Software-defined networking in a multi-purpose DWDM-centric metro/aggregation network

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Abstract—**A DWDM-centric solution is a promising approach to build a multiservice metro/aggregation network that meets the future requirements on capacity, cost, and energy-efficiency for both residential, business and mobile backhaul/fronthaul transport. We propose to use SDN to provide a suitable control mechanism of the optical and packet layers in the network. We also introduce a discovery unit, which detects newly connected DWDM clients and sets up the corresponding optical service. This is demonstrated for the case of a converged fixed and mobile infrastructure. We then describe how this network and control architecture can be used to provide services to different client network applications, where the details of the physical infrastructure are hidden through network virtualization.**

Keywords—SDN; DWDM; converged networks; mobile backhaul;

I. INTRODUCTION

Software-defined networking (SDN) is a concept in which network control and forwarding are decoupled, and network state and intelligence are moved to a logically centralized control plane. Data plane elements are configured and programmed by the remote control plane via open interfaces, e.g. OpenFlow [1]. At the same time, the centralized control plane presents an abstracted view of the entire network to any type of control program or service application using the network. By exposing a common, open API to abstract the underlying networking details, SDN enables easy programmability, automation, and network control of even multi-domain and multi-technology environments. This can potentially translate into great savings in terms of operational costs (i.e. OPEX). This programmable interface offers the necessary premises for the introduction of new network applications in a rapid and simple way. Also CAPEX reductions can be expected, since control and data plane separation allows utilization of inexpensive and simple networking nodes. Furthermore, SDN enables efficient network virtualization, allowing to share network infrastructure for e.g. multi-tenency or service-isolation scenarios. This opens up opportunities for new business models and promises further economical effects by sharing infrastructure costs (i.e. CAPEX) [2].

SDN concepts have been well studied and demonstrated in numerous cases for data center use cases and packet domains in general [3][4][5]. The current trend is the extension of SDN protocols (primarily OpenFlow) to other domains than the traditional packet and data center domains. One of these extensions covers optical transport networks [6][7][8][9]. While this is work in progress, the expected benefits of extending SDN to optical transport networks is mainly the integration of the packet domain with the optical domain, for a more flexible and optimal control of both network layers and resources. It is also suggested that the integration of multiple domains and the support of different control mechanisms (programmatic interfaces) is better supported with an SDN architecture, as described in e.g. [10].

In the metro/aggregation segment traffic growth is driving evolution towards the use of dense wavelength-division multiplexing (DWDM) technologies which currently are predominantly used in the core and increasingly in metro. This evolution is driven by cost reduction of DWDM technology as well as the need for reducing cost and energy consumption as traffic volumes grow [11][12]. At low volumes, packet networks are cost effective as CAPEX is driven by physical links (fibers, fiber lengths, ports, port capacity, etc.) rather than packet processing (switching, routing, etc.). Link costs depend mainly on the number of clients, peak client capacity and link lengths, whilst packet processing is driven by traffic volume. For growing volumes, the cost portion associated with packet processing is expected to grow. Such costs include not only CAPEX, but also operational aspects such as energy consumption. With DWDM, the scaling of CAPEX associated with packet processing and fiber infrastructure can be mitigated to provide a more scalable and future proof transport solution

In addition to traffic volume, new developments in the mobile domain have introduced stringent transport requirements which have challenged packet based transport and led to the wider spread adoption of WDM. One example is RAN architectures based on centralized baseband processing where centralization is used as an avenue to reduce costs and energy consumption in the RAN through site simplification and resource pooling. Such RAN architectures, based on fronthaul (e.g. Common Public Radio Interface (CPRI) [13][14]), introduce stringent transport requirements in terms of bandwidth, latency and jitter. Another related example is radio interference coordination across neighboring base stations (e.g. coordinated multipoint (CoMP) technology [15][16]) where coordination is used to improve radio performance. Such schemes can be implemented using CPRI-based deployment making tight coordination possible. But some coordination features can also be supported with traditional backhaul over the X2 interface between adjacent base stations. Beyond fixed and mobile access, the metro/aggregation infrastructure also has to cater for transport needs of distributed data centers and content distribution networks. For example, in order to synchronize data-centers it is desirable to be able to regularly schedule high capacity point-to-point connections over the infrastructure, which conveniently could be handled by DWDM-centric transport.

SDN is assumed to play an important role in future transport networks [17][18], and many of the foreseen benefits are highly relevant in the metro/aggregation region. It is important to understand how DWDM-centric network solutions can be integrated into a wider SDN context in order to exploit benefits such as programmability, automation and virtualization. In a service-provider environment, SDN provides a potential solution for cost-effective network operations, and for isolation of different clients by means of network virtualization.

The organization of this paper is as follows. First, section II presents a DWDM-centric solution for the metro/aggregation domain. We then introduce the discovery unit in section III to enable the optical layer control to automatically configure the network after attachment of new optical equipment. Section IV then reports on a demo that shows key elements of the discovery process. Then section V outlines the role of the DWDM-solution in relation to the packet-based SDN. Finally, section VI describes the applicability of DWDM-centric metro/aggregation in different scenarios and Section VII concludes this paper.

II. DWDM-CENTRIC METRO/AGGREGATION

In this section we describe a DWDM-centric solution for the metro/aggregation, previously proposed in [11], spanning from the access to the service edge. For metro/aggregation it is important that the transport infrastructure remains flexible and scalable to support service changes as well as the increasing number of clients. With the large quantity of network elements in the metro/aggregation, compared to current main application areas for DWDM, operational aspect are of increased importance. Hence simplification of operational processes and reduction of planning needs are important aspects. These aspects as well as protection, introduce a number of flexibility requirements on the DWDM-centric solution:

- Service changes: Ability to easily upgrade or change services.
- Extensibility: Ability to easily extend the network with more access ports/sites/rings etc.
- Colorless clients: Clients can connect to any access port which reduces planning needs.
- Protection: Ability to switch to alternative paths in case of failure.
- Resource lean network dimensioning: Ability to dynamically reallocate resources depending on needs.

Fig. 1 presents a DWDM-centric solution [11] that can meet these requirements. It is a solution that provides flexible wavelength connectivity between the access and service edge. A central idea here is to simplify the network and the switching nodes as much as possible. As a result the full functionality of the reconfigurable optical add/drop multiplexer (ROADM) is not needed. The solution is based on wavelength-selective switches (WSSes), mini-ROADMs and reconfigurable optical interfaces. Together these building blocks enable flexible selection and routing of wavelengths through the optical network between client and service edge interfaces.

In this network solution, mini-ROADMs are used in the access rings to add/drop wavelengths to clients. At central office locations, WSSes are used to aggregate wavelengths from access rings or trees. The WSS flexibility is here used for provisioning wavelength resources between different access segments and for providing access ring protection. These central office WSSes may be either directly connected to the services edge WSSes via point-to-point fiber or alternatively via intermediate central office WSSes. The service edge WSSes enable flexible service provisioning.

This network architecture supports the evolving traffic pattern where an increasing part of the traffic flows between a

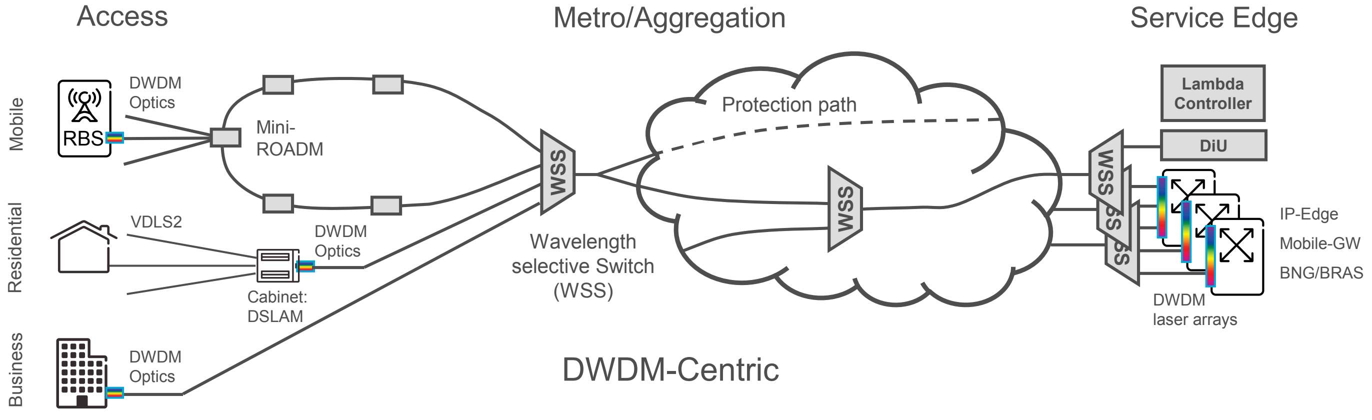

Fig. 1. Schematic view of a DWDM-centric solution for an aggregation/metro region. The solution is based on wavelength selective switches (WSSes), mini-ROADMs and reconfigurable optical interfaces. Together these building blocks enable sufficient flexibility in and routing of wavelengths through the optical network between client and service edge interfaces. On the service edge side, the discovery unit (DiU) enables the identification of newly connected client equipment. On the access side, the network connects to mobile access, fixed access, and business applications.

few central locations and the access side. Depending on the connectivity needs, additional flexibility can be added to the basic architecture in [11] to allow for a certain amount of lateral connectivity within an aggregation region. And based on how different flexibility aspects are valued, some of the flexibility can be constricted by wavelength ridged elements (OADMs, AWGs, fixed wavelength interfaces) in order to save CAPEX.

In line with the goal of simplifying the network nodes, SDN-based control is suitable for the DWDM-centric network. The control plane functions are centralized in a Lambda Control Unit (LCU), and in the network nodes, a minimal set of software functions are kept. A relatively simple programmatic interface is used between the nodes and the controller. This interface can be based on NetConf, SNMP, future extensions of OpenFlow, or a custom protocol.

Service assurance is handled through use of smart optical interfaces on the client and service edge side, capable of collecting PM data, and by providing OAM connectivity between the optical interfaces and the LCU. The optical interfaces provide the demarcation points between the DWDM transport and what is carried over the transport, to enable a well-defined measurement point for a service-level agreement. Fig. 1 illustrates the separation between the packet and optical domains and the demarcation points of the DWDM-centric solution. On the client side the demarcation points are the DWDM SFPs in the RBS, enterprise client and aggregation switch for residential clients. For the service edge, the demarcation points are the DWDM laser arrays.

III. OPTICAL FLOW DISCOVERY

The previous section outlines the building blocks for a flexible DWDM-centric solution for metro/aggregation. In addition to flexibility, automation is key for reducing operational complexity. For the DWDM-centric solution, a particularly important part of the control is the discovery and provisioning of new clients. Here we propose a solution, analogous to OpenFlow, for automating this control.

Within a packet domain, an OpenFlow controller configures the forwarding rules and actions to take on packet flows entering a switch. This can be done proactively or reactively. In the proactive case the OpenFlow controller has already programmed matching flow rules in the switches along the path prior to the arrival of a flow. In the reactive mode, the switch can be configured to handle unknown flows, which is key to the operation of OpenFlow. When a packet which belongs to an *unknown flow* is detected, its header information is sent to the controller. Then, the controller identifies the packet and configures the switches to route the flow to its destination, in accordance with defined policies in place. In this context, it is desirable to pro-actively establish an optical circuit flow based on expected demand. If the optical circuit is to be established reactively, after detection of a packet flow, the controller has to signal the optical circuit establishment before configuring the packet flow tables in the switches along the path of the packet flow.

In the optical layer, flexibility is enabled by reconfigurable optical interfaces and ROADMs, and implemented through control mechanisms such as GMPLS, NMS/EMS, or lately by optical SDN protocol extensions (work in progress [9]). Our goal is to support automatic discovery of client nodes attached to the optical network analogous to how packet flows are detected in the OpenFlow case, and depending on the attached equipment, to enable automatic configuration of the optical nodes to provision wavelength paths between the client node and the corresponding service equipment. As illustrated in Fig. 1, a discovery unit (DiU) is located centrally in the network, logically connected to the LCU. The DiU is responsible for identifying new clients that are attached to the domain. Initially, there is a wavelength pre-assignment in the optical domain such that each client port is assigned a unique wavelength pair (upstream/downstream) which is routed to the DiU through the WSSes. In order to be detected, the tunable

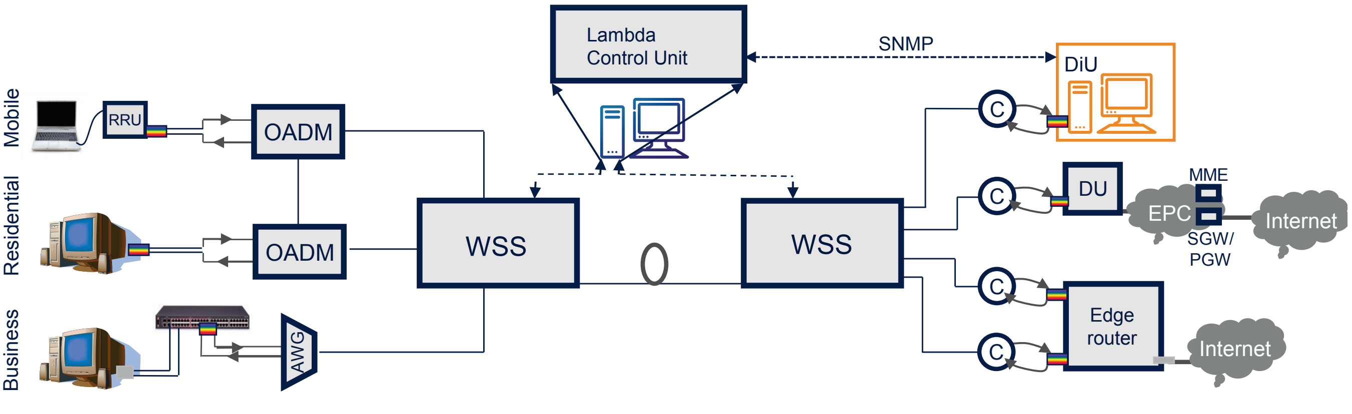

Fig. 2. The demo set-up of DWDM centric metro/aggregation supporting client discovery and simplified service discovery. The demo is based on fixed optical add drop multiplexers (OADMs) instead of mini-ROADMs, which are connected to the service edged through wavelength selective switches. On the service edge side, there is a digital unit (DU) connected to a mobile core (EPC, MME, SGW, PGW) which serves the remote radio unit (RRU), and an edge router which serves the residential and business connections.

client optics must be transmitting and it then scans the transmitter across the wavelength spectrum upon connection. In the scanning process, as the client optical interface transmits on the pre-assigned upstream wavelength, it is discovered by the DiU. The DiU is capable of wavelength identification in order to determine the optical port to which the new client is attached and to transmit an acknowledgement of discovery. If multiple clients attach simultaneously, the WSSes can be controlled to isolate a single new client with a bi-furcated search method. Furthermore, the DiU identifies the service type, either by protocol identification or through setting up a temporary communication link to the client in order to extract its identity by its serial number. The existence of a newly connected client as well as the extracted client information is passed on to the Lambda Controller Unit (LCU) which provisions the wavelength path according to predefined policies. In the provisioning, the LCU optionally assigns a new wavelength to the client node, and then configures the mini-ROADMs and WSS in the network to setup the wavelength path between the client node and the service edge.

IV. DEMONSTRATION SETUP

The demonstration set-up for the DWDM-centric metro/aggregation solution is shown in Fig. 2. It is based on bi-directional WSSes connected with 20km fiber. Fig. 2 depicts three types of client nodes connected to their respective service edge nodes via the DWDM-centric network. These clients are a remote radio unit (RRU) connected via a 2.5 Gb/s CPRI fronthaul connection to a digital unit (DU), an enterprise client connected via a 10 Gb/s connection to a 10G service edge port, and a residential client connected via a 1Gb/s connection to a 1G service edge port.

The setup demonstrates the DWDM solution with its centralize control, and automatic client and service discovery. The client interfaces of the demonstrator are fixed DWDM transceivers and tunable attachment is left for future implementation. The DiU functionality is implemented using an off-the-shelf Ethernet card. Here, the DiU waits in standby for the establishment of an Ethernet connection. Client discovery is enabled by monitoring of the incoming signal power at the optical interface for the presence of Ethernet link layer connectivity and by measuring the level of received optical power at the DiU. Since the Ethernet card in this case can detect both 1 Gbps and 10 Gbps standards, it is possible to detect all three possible clients based on received signal power level and an exclusion test. Once a new client is detected, the DiU sends an SNMP trap to the LCU with information about the identity of the new client node and the type of connectivity service. Upon reception of the SNMP traps, the LCU configures the WSSes to provision the wavelength path between the client node and the service edge nodes. Support for multiple clients of the same service type in the demonstrator would require wavelength identification capabilities at the DiU as described in the previous section.

V. RELATION BETWEEN PACKET AND OPTICAL SDN

The DWDM-centric network described above simplifies the metro/aggregation architecture by moving the higher layer functionality to the edges of the network and thus simplifying the overall physical architecture.

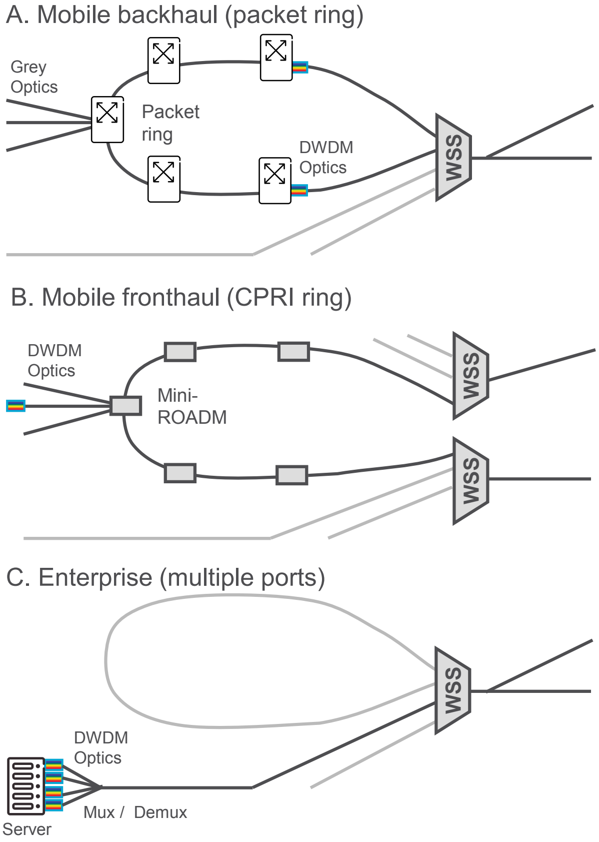

Fig. 3. Details on the different scenarios for the access ring: (a) head/tail DWDM with on packet switches and grey optics, (b) DWDM-ring/horse-shoe connected to two WSSes to provide redundancy, and (c) enterprise site or distributed data center connected directly to the WSS.

In a pure DWDM-centric metro/aggregation scenario, the DWDM-centric solution bridges the full distance between the service edge and the clients, providing dedicated wavelength connectivity between the end-points. This scenario provides inherent isolation of the data plane between different e.g. services and operators sharing the infrastructure. Network control (e.g. service provisioning) is handled through the LCU via the internal control of the DWDM-centric solution. Note that in this scenario there is a strong need for flexibility and automation in the DWDM-centric solution in order to handle commonly occurring processes such as:

- Client/service discovery and service provisioning
- Client service change request (service type, capacity, etc.)
- Connectivity request (P2P connectivity)

However, the lack of packet layer aggregation points in the previous scenario may in the short term result in scalability issues which makes it likely that the DWDM-centric solution will be complemented with packet layer aggregation nodes. One example of such a configuration is shown in Fig. 3a (head/tail scenario), where traffic is aggregated in the packet layer prior to entering the DWDM-centric domain. This requires integration between the packet and DWDM layers. The DWDM-centric solution can be seen as providing wavelength connectivity services to the higher layer control. In this hybrid scenario the need for flexibility in the optical layer is reduced compared to the pure DWDM scenario as the role of the DWDM solution in the hybrid scenario is to provide connectivity services to the aggregation nodes rather than end-clients which are more static in nature. Some of the required network flexibility is now managed on the packet level relieving the optical layer from such control. There are cases which still require interaction between the SDN functions on different layers. From the higher layer control, provisioning of a new aggregation node will require wavelength connectivity services from the optical domain. Provisioning of individual clients connected via an aggregation node will generally be handled by packet or CPRI layers but may trigger capacity related changes in the optical domain as will be discussed below.

For the proposed DWDM-centric aggregation solution, capacity is managed in a rather coarse manner by either modifying wavelength service (e.g. from 1Gb/s to 10Gb/s) or by setting up / tearing down wavelengths. For the latter to provide a more fine granular capacity control beyond “connectivity” and “no connectivity”, the existence of multiple connection points (multiple ports) between an access segment and the DWDM-centric transport is required. These multiple connection points could form the basis for enabling a coarse capacity management in the optical domain and subject to coordination between the optical and packet layer.

For wavelength services, traffic separation between different services and multiple operators are provided by the nature of the optical layer. For packet-based services, proper traffic separation needs to be supported in the switching nodes. Here, SDN provides a possible solution for virtualizing a network infrastructure into several slices for different clients. These clients would see their slice of the network and through this abstract view they would be able to control their network resources. This is an attractive feature when several different services are using the same physical network, as described below.

VI. APPLICATION TO DIFFERENT SCENARIOS

In the following we describe three examples shown in Fig. 3, addressing specific network scenarios: mobile backhaul, CPRI deployment, and enterprise connectivity. For the 1st and 3rd cases, VPNs on IP or Ethernet layers are typically used. We also outline how different clients would co-exist on the same infrastructure to provide separation and coordination between clients.

A. Mobile Backhaul

In a mobile backhaul network, there are two main interfaces which define the connectivity needs. The S1 interface connects the radio base station to the mobile core network, both for user-plane and control traffic. It is complemented by the X2 interface which connects neighbors in the cell structure to support e.g. hand-over and radio coordination. The capacity needs of the S1 interface is given by the user traffic, and is typically in the 100’s of Mbps capacity range.

In this scenario we assume access rings consisting of packet aggregation switches that are connected to a number of clients connected as leafs to the switches forming the access ring as shown in Fig. 3a. An effect of this is that in most cases X2 traffic between neighbor cells can be switched locally, providing an optimized traffic path between base stations. At the head and tail of the access ring, the connection to the DWDM domain is made. Each switch in this ring will then have two directions to connect to the service edge through the respective wavelengths of the head and tail.

Supporting multiple clients in the network can be simplified by use of network virtualization. When a new radio base station is connected to the switch in the access ring, the corresponding port on the access-ring switch is allocated to the virtual network of that mobile operator, and the configuration of the virtualized switch exposed to that operator is updated to reflect the newly allocated port. After setting up the initial connectivity to the mobile core through the S1 interface, the neighbor cells are detected by the self-organizing network (SON) features in the mobile network. Based on the neighbor information the required X2 connections are identified, and the SDN controller of the mobile operator configures the forwarding rules in the access rings and the central switch.

In order to utilize the capacity in the DWDM-domain efficiently, all connections can be routed through a single direction of the ring, e.g. through the “head” node. To realize this, the packet and optical layer need to have the detailed knowledge on the traffic situation as outlined previously, and the ability to make this switching in a coordinated manner. Once this procedure is executed, the free capacity in the DWDM domain can be used for other services.

B. Fronthaul / CPRI

There is an interest from some operators in separating the radio antenna equipment from the base band equipment. Centralized baseband solutions are also an important part of the FP7 project COMBO. To achieve this, the CPRI protocol is used for connecting the radio head (RRU) and the baseband (BB). Fig. 3b shows how the DWDM-centric solution could be applied in the access ring for this case. In this figure, we also show how the access ring can be connected to two separate WSSes to provide additional resilience to equipment failure. With the foreseen evolution towards small cells, each small cell would need an individual CPRI connection, which requires a large number of wavelengths when all cells are in operation. One way to reduce the number of wavelengths needed is to allow for dynamic setup and power down of small cells in response to traffic variations. Such traffic variation could come from movement of people from business areas to residential areas during the day and the following daily traffic variations.

In order for this to be realized, the lambda controller needs to have a north-bound interface allowing the control of wavelength resources from the radio network. When capacity requirements moves, the radio network will need to optimize the usage of small cells together with the availability of wavelengths, and then instruct the lambda controller to realize the needed connectivity. At times with low traffic, fewer small cells would be needed as macro cells would provide coverage and capacity for most users. Then the radio network could release wavelength for use of other clients and applications, as described in the section below.

C. *Enterprise*

For an enterprise there are normally a number of sites that need to be connected over a service provider network. These sites will have different connectivity needs depending on the site: a small office, a large corporate campus, or enterprise data centers supporting business applications and/or storage. Hence the capacity needs for each site can vary a lot, from Mbps range for a small office to a several tens or even hundreds of Gbps for an enterprise data center. A small office could be connected on an Ethernet port on the access ring in Fig. 3a. A corporate campus would be connected on a wavelength with a 1Gbps or 10Gbps interface. As shown in Fig. 3c, an enterprise site or a distributed datacenter could have a number of 10G interfaces to support its connectivity needs, and support a flexible bandwidth configuration. This flexible bandwidth would be exploited to perform data transfer for applications that are not time critical.

At time of low traffic for other network clients, there would be free wavelengths as described in the sections A & B above. Based on the free capacity, applications would request to use the spare capacity in the network. To accomplish this, there is a need to be able to expose information on the network state to applications, as well as requesting resources in the network from an application.

VII. CONCLUSIONS

DWDM technology is expected to become more prevalent in the metro/aggregation as traffic volumes grow. A DWDM-centric solution to meet future requirements from traffic demand, transport services, operational aspects was presented and demonstrated. In analogy to the discovery process in OpenFlow, the concept of the discovery unit (DiU) is introduced in the optical domain to automate connection set-up. Furthermore we propose to use SDN as the network control mechanism, and describe the relation between SDN on the packet and optical layers. This is then applied to three different scenarios in the metro/aggregation domain, which shows how our network solution can be used for multiple purposes.

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