2011 [7].

5.1.1 *European regulation instruments*

The EU legal framework for regulating telecommunications services was put into place with the aim of developing a better European market for telecommunications, for both networks and services.

There are several instruments used by the European Commission to implement its goals and they have different degrees of enforceability for the Member States' legislative bodies (i.e. obligation to follow a given instrument); thus, such instruments (treaties, regulations, directives, decisions, and recommendations) may have a direct or indirect effect on the laws of the EU's Member States:

- Any action undertaken by the EU is founded on treaties approved by the EU Member States. To achieve their aims, legislative acts such as regulations, decisions, directives and recommendations are used.
- Regulations are binding legislative acts that have to be implemented in their entirety across all EU Member States. For example, the EU has capped the maximum amount telecoms companies can charge a user for the roaming costs of their cellular telephone (EC Regulation No 544/2009) [8].
- Directives are not as binding as regulations. Instead, they are a goal that each Member State will implement according to its legislative processes. In the Framework Directive (Directive 2002/21/EC), the EC set out a roadmap in establishing a harmonized regulatory framework for electronic communication networks and services [9].
- Decisions are binding legislative acts that are directly applicable to whom it is addressed (e.g. The European Commission's March 2004 Decision [10]).
- Recommendations are not binding. Instead they express the known views of an institution. In its recommendation of 30th of March 2012 (Action for Stability, Growth and Jobs [11]), the EC stressed the potential of the ICT industry in a job-rich recovery for the EU.

The three main bodies governing European telecommunication regulation are:

- European Commission (EC)
- Body of European Regulators of Electronic Communications (BEREC)
- National Regulator Authorities (NRA)

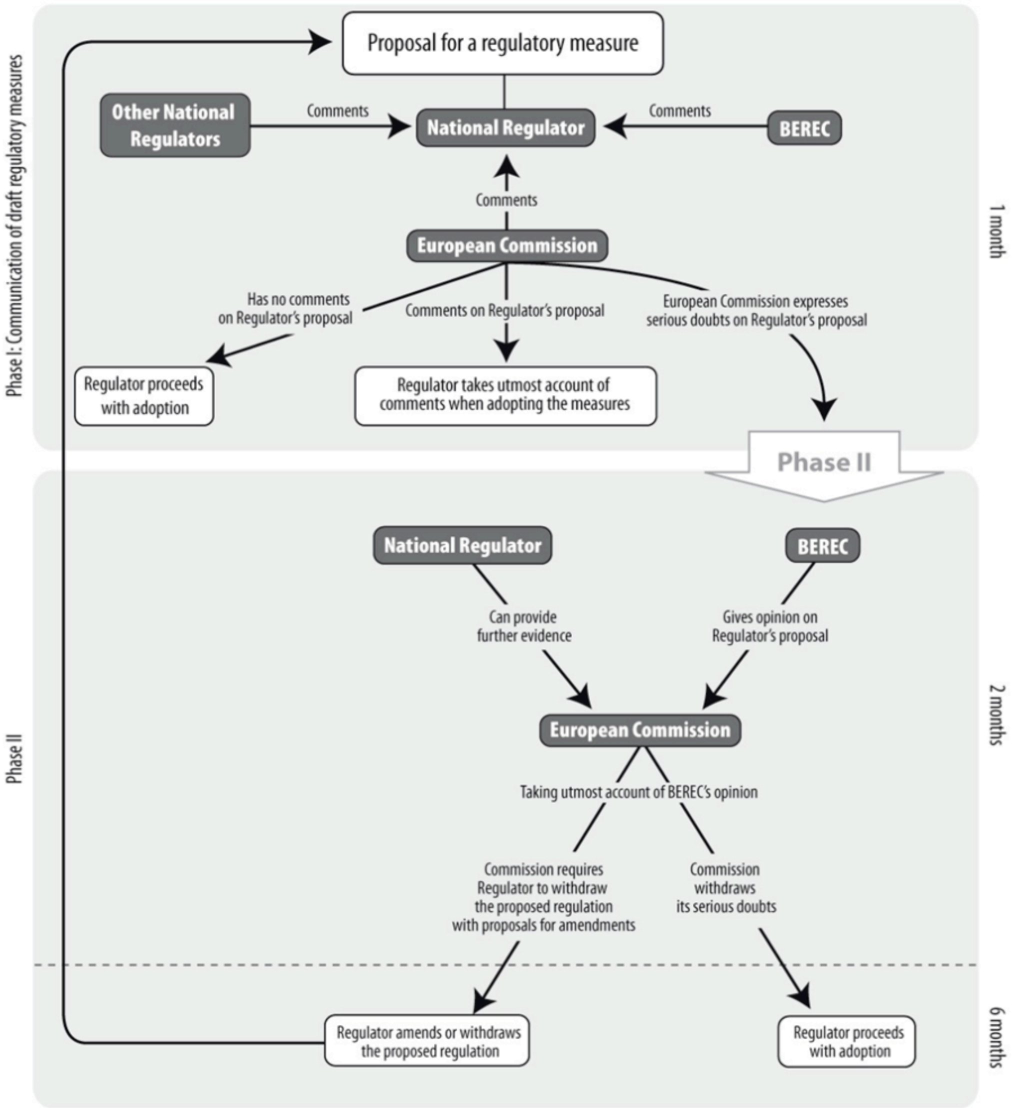

Figure 4 interaction among European regulation bodies

Figure 4 shows the interworking among European bodies involved in Telecommunications regulatory aspects in order to provide a regulator rule and its adoption.

5.1.1.1 European Commission

The European Commission (EC) is the highest pan-EU regulation body. The Directorate General (DG) which is responsible for Broadband Access regulation is the newly formed (on 25th April, effective 1st July 2012), "DG Connect", which stands for the key areas they cover (Communication Networks, Content and Technology).

5.1.1.2 Body of European Regulators of Electronic Communications (BEREC)

The Body of European Regulators of Electronic Communications is the regulating agency of the Telecommunication market in the European Union. It was created by the Telecoms Package, which was passed in September 2009. BEREC includes national regulatory authorities (NRAs) on its board and an administrative staff including Community officials..

The Members of BEREC met for the first time in January 2010 in Brussels to elect a chairman and vice chairmen, who will serve a 12-month term and will likely focus initially on topics such as Next Generation Access, Net Neutrality, Universal Service Obligations and the functional separation of local network access and backhaul network access.

5.1.1.3 National Regulator Authorities

The national regulatory authorities (NRAs) have the role to implement the EU regulatory framework for telephony, the Internet and radio and often media broadcasting in their Member State. The NRA works on consumer and competition issues, efficient utilization of resources and secure communications. One of their most important responsibilities is to regulate the behaviour of operators with Significant Market Power (hereafter SMP) within the national markets in order to ensure that there is sufficient competition. Ex-ante regulations (regulation where strong market intervention is taken by the regulator) are usually taken towards SMP. NRAs have the task of promoting obligations to encourage measures to achieve the Digital Agenda targets, to monitor the efficiency of actions taken, as well as the level of competition in the telecommunications market.

5.1.1.4 Application of European regulatory in Next Generation Access network

The European Commission also encourages member States' to produce balanced policy actions and plans to encourage private-sector investment and action for adoption of the common framework resulting from the revised EU regulatory framework for Telecommunications.

The most appealing approach is to set an appropriate coordination of planning and rules for sharing physical infrastructure, targeting and financing measures to reduce risk and to promote new open infrastructures.

Since the incumbent operators are not currently deploying a full scale Next Generation Access Networks (NGANs), other investment paths should be explored. However at present the European Union does not always allow public investments in broadband infrastructure and it is uncertain that the goals in the Digital Agenda can be reached because high Sovereign debts in European Countries have generated rules that block initiatives from the public sector (e.g. municipalities).

5.1.1.5 Italian regulatory aspects on access and core networks

This sub-section outlines the responsibilities of the Italian NRA as an example of NRA obligations and responsibilities within the European Union.

5.1.1.6 The AGCOM "Autorità delle garanzie per le telecomunicazioni"

The NRA in Italy is the AGCom "Autorità delle garanzie per le telecomunicazioni", that is an independent authority, established by Law 249 of 31 July 1997. Independence and autonomy are essential elements that characterize the activities and deliberations. Likewise the other Italian authorities, the NRA must report on its activities to the Parliament, which established its roles, defined its bylaws and elects its organs:

- the President
- the Commission for the infrastructure and networks
- the Commission for the services and products the Council.

Each Commission is a collegial body, consisting of the Chairman and two Commissioners.

The Council consists of the President and all the Commissioners.

The NRA is primarily an authority to guarantee the law establishing. The Authority has dual responsibility of ensuring fair competition among the market players and to protect the consumption of citizens' fundamental freedoms.

The authority for the Communications Regulatory Authority is "converging", that means to attribute to a single body; functions of regulation and supervision in the areas of telecommunications, media and publishing. It is a choice justified by the changes brought about by the development of digital technology, which merges - video, voice, data enabling them to become increasingly interactive. Telephone, television and computers are also converging on to the same technology platforms, thereby expanding the range of services available.

The model adopted by the Authority is almost an exception in the international scene and is now watched with growing interest from many countries.

In this sense, The Communications Regulatory authority covers:

- operators, through:
  - the implementation of liberalization in the telecommunications sector, with activities for regulation, supervision and dispute resolution;
  - rationalization of resources in the sector;
  - the application of antitrust law in the communications and verification of any dominant positions;
  - the management of the Unified Register of Communications Operators;
  - the protection of the copyright in the computer industry and audiovisual content sector.
- citizens, through:
  - supervision on the quality and methods of distribution of services and products, including advertising;
  - the resolution of disputes between operators and users;
  - enforcement of the universal service obligation and the provision of standards to safeguard disadvantaged groups;
  - the protection of pluralism, social, political and economic in the field of radio and television.

5.1.1.7 Current synthesis of AGCOM obligations for access networks and use of network infrastructure

These section reports the current obligations for access network use (mainly owned by Telecom Italia S.p.A.). The rules are governed by Del. AGCom 1/12/CONS [12]. For sake of simplicity, it is possible to split them into three main categories:

- Obligations related to the overall market for physical access to network infrastructures:
    - access to infrastructure installation (cable ducts, manholes, poles, etc..) and to dark fibre. Also to access points in the network for example the central office/local exchange, the primary cables (or e-side cables) the secondary cables (or d-side cables) and the in building cable infrastructure.
    - For FTTH and FTTB access to the terminating segment in copper and fibre should be guaranteed. In the case of FTTN, there is the obligation to provide Sub Loop Unbundling.
    - Physical and virtual co-location in the local exchange and at the points of concentration (e.g. active cabinets).
    - Access to LLU fibre where technically feasible and admission to end-to-end solution comprehensive of the LLU fibre.
    - Services are published (and sold) under conditions equivalent to those applied to its retail divisions and accounting separation.
    - Prices based on the industrial cost. In the case of new construction of infrastructure and in the absence of forms of co-investment a risk factor may be applied.
- Obligations related to the overall market for wholesale broadband (bit-stream)
    - Provision of bit-stream access services on fiber network regardless of network (FTTH, FTTB, FTTN) delivered via Ethernet interface level:
- nodes of the local exchange (VULA - Virtual Unbundled Local Access)
- parent nodes at the level of collection area
- distant nodes at the level of macro-collection (30 macro-identified); any node feeder of a macro can act as a parent and distant with a suitable backhaul
- remote nodes with delivery at the IP layer.
    - Delivery of ways to access the functionality of multicast and delivery of all CoS available on the Telecom Italia network
    - Long distance transport service for the collection of traffic from feeder nodes belonging to different macro-areas.
    - Services are published (and sold) under conditions equivalent to those applied to its retail divisions and accounting separation
    - For VULA and bit-stream in the collect area there is the obligation of non-discrimination in competitive areas, and cost orientation with risk premium in the other.
    - OLO should be able to offers broadband at the same conditions as Telecom Italia's access to broadband fibre only 60 days after publication of the offer bit-stream over fibre approved by the Authority.
- Copper to fibre migration
    - Telecom Italia is required to inform the OLOs with a 5-year notice of the intention to dispose or to convert access points at the local exchanges.

- Telecom Italia must inform at least 3 years in advance OLOs about the sale or conversion of power stations that are not open to LLU on copper.

5.1.2 The NGN ITU-T open access model applied to the DISCUS architecture

DISCUS is designing and validating a network architecture based on LR-PONs and flat optical core networks in order to produce a simplified and evolvable architecture that will be the foundation of communications for the long term future.

The majority of rules and obligations currently imposed by the European Regulator bodies (EC, BEREC and NRAs) are tailored for current access network based on FTTH, FTTB, or FTTN, because the main spirit of regulatory bodies is to enhance competiveness and in the difficult-replicable infrastructure, in order to guarantee a fair access, of course remain.

Merely dedicated to the DISCUS, the regulator rules tailored on the innovative architecture devised by the Project could inherited what is described about the copper to fibre migration in Italy, based on a scenario where the incumbent Operator owns the infrastructure and must communicate in advance with OLOs about changes in the infrastructure (topology, power stations, …).

Finally, it is fundamental that new regulator rules will be compliant with the important principle imposed by the European Digital agenda of guaranteeing to all Europeans the access to internet of above 30 Megabits per second (Mbit/s) and 50% or more of European households have subscriptions above 100Mbit/s. In order to achieve this goal Telecommunication market should operate in a competitive behaviour. The main rule to be applied are:

- The Incumbent Operator is obliged of non-discrimination in competitive areas.
- In the other areas, the cost offered by Incumbent Operator to OLOs for fibre and transport services might be orientated applying a risk premium

6 Appendix II: Open Access Models in FTTH Networks

6.1 Introduction

This appendix reports the finding of a survey on current views on Open Access networks. There are basically three reasons for Open Access:

1. **Network coverage:**

   Telecom operators usually are not willing to roll out a fibre network covering all areas of a country due to exorbitant cost which does not correspond to an adequate return of investment for privately owned companies in the usually expected timeframe of 5 to 7 years. So they are restricting themselves to deploy only in the most densely populated areas (large towns, etc.) and neglecting the rest. Another consequence also due to cost reasons is the restriction to a FTTC type network instead of a true FTTH network.

2. **Cost effectiveness:**

An open access infrastructure allows the costs to be shared among multiple service providers; it also increases the utilization of the infrastructure.

3. **Competition:**

The original copper access network operated by incumbent operators was largely constructed during the phase of public ownership. It was therefore perfectly reasonable for this infrastructure to be available to competitive operators on equally and fair terms and Local Loop Unbundling (LLU) regulations were put in place to ensure this. A fibre to the premises or node infrastructure will now however be financed by the network operator/s that build it and they will be reluctant to share that infrastructure without a fair return on that investment. Therefore it may be necessary to establish a regulatory structure to enable open access to the network in a regulated manner so that adequate competition continues to exist. It is difficult enough to build a single access fibre network and make a sensible return on that investment, the construction of multiple fibre networks by multiple competitors is doomed to economic failure and will not happen, therefore some regulated mechanism to open up the access network while making it a reasonable business case for the operator that builds the network (probably the incumbent operator) will be necessary

6.2 Open access principles

Open access to networks means that ownership and access to the different layers of the network are separated from each other and competition is created in all network layers. All interested operators and service providers must be able to obtain access to the network on fair, equivalent and non-discriminatory terms, i.e., the price for access is identical for all parties.

The different layers of an FTTH network can be described as shown in Figure 5:

- **Layer 1:** involves the passive infrastructure (ducts, trenches, poles, fibres, fibre enclosures, splicing shelves, in-house wiring, etc.); sometimes it is distinguished even between a Layer "0" (ducts, trenches, poles) and a "real" Layer 1 with the transmission medium (fibre). With regard to the network ownership one can distinguish between ownership of the passive infrastructure of the optical access network, i.e., ducts, poles, enclosures (Layer "0") and ownership of "dark" fibres and in-house wiring (Layer 1). This separation does not hold of course when fibres are directly buried.
- **Layer 2:** is the active network (electronic network equipment, business and operations support)
- **Layer 3:** is attributed to the retail services (residential, public and business) with direct contact to the end users

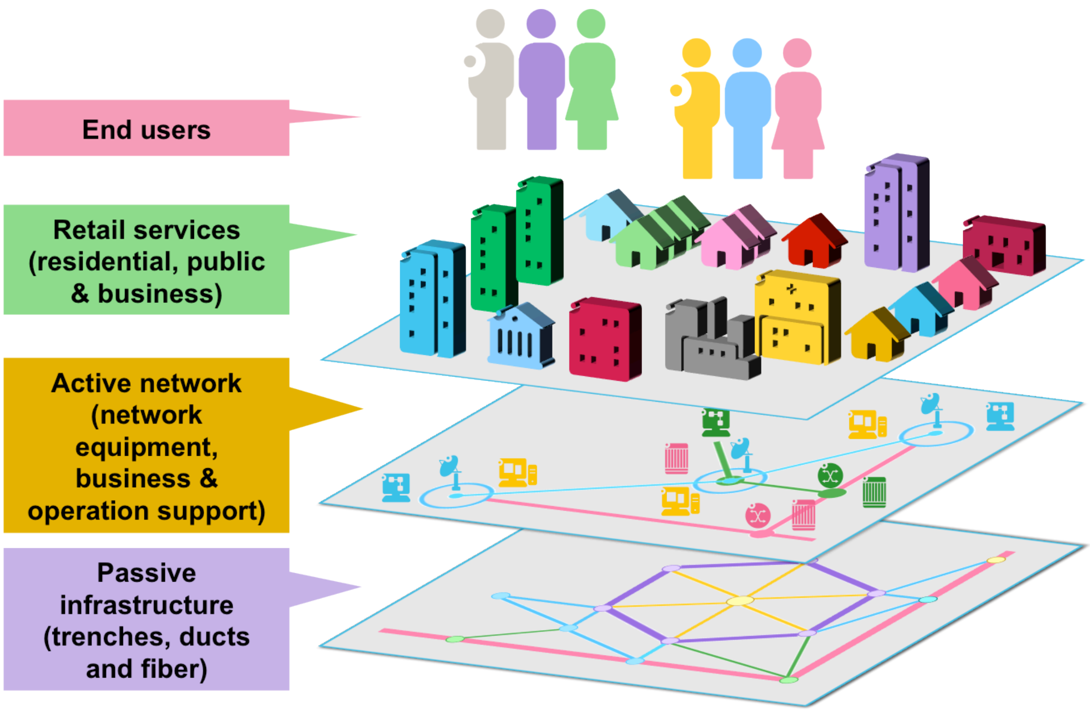

Figure 5 FTTH network layers (Source: FTTH Business Guide 2012 – FTTH Council Europe)

According to this segmentation, ownership of each of the different network layers can be in one or more hands.

Infrastructure providers have ownership of the passive infrastructure including (or not) the (dark) fibres. If fibres are not included other infrastructure providers can gain access to the ducts to blow their own fibre strands into the ducts and rent them to operators. Duct sharing however has serious practical difficulties relating to physical security when multiple parties have open access to layer 0. A third party can easily damage existing installed fibres and cables. There could be different working practices between operators and shared fibre joints may need to be opened by more than one network provider which could disturb working fibre causing transient errors on working systems.

Network operators will supply all the necessary active electronic equipment and services to operate the network.

On the highest level (internet) service providers can gain access to the network and deliver services (internet access, IPTV, voice) to end customers.

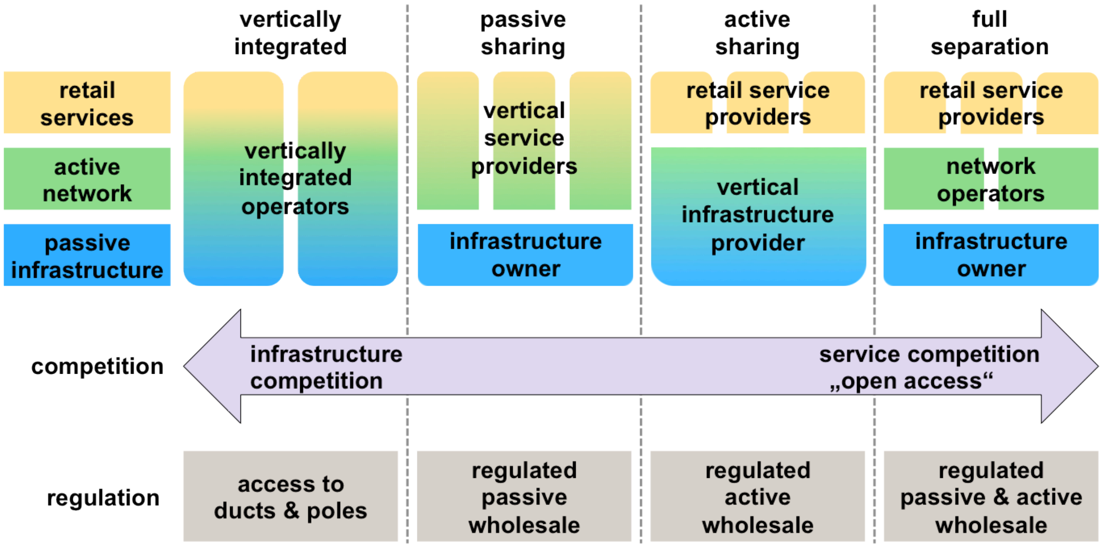

Figure 6 FTTH Business Models (Source: FTTH Business Handbook 2012 – FTTH Council Europe)

With regard to different kinds of ownership of the different network layers we can define several possible FTTH business scenarios (see Figure 6):

- **Vertically integrated:**

  Only one company owns and controls all layers of the network which is the traditional telecom model applied by most of the incumbent operators like Deutsche Telekom, Orange or Verizon. If a second operator is interested in offering services they would have to build or lease their own infrastructure, operate the network and offer services directly to end customers. This is the purest form of infrastructure competition but probably the least efficient and most costly.

- **Passive sharing:**
  A single passive infrastructure is owned by one infrastructure provider. Network operation and service provisioning is also concentrated in one hand. If a second service provider wants to enter the business he can share the same passive infrastructure but has to invest in active electronic equipment for network management.
- **Active sharing:**
  A single organization owns the passive as well as the active infrastructure and also operates the network. This vertical infrastructure provider offers wholesales access to various retail service providers who then compete with each other for customers.
  Their could also be separation of the passive infrastructure ownership and the active infrastructure ownership in which case a service provider would negotiate services from either both providers or the active provider where they have negotiated the physical layer access for their active equipment.
- **Full separation:**
  The different layers have different ownership. We have one infrastructure provider, one (or more) network operators and one (or usually many)

service providers which are clearly separated one from another. The infrastructure provider is generating income by providing access to the passive infrastructure to one or more network operators, who in turn wholesale access to retail service providers.

The most obvious business model for an Open Access network is full separation, but other models are also possible. Functional separation separates the ownership of the network from service provision.

One driving force behind the idea of open access networks is the need to achieve significant cost savings by means of sharing the infrastructure, i.e., infrastructure should be used by more than only one party whenever possible.

Since the cost for civil works is by far the largest part of the total network cost it makes not much sense to duplicate this part of the network for sake of competition. Privately owned telecom companies are expected to have a ROI of about 5-7 years, so they tend to build FTTH networks preferably in densely populated areas, if at all. Very often they are restricting themselves to an FTTC approach. This is the chance for organizations with a long-term view like municipalities and utilities. They can afford a ROI of 20 years and above. A fibre network could also be seen as a kind of common public infrastructure which should then also be owned by the community.

Therefore, in an open access approach it makes most sense if the layer "0" passive infrastructure does exist only once (neglecting competition from cable operators) and can be owned not only by private companies but to an increasing part also by municipalities and national utilities.

6.2.1 Access to FTTH networks

Entrance to access networks is possible at different levels. The lower the entry level the more differentiation is possible, but the associated cost is higher; the higher the entry level the less differentiation is possible, but the cost is lower.

6.2.1.1 Passive Layer Access

On the lowest level, access is given to the passive layer. Here the passive infrastructure is shared, e.g., ducts, poles, dark fibre, enclosures, splitter cabinets, and also very important, the in-house wiring. This type of access is of interest for network operators. In terms of effectiveness it is optimal to have only one passive infrastructure provider.

There is only place for more than one network operator if at least more than one fibre (or wavelength per fibre in the future) to every end customer is available. A special variant is the possibility that network operators blow their own fibre strands into the ducts (supply of only the transmission medium) and share only the rest of the passive infrastructure. This approach is rather common in Europe.

The situation may also be different for different network topologies. In Point-to-point (PtP) networks every service provider usually gets his own fibre to customer.

The access point is usually located at the Optical Distribution Frame (ODF) at the Central Office (CO).

PtP open access FTTH networks have been deployed in Europe by early adopters like the municipalities and utilities in the Nordics. Stokab in Stockholm and Hafslund in Oslo are providing dark fibre services to a lot of network operators and service providers. In the Netherlands, Reggefiber at a national level and the Amsterdam CityNet are running PtP networks. In Switzerland Swisscom in cooperation with utilities is providing 4 fibres per apartment plus 4 fibres per building. One fibre is intended for Swisscom, one for the utility and the rest is reserved for future use.

In Point-to-Multipoint (PtMP) networks (PONs) this isn't as easy because of the ubiquitous passive splitter (Figure 7). One would have to supply multiple fibre strands (one per service provider) and multiple splitters (one per service provider). Behind the last splitter the situation is the same as in a single PON structure. The selection of a service provider is done by changing to the appropriate splitter.

The access point is the concentration or flexibility point. Usually this is the last splitter location.

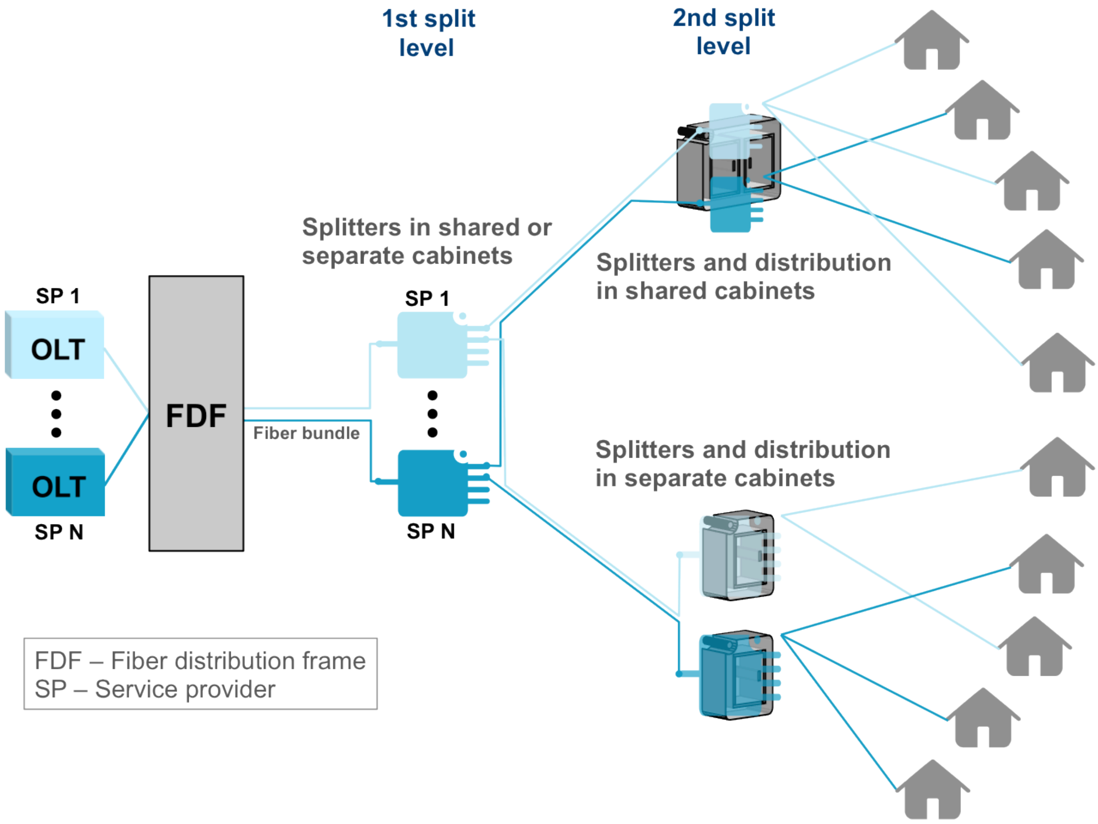

Figure 7 Fibre path unbundling for GPON (Source: ECI Telecom)

This type of unbundling (at the passive layer) is the preferred one for PtP topologies (PtP is similar to LLU for the copper network. In this case the regulatory environment for copper LLU can be largely carried over and adapted to the fibre network).

Generally it offers the highest level of opportunity for differentiation, but there is a risk of duplicative investment and fragmentation, thus increasing the cost of competition. From a customer perspective it does not enable simultaneous multiple access to different service and network providers and will still lead to contractual lock-in. also physical work may be required to change service providers (e.g.. field splicing to reroute fibre and/or changing optical jumpers at the ODF) again limiting the ease of changing service providers.

6.2.1.2 Active Layer Access

On the next level access is given to the active (data link) layer. The active physical network equipment such as OLT and ONUs is shared and (mostly Ethernet) bit stream service is offered which is of interest for service providers. This is the most important kind of unbundling for PON systems. The access point is in the CO/ Local Exchange. The cost is lower than that for passive unbundling, but there are limitations in product and price innovation and differentiation.

The large national FTTH networks in Australia, New Zealand and Singapore are using GPON networks at least in part of their open access deployments and offer Ethernet bit stream access to service providers. Also nearly all other GPON open networks offer bit stream access as well.

6.2.1.3 Wavelength layer access

An alternative to or an addition to bit stream sharing at the electrical protocol layers would be to use the optical wavelength domain. This allows passive sharing with active layer access but does have consequences for the technology requirements at the OLT and ONT and also depending on the nature of the sharing could restrict some flexibility of wavelength usage and business model options. Wavelength usage is discussed in more detail in the next section

6.3 Summary of open access options

Business Model	**Pros**		**Cons**	
	User	**Operator**	**User**	**Operator**
Vertically integrated		total control of the whole network, value chain and cash flow	no choice of different SPs because of no competition?	competition only via duplicate infrastructure; complex operation; highest costs
Passive sharing		IP: simple operations;		IP: largest part of costs

		highest revenue potential NO/SP: gain significant margin for modest investment		
Active sharing		SP: lowest entry costs to the business		SP: less possibility of differentiation and innovation
Full separation	highest level of competition and innovation;	SP: lowest entry threshold		highest level of necessary coordination SP: less possibility of differentiation and innovation

IP: infrastructure provider; NO: network operator; SP: service provider

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Abbreviations

AGCom	Autorità delle garanzie per le telecomunicazioni
BEREC	Body of European Regulators of Electronic Communications
CO	Central Office
CPE	Customer Premises Equipment
DSL	Digital Subscriber Line
EC	European Community
EDFA	Erbium-Doped Fibre Amplifier
EU	European Union
FP7	Framework Program 7
FTTB	Fibre-To-The-Building
FTTC	Fibre-To-The-Cabinet
FTTH	Fibre-To-The-Home
FTTN	Fibre-To-The-Node
FTTP	Fibre-To-The-Premises
GE	Gigabit Ethernet
LLU	Local Loop Unbundling
LR-PON	Long-Reach Passive Optical Network
NGAN	Next Generation Access Network
NO	Network Operator
NRA	National Regulator Authority
NTE	Network Termination Equipment
ODF	Optical Distribution Frame
ODN	Optical Distribution Network
OLO	Other Licensed Operator
OLT	Optical Line Terminal

ONU	Optical Network Unit
OSNR	Optical Signal-To-Noise Ratio
PON	Passive Optical Network
PtMP	Point to Multi Point
PtP	Point to Point
RE	Reach Extender
ROI	Return On Investment
SMP	Significant Market Power
SP	Service Provider
SW	Shared Wavelengths
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
VC	Virtual Circuit
VLAN	Virtual Local Area Network
VoD	Video on Demand
VoIP	Voice over IP
VULA	Virtual Unbundled Local Access
WDM	Wavelength Division Multiplexing
WpSP	Wavelength per Service Provider
WpST	Wavelength per Service Type
WpU	Wavelength per User