

## 5. Qualitative survey results

The two broad objectives have been identified as discussion of the graphical summaries of the results, and assessment of the objective clarity of the questionnaire's questions. We have refrained from further qualification of the objective (e.g., it might seem plausible to express the objective as a desire to learn about reviewers' opinions on accuracy of the data), because the sources (interviews, emails, reports) at the foundation of qualitative surveys have the potential to supply raw data that exceeds, or at least encompasses, narrower objectives. This liberal mindset is not a substitute for accurate analysis; rather, it is a pre-requisite. Analytical techniques that develop results from qualitative surveys' raw data have been used in [1], to high yield. There, the PAD method (a development of the well-known technique of structural coding), was shown to elicit the dynamics of research as it worked through a corpus of research units (a collection of papers addressing a problem domain). Through three rich collections of codes, under problem, approach and development categories, it was possible to observe the formation of patterns in the linkages between subsets of each of the three categories. Therefore, while an initial statement of objectives must be broad, the processing of the raw data obtains an analysis that mines and extracts detail, including – but not limited to – the aforementioned better understanding of the accuracy of the data collected.

All the resources mined for this qualitative survey are available online. The resources have already been referred to earlier in this work. Table I collects references to, and descriptions of the resources under one structure, for convenience's sake.

Table I RESOURCES COLLECTED DURING DATA STAGE OF QUALITATIVE SURVEY

Resource description	Ref. #	URL
Face-to-face interview: anonymous_1 <sup>1</sup>		
Face-to-face interview: <a href="#">Ovidiu-Mădălin Roset</a> <sup>2</sup>	[2]	<a href="https://drive.google.com/open?id=1H8SeNQ7PZ5EVQ7q1fYgT4EGTYZ51mgvu&amp;usp=drive_fs">https://drive.google.com/open?id=1H8SeNQ7PZ5EVQ7q1fYgT4EGTYZ51mgvu&amp;usp=drive_fs</a>
Face-to-face interview: <a href="#">Haider Khalid</a> <sup>3</sup>	[3]	<a href="https://drive.google.com/open?id=1Lnfl6L4elnFCuz85bn6Thjwc77OYb_ji&amp;usp=drive_fs">https://drive.google.com/open?id=1Lnfl6L4elnFCuz85bn6Thjwc77OYb_ji&amp;usp=drive_fs</a>
E-mail thread: <a href="#">Mark Tinka</a> <sup>4</sup>	[4]	<a href="https://drive.google.com/file/d/1eltC-QaLPiZitrIngEWAUS5gtiimY-jw/view?usp=sharing">https://drive.google.com/file/d/1eltC-QaLPiZitrIngEWAUS5gtiimY-jw/view?usp=sharing</a>
E-mail thread: <a href="#">Philip Smith</a> <sup>5</sup>	[5]	<a href="https://drive.google.com/open?id=1bN0RS_M93UojmdA0oYMYqJI9Ql_uM8Hk&amp;usp=drive_fs">https://drive.google.com/open?id=1bN0RS_M93UojmdA0oYMYqJI9Ql_uM8Hk&amp;usp=drive_fs</a>
E-mail thread: <a href="#">Daniel King</a> <sup>6</sup>	[6]	<a href="https://drive.google.com/open?id=1ayHhTdpfdIWMZuyLPTapKDZS1-cUFIRM&amp;usp=drive_fs">https://drive.google.com/open?id=1ayHhTdpfdIWMZuyLPTapKDZS1-cUFIRM&amp;usp=drive_fs</a>

<sup>1</sup> We have not been given permission to publish the recording of anonymous\_1's interview.

<sup>2</sup> <https://www.linkedin.com/in/ovi12/>

<sup>3</sup> <https://www.linkedin.com/in/haider-khalid/>

<sup>4</sup> <https://www.linkedin.com/in/mark-tinka-5b03055/>

<sup>5</sup> <https://www.linkedin.com/in/philip-smith-154502/>

<sup>6</sup> <https://www.linkedin.com/in/danielking/>

E-mail thread: anonymous_2	[7]	<a href="https://drive.google.com/open?id=1eI7oH18k_dWsupVPNjCfGHSAaa_7tkX3&amp;usp=drive_fs">https://drive.google.com/open?id=1eI7oH18k_dWsupVPNjCfGHSAaa_7tkX3&amp;usp=drive_fs</a>
Written assessment: Haider Khalid <sup>7</sup>	[8]	<a href="https://drive.google.com/file/d/1gith5v8W2x4DIl_I5oyPW9n39uT9fnGc/view?usp=sharing">https://drive.google.com/file/d/1gith5v8W2x4DIl_I5oyPW9n39uT9fnGc/view?usp=sharing</a>

### 5.1 Face-to-face interview saliences

Face-to-face interviews were conducted online, over Zoom, and recorded with the permission of the interviewees. Duration ranged between 50 and 90 minutes. Reviewer anonymous\_1 and Haider Khalid were recruited by SG Analytics, on the basis of the advice of reviewer anonymous\_2, with which Mark Tinka concurred, to source interviewees directly involved with daily network operations. We recruited Ovidiu-Mădălin Roșeț directly, on the basis of the same advice and on the basis of personal experience of his technical networking skills. Both Haider and Ovidiu are CCIEs.

Face-to-face discussions provided the opportunity to listen to narratives that described metro-aggregation and metro-core architectures. Such narratives address the degree of assurance which can be obtained about the integrity of the communication channel between questioner and respondent in the impersonal medium of the questionnaire. That is: since questions are text on paper, they are always, to some degree, subject to interpretation. The medium of a discussion reduces the subjectivity; the parties in a discussion have reasonable opportunity to solicit clarification in case of doubt. Indeed, the responses to the questionnaire *did* include the occasional unexpected interpretation. For example, one otherwise coherent respondent claimed, when asked about the location of the Internet BNG, that “BNGs have been dead for a long time! We use IP only, termination happens directly on the connected switch unless it is a wholesale circuit in which case it[]s dragged over to the handover”. Here, it seems that the respondent was thinking about the service edge in terms of the PE router. This is indeed a possible interpretation: it is the “IP edge” that was referred to in [9]; what exactly has “been dead for a long time” is unclear.

In this sub-section, references to “I” and “me” in the course of narration of the discussion, regard the interviewer, who was Etienne-Victor Depasquale.

Ovidiu-Mădălin Roșeț

On Layer 2 and higher metro-aggregation technologies

*“the old way of doing things”*

In the following, references to the CSP in the object of the discussion are replaced by the placeholder CSP\_X. Suffice it to say that CSP\_X is a highly reputable organization, and is not an agent of dubious practices.

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<sup>7</sup> <https://www.linkedin.com/in/haider-khalid/>

*“So from what I’ve seen, and now, I’m talking about some providers, ..., more about providers ... in the region.*

*So it’s [] a thing of evolution and maybe that’s also a thing, I don’t know. What’s the budget of those companies and how long has it been since they’ve upgraded and so on.*

*Because ... ten years back you would have a lot of switches in the access and aggregation, because the switches have high ports density. They’re quite cheap. And you could deploy either spanning tree, for redundancy items, you know, those ring topologies where you deploy them for the loop prevention.*

*And this is where this PB would apply if you would have a pure layer 2 network in the access and the aggregation, ... you would configure the IP ... the service layer would be on some routers on the core and you would have pure layer 2 on access and aggregation switches.*

*But the PB, I think it is needed ... if you have many, many customers, then you would start needing different VLANs – S-VLANs, C-VLANs and stuff like that.*

*In CSP\_X ..., so I don’t know exactly how many customers it had. And also I have to mention something else, first of all, CSP\_X didn’t provide broadband services up until just a few years ago.*

*So what I am talking about is CSP\_X network, while they had sites of telco, so 2G, 3G, 4G and so on, and enterprise customers, but not residential. So we didn’t have BNG, we didn’t provide those services and that’s what I am referring to.*

*And when I first started working at CSP\_X, we had what I was saying: a lot of switches and IP on some core routers and you would just have VLANs for each of your customers.*

*If maybe we had more than 4000 customers, we would run out of VLANs, we would deploy C-VLAN, service VLAN and so on, and maybe got into PB and Q-in-Q. But in our case, it wasn’t. It wasn’t needed.*

*So maybe the size is also important because you’d need to fit more services and you would need more VLANs and you would deploy PB.*

***But ... this is the old way of doing things. No one sane would deploy now switches in access and aggregation and no integrators, vendors are offering this solution. So: I also work for a system integrator and I wouldn’t go with switches in the access or aggregation. ”***

This assertion begged a clarification: what features would one expect on these Ethernet switches? We posed this question.

*“The basic ones so Q-in-Q would be one of them, just to carry VLANs and have some kind of loop-prevention protocol, like as I said, spanning tree, so really basic. I don’t know how people in other countries say it, but here in Romania, we say just to carry those VLANs.”*

**Key takeaway:** Ethernet switches supporting spanning-tree protocol and basic VLANs were the cheap and effective way of aggregating from the access node upwards towards the provider edge of the metro core.

*“the intermedia[te] step”*

I pressed for clarification on what the future of metro-aggregation looks like. Ovidiu’s position as a system integrator enables him to broaden his vision beyond an extant portfolio of technologies, towards accommodation of a diverse set of customers, whether CSPs or otherwise. The answer branched into validation of the NOG respondents’ commonest choice of layer 2+<sup>8</sup> aggregation (seamless MPLS), and then branched again towards a welcome insight into how large routing domains can be constructed.

*“So I’ll tell you what we’re moving into, but I’ll give you the intermediary (sic) step ... in CSP\_X we moved from layer two switches, from Ethernet switches in access and aggregation to bringing the IP into the access area. And that involved seamless MPLS. You could deploy one big domain, let’s say one IP domain one, let’s say ISIS routing domain and put inside that routing domain our whole routers in Country\_X.*

*But you have ... do you know why you can’t actually do that in large networks because if not, I can explain.”*

Ovidiu elaborated, as follows.

*“So you would have an IGP that needs to run the shortest path first algorithm on 1000 nodes. If you have a small change in one part of your network, that small change or failure would cause an SPF re-run on a totally different part of your network and it’s not viable. And you would need a lot of resources on access nodes, because you would need to have the whole map. And ... this can’t be done.”*

It was next explained how seamless MPLS solves this problem, and plays an important role in the stack of transport layers.

*“This is where seamless MPLS comes into play because you would just split. Let’s say you have Romania and you split it in ten regions and each region [] has its own routing domain and you still need to provide end-to-end LSPs, and you use BGP labelled unicast for that, to advertise the loopbacks for other regions, to advertise the label for them. In this way you use BGP labelled unicast, and this is the next step that providers move to from layer two to the three in the access.”*

The next statement was an assertion of first-hand source status:

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<sup>8</sup> Layer 2+ is a somewhat loose term that is used here to refer to technologies that fit above OSI layer 1 but below OSI layer 3. In this work, the only significant members of the implied set are IEEE 802, 802.1, 802.3 and MPLS (RFC 3031).

*“That’s when I got in CSP\_X, when we were migrating from that old network with Ethernet switches to this new network with seamless. And I’m quite aware of what we were doing and how we were moving services from the core to the access. And I understand the reasoning and that’s what I’m trying to explain and I hope it was delivered for you.”*

**Key takeaway:** Seamless MPLS is enabling “IPfication” of the network, wherein the CSP is able to bring IP connectivity into the access network. Moreover, seamless MPLS, through BGP-LU, supports end-to-end LSPs in large networks.

#### *The future*

My line of questioning moved towards provision of MEF-compliant ETH layer services, which, operators claim to support in their overwhelming majority. In the process of answering, Ovidiu started addressing the future of metro-aggregation.

*“Yes, definitely. Going back to what we discussed about pure layer 2 Ethernet networks and Seamless MPLS - the next step is with Segment Routing and EVPN. That’s what everyone goes with now, but anyway, even with the seamless MPLS and with segment routing and EVPN, you would provide layer two circuits for your customers.”*

This was qualified further ...

*“If it’s seamless MPLS, you’re using layer 2 VPN technologies like virtual private wire services, or VPLS where you would emulate an E-LAN and with EVPN, it’s the VPN that does all of these.”*

... and followed by another valuable insight:

*“But yes, you definitely provide layer two access to your customer. So you could sell layer two circuits to your customer and ... from what I know from industry, it’s more frequent for Tier 1, let’s say, providers to provide layer two circuits for other providers – a circuit between countries or something like that. So that’s where it’s more popular.”*

**Key takeaway:** EVPN, signalled with the support of Segment Routing in the control plane, is the successor that takes up the mantle of adopting MPLS in the data plane.

#### *On Layer 0, 1 metro-aggregation technologies*

The interview proceeded towards discussion of the results of asking CSPs about their motivation for migrations towards transport systems with integrated DWDM pluggable (away from separate transponders and muxponders), and towards open OLS. The charts’ interpretation was dwelt on first, notably that each motive’s importance can best be read by reading its skewness, with negatively

skewed distribution indicating high relevance and positively skewed distribution indicating low relevance.

*“So, first of all, in Cisco, if you want to dig deeper in Cisco, they call it routed optical networks.*

*So maybe you’re going to get some more insights of how Cisco does it because in the meantime I’m working for the system integrator, which is a Cisco partner.*

*So ... I’m looking at everything through the Cisco lenses.*

*So, your first of the first big advantage of open XR and everything is the one that DWDM optics can now be packed into switching and routing infrastructure, faceplate and so on and so on.*

*So yeah, the first big advantage is that these new DWDM optics can now be packed into the routing infrastructure faceplate.*

*But I want to tell you that this is quite a new subject, let’s say. And this is new technology, right?*

*I don’t think you would see it too much deployed yet because if you want to do it, you would need new hardware.*

*But of course, me as a vendor, I’m always pushing new technology because I want to sell new hardware.*

*It’s good. But right now, maybe existing networks don’t need it yet because they still have all those transponders and all that transport infrastructure that may not be out of support and so on and so on.*

*I think [] we will move from the legacy transport networks to the routed optical ones.*

***Once those transport devices will [reach] the end of life, or maybe if have some greenfield deployment and you’re starting from scratch and you’re deploying these.”***

Unsolicited, Ovidiu then proffered more detail: reduction in OPEX, due to lower electricity costs.

*“So that’s one thing. But the other thing that I would say to a customer to convince him to migrate to these is that you’re spending [] a lot on electricity because you have devices that are plugged in.*

*And I think that’s a really quite big advantage, especially now because you’re spending a lot on OpEx, especially now when the electricity bills are higher and higher and electricity is quite expensive. So that’s also an advantage.*

*It’s not just that you can plug it in your router, but it’s also that you’re moving away from the transponder and [you’re saving money on the power which you would have, which you would have consumed on the transponder].”*

## Key takeaways:

1. DWDM is new technology, unlikely to be widely deployed<sup>9</sup> because it requires new hardware.
  - a. This helps to explain the dominance of routed optical networks.
2. Apart from operational simplicity, another significant advantage is reduction in OPEX, from saving electricity on separate transponder equipment.

### On technology stacks for metro-aggregation

It was time to address stacks of technology and this was the opportunity to ask about the interpretation of “routed optical networks”.

*“I don’t think they thought about Cisco’s routed optical networks when they chose this.”*

This, of course, corresponded to Eduard Vasylenko’s claim about the lack of association between the term “routed optical networks” and Cisco’s use thereof. This posed the question of what interpretation might have been, so clarification was asked for, in the hope that it might correspond to some colloquialism among the community of CSPs. This would allow a pinning of operators’ choice to the meaning behind the colloquialism. At first, difficulty was found, as may be read from the extract below.

*“It’s a hard question. So what did they think when they chose this optical networks over Ethernet.*

*So I think of without ROADMs Let me have a look at the others.*

*So, DWDM with SDH Ethernet and IP/MPLS – this is quite traditional for big service providers.*

...

*I don’t know why they chose it, why so many of them chose routed optical network.”*

I observed that “routed optical networks” was the only choice, excluding the legacy SDH/SONET case, that excluded ROADMs. That drew the next comment.

*“And also this question is about metro aggregation, so how you’re aggregating them again.*

*You might not need DWDM if you have a small metro network, right?*

*And maybe that’s what they thought about, no ROADMs.*

*So. Yeah. No wavelength division multiplexing or maybe something like that.*

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<sup>9</sup> The likelihood referred to pertains to the need to amortize installed equipment. In the circumstance that equipment is not fully amortized, an operator may have to delay installation of newer technology.

*Just some fibers that you deploy between on small distances, between some routers and maybe that's what they were thinking they had in their network."*

### **Key takeaways:**

1. Routed optical networks are most likely interpreted as fibre drawn between routers.
2. It was reaffirmed that WDM may not need to be considered, given a glut of fibre.

Haider Khalid

On clarity of the questions in the questionnaire

*Overall*

As regards the questions, I asked *"whether you feel they were clear, whether they were open to interpretation, and whether there are things that really needed to be improved"*.

Haider's difficulty was limited to those questions regarding "transmission", which is out of his scope.

*"Most of the questions were clear ... some of the questions that I've found a bit of ambiguity in them not because the question was ambiguous... I think it was because probably I was not too familiar with those technologies, like the question related to the WDM type technologies ... probably because I'm not familiar with the technologies.' So, I won't blame the question. Maybe the question is clear."*

I then proceeded to enquire about the dissemination of knowledge about standardized reference points (T, U, U1, V, A10) among network engineers. While reference to these RPs was always accompanied by an explanatory graphic in the questionnaire, I wanted to understand obstacles to apprehension both for the survey's purpose and to form my own understanding of jargon familiar to the groups within my research's scope. Haider answered as follows.

*"So the diagram itself is very, very clear. So I can see the IP/MPLS based aggregation networks and the way you have drawn these cloud networks, this shows the IP/MPLS backbone aggregation. I think the terminology that you have used like U1 and V, I think these are the terminology that we don't use in industry standards.*

*So what we use is the UNI and the NNI.*

*So the UNI is the user-network interface and the NNI is the network-network interface.*

*So I'm not sure if these two are related to the same that I'm talking about U1 and V1 that you are saying.*

*Then the traffic flow I'm not able to understand from this diagram because you haven't shown any arrows for the traffic flow, if this is related to some traffic flow from the user side."*

These comments cast some doubt on the use of reference points among CSPs' technical personnel, and so I pursued this further, and referred to another of the graphics.



*“The reason why I used the T and the U and the V when they are standardized by the ITU and the broadband forum ... if they are used properly, they tend to be specific with regard to the point in the traffic flow which they are referring to ... [moreover], as regards the graphics, well, there are a couple more like that.”*

Haider’s response affirmed the value of intrinsic clarity in graphics.

*“I think over here, the good thing is that you have mentioned the terminologies, like you mentioned the device at the right hand side, like the PC and—the STBs - the set-top box. And you have mentioned at the left hand side - the NSP or the PSTN. So that plays the flow of traffic like it's coming from the user to the network or from the network to the user. So I think this explains itself the terminology that you have used here. That's why I think it's okay.”*

Indeed, while discussing aggregation results, I referred to the V reference point and the A10 reference point – to which Haider replied:

*“from the access to the provider edge”.*

Haider’s recognition was based on his view of the TR-178 graphic. This was a good indication of the interpretability of the graphic presented as the basis of a number of questionnaire questions.

*On the interpretation of the term “routed optical networks”*

Haider commented as follows.

*“I would say that if somebody who has not worked on Cisco and is from like Juniper or maybe from Ericsson or Huawei or other vendors than Cisco, ... I think that person would not be able to understand this because this is more like into vendor stuff. So I would say that it's better to keep it industry standard so that it entertains all the audiences like without any difference. So all the audiences should understand what is like being asked.”*

However, he qualified this with:

*“[Y]ou know, Cisco is [] actually the go to vendor for everybody. So, yeah, some use Cisco terms quite interchangeably.”*

### **Key takeaways:**

1. Reference points may not be widely known among CSPs.
2. Routed optical networks is not a term that has precise meaning.

*On Layer 2 and higher metro-aggregation technologies*

Shortly after introducing the results to the question about layer 2 and higher aggregation from access node to service edge, Haider proffered the following.

*“Just to let you know, that provider edge is the term that we use in the ISPs. So, [] because I've worked for multiple ISP, then we [] have always used and heard provider edge ... service edge is used but not as frequently as provider edge.”*

A significant contribution followed, when Haider interpreted the results.

*“I would agree with the right side [(the SGA results)], because in most of the networks, seamless MPLS is being integrated **now** in many networks. But still, most of the - I would say probably 70 to 80% - of the networks around the world, because I work in different parts of the world and I know in the Middle East, in the Asian region and even in the European region, most of the networks, they do this QinQ and bridging stuff between the access and aggregation. So, **the MPLS starts at the provider edge** and then it'll go so: from the provider edge down to the customer side, the access and the aggregation, they prefer using QinQ and the provider bridging. Some of the ISPs - they do seamless MPLS, but it's not as common as the other technology. So, I would say 70 to 80%, where I work in the Middle East and in Asian like South Asia and even in the European countries, I've seen this provider bridging and QinQ in most of the access.”*

#### **Key takeaways:**

1. When Haider's comments are combined with Ovidiu's and with the statistics, it emerges that the subset of Regional and Tier 1 operators which are active in the access and aggregation, are more likely to operate:
  - a) IEEE 802.1Q-2022 aggregation all the way up to the metro core, and
  - b) IP/MPLS switching in the metro core.

#### **On Layer 0, 1 metro-aggregation technologies**

I presented the results of the question asking CSPs to rank their motives for migration towards integrated DWDM pluggable and open OLS. Haider agreed that the facility to pack DWDM pluggables densely is an important motivator, as well as the importance of mixing of grey and coloured pluggables. For the NOG respondents, these were the motives that leant most and second most towards high relevance.

*“[W]hen I was working in the Middle East, so there was DWDM over there in the Middle East, the ISP that I was working for. And they used DWDM technology ...the thing that the line card can now carry a mix of the grey optics as well as the DWDM optics ... that is also a very important factor, because previously when we had GBIC cards, those were big, big cards. We couldn't insert those cards in the back end switching and routing blades on the routers. So I think this is also a very important factor for DWDM to be implemented in the networks that because of the optics size to be reduced as the same as the grey optics, that is a convincing factor for DWDM to be successful.”*

I tried to elicit another perspective on the role which OTN would play. Haider's response at first indicated conflation with other optical networks that are deployed downstream of the access node. Nonetheless, his answer was a useful reaffirmation of his previous elaboration on the co-distribution of technologies by metro area segment.

*"So, I would say that current ISP, the next generation networks, they are not going towards OTN because they are moving towards XGS-PON. So, like even in the [ ] European countries like in the UK that I'm working the company currently I'm working for. So that is one of the biggest ISP in the UK. So, they are also moving towards XGS-PON now. So, they are like, you know, in XGS-PON we have the OLTs, the optical line terminals and that is the fibre to the home. So, we provide fibre services from the service end down to the customer premises. So, it's a direct fibre connection from the core to the customer edge. So that technology, the technology that we used to provide that previously it was GPON, but that was 1G downlink and I think 1G uplink. But now with the advancement in technologies, we are shifting towards XGS-PON. So that is symmetric 10G both ways from the customer edge to the user side and from the user edge back to the core. So, for that technology to be implemented, we need OLTs and ONTs. ONTs are installed at the customer end - optical network terminals and the optical line terminals, they are installed in exchanges at the access as an access node and from all the different customers they have, each customer will have its own ONT where the fibre terminates directly in ' customer's home and from that, ONT, that fibre goes to the exchange to the OLT and one OLT can serve one area. For example, if in Manchester we have an exchange, the Manchester exchange will have an OLT that will be serving thousands of customers in Manchester, and from that OLT then we are facing towards the network side. From that OLT, we get the traffic to the aggregation layer, or you can call that the Metro network, and then from there we can get the traffic to the provider edge in the core. Once we reach the provider edge, then we have MPLS and we switch traffic on the basis of MPLS. So, this is what we are moving to now."*

Summarizing:

- XGS-PON from customer edge to AN ("exchange"),
- aggregation (presumably 802.1Q S-VID (service VLAN identifier) and C-VID (customer VLAN identifier)),
- provider edge to metro core MPLS label-switched paths.

For example, in such a network, an L3VPN can be supported through marking customer subnets by a particular {S-VID, C-VID} combination.

To try and obtain more insight on the role of OTN as an aggregation technology, I described it as a successor (in the sense that it employs TDM) to SONET/SDH. This elicited recognition.

*“Yes. Okay. All right. It is being used. I agree. Yeah. Yeah ... I would say that in future this will be dismantled. That's my understanding. Yeah. Yeah. It seems to be that way ... So yeah. Yep. So I think, I suppose, they're moving towards packet based now. So they're moving towards packet based.”*

Later in the discussion, Haider indicated that SDH is still in use in his organization, so I asked:

*“Is there any thought of dropping it in favour of something else?”*

The reply was unequivocal ...

*“Yes, they are. They are planning to replace that with DWDM all across the transmission.”*

... and, moreover, the reply was coherent. The organization involved is a large one, with several million subscribers. The need for return on investment in SONET/SDH technology would have supported its retention well past some form of collective realization in the sector of CSPs that the technology had been superseded.

Topology was the next point of discussion; I sought Haider's perspective on the results about the question whether meshes are likely to be more common in the future among metro-core nodes.

*“I would say it entirely depends upon the design of the network. So who is the designer of the network? So I would say that the ISPs that I have worked with, **so probably 80%, 70 to 80% were using full mesh in the metro network**, but there was some ISP's they were not using, they were using some other topologies like ring topology in the metro. But again, because it depends upon the design of the network, like how big is the neighbourhood? If a network is too big, then full mesh is not recommended because ... if you're doing full mesh in a very big network, then it means you have to have lots of connection' and that's not scalable. So, if you have a smaller ISP, full mesh is always definitely recommended, but even with bigger ISPs, I've seen full mesh. But, I think, for that, to implement it requires a lot of resource, a lot of effort to get full mesh cabling in large networks. But again, full mesh is something that is being used a lot in that area.”*

On this reading, even access nodes aggregators (e.g., the Ethernet switches upstream of the V RP) are fully meshed in 70 – 80% of CSPs. This does agree with one anecdote which I can personally relate with regard to a local CSP. Rings, therefore, while apparently convenient, do not give CSPs the desired level of assurance on service availability.

### **Key takeaways:**

1. While rings are commonly used as examples in literature (see, for example [10], [11, Ch. 17]), mesh interconnection of access nodes aggregators (for emphasis's sake: access nodes are devices like DSLAMs, CMTSs and OLTs, which aggregate subscriber lines) is at least equally likely.

2. Another example of SONET/SDH's removal from aggregation technology stacks, was given.

#### On technology stacks for metro-aggregation

When asked about technology stacks for metro aggregation, Haider replied as follows.

*"So, I'll tell you, because I worked for one of the biggest ISPs in the Middle East and I'm working for one of the biggest ISPs in the UK. So, we have a subscriber base of around 6 million subscribers. So, this is a big ISP and both ISPs in the Middle East and in England, both are using ... IP/MPLS plus Ethernet plus DWDM ... this is what being used for both big ISP that I worked for in England and in the Middle East. So, so I would say that this is the more preferred."*

I asked Haider about use of ROADMs; while he was unable to reply, his answer drew attention to the classical division between "transmission" people and those (like Haider) who work at higher OSI layers (MPLS and IP, notably). Now, other than the implementation of DWDM for higher utilization of point-to-point physical cabling, all implementations of DWDM requires some form of filtering to select specific wavelengths. While there are some variants in the genre of optical cross-connects (OXC's), the ROADM, notably in its colourless-directionless-contentionless-flexible grid form, represents the state of the art of the genre. Haider's reply – in so far as it seems to correlate CSP size to technology stack – therefore reaffirms the correlation between answers given to this question by SGA respondents, and large subscriber base size.

#### Key takeaways:

1. Regional and Tier 1 CSPs active in the metro area are adopting IP/MPLS over Ethernet over an optical network comprising DWDM links that are optically switched using ROADMs.

#### Reviewer anonymous\_1

#### On Layer 2 and higher metro-aggregation technologies

Dave's position with AT&T gives good visibility into the current implementation of a large CSP occupying both regional and Tier 1 roles.

*"So generally, what I see is from the edge down to, let's say, the access site, it's most mostly like Q-in-Q, it's mostly Ethernet over VLAN with some kind of VLAN ... Then, that connects up with MPLS in the backbone. So, it'll be like MPLS in a backbone, and then it'll be like some kind of Q-in-Q down to the site."*

#### Key takeaway:

1. Further emphasis is made on what was observed earlier about aggregation in regional operators' networks:

- a. IEEE 802.1Q-2022 aggregation all the way up to the metro core, and
- b. IP/MPLS switching in the metro core.

On Layer 0, 1 metro-aggregation technologies

I addressed the motives for migrating towards integrated DWDM pluggables.

*“The blue bar is huge, right? Because if you can plug it right into, you know, your access nod’, now you’re eliminating a piece of hardware that’s a potential point of failure, right? So, you know, a lot of times now the fibre will come in to a facility, and you have to have some kind of fibre box or some kind of piece of equipment that is like a fibre converter, right? You plug it into a fibre port on a switch, and then it comes out the other side of the switch as copper, and then the copper plugs into your router. Right? So, if you could plug the fibre directly into your router faceplate, I mean that’s huge, right? You’re eliminating that point of failure.”*

I asked Dave what he thought about OTN being displaced by packet networks.

*“You’re talking about something kind of TDM wise ... Oh, yeah, yeah. I agree 100%. Right now, what happens is, you know it’s’ it’s, it’s all Ethernet.”*

On technology stacks for metro-aggregation

*“So, I find the first four bars, SONET and Ethernet plus MPLS ... I find them more in the local PTTs<sup>10</sup>. They’re running, kind of because it’s you know, it’s a large investment to, you know, overhaul your network. Right? So, they’re using what they can for as long as it is as long as they can use it. Right? So, every once in a while, we come across Ethernet over SONET, or Ethernet over ATM. And, you know, so, you know, I find that more in the local providers than us. We don’t have anything like that. It’s just strictly Ethernet.”*

### **Key takeaways:**

1. Return on investment is a key criterion in determination of the rate of penetration of replacement technologies. SONET/SDH is particularly hard to displace in the “local PTTs” – these are the CSPs of a smaller, regional scope, the descendants of what are colloquially referred to as the “Baby Bells”, when AT&T was broken into Regional Bell Operating Companies.
2. It was reaffirmed that elimination of transponders is a primary determinant in migration to integrated DWDM pluggables.

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<sup>10</sup> Postal, telegraph, and telephone service

## 5.2 Written media: e-mails and reports

The two broad objectives (discussion of the graphical summaries of the results and assessment of the objective clarity of the questionnaire's questions) were further pursued through written media. This approach facilitates reflection on both parties' sides, whilst lacking the immediacy obtained in face-to-face interviews. For convenience's sake, the portion of Table I pertinent to written media, is reproduced below as Table II .

Table II WRITTEN RESOURCES COLLECTED DURING DATA STAGE OF QUALITATIVE SURVEY		
E-mail thread: <a href="#">Mark Tinka</a> <sup>11</sup>	[4]	<a href="https://data.mendeley.com/api/datasets/k72dntnfgv/draft/files/fba419c4-45c6-4332-917a-24babad0935b">https://data.mendeley.com/api/datasets/k72dntnfgv/draft/files/fba419c4-45c6-4332-917a-24babad0935b</a>
E-mail thread: <a href="#">Philip Smith</a> <sup>12</sup>	[5]	<a href="https://drive.google.com/open?id=1bN0RS_M93UojmdA0oYMYqJI9Q1_uM8Hk&amp;usp=drive_fs">https://drive.google.com/open?id=1bN0RS_M93UojmdA0oYMYqJI9Q1_uM8Hk&amp;usp=drive_fs</a>
E-mail thread: <a href="#">Daniel King</a> <sup>13</sup>	[6]	<a href="https://drive.google.com/open?id=1ayHhTdpfdIWMZuyLPTapKDZS1-cUFIRM&amp;usp=drive_fs">https://drive.google.com/open?id=1ayHhTdpfdIWMZuyLPTapKDZS1-cUFIRM&amp;usp=drive_fs</a>
E-mail thread: anonymous_2	[7]	<a href="https://drive.google.com/open?id=1el7oH18k_dWsupVPNjCfGHSAaa_7tkX3&amp;usp=drive_fs">https://drive.google.com/open?id=1el7oH18k_dWsupVPNjCfGHSAaa_7tkX3&amp;usp=drive_fs</a>
Written assessment: <a href="#">Haider Khalid</a> <sup>14</sup>	[8]	<a href="https://drive.google.com/file/d/1gith5v8W2x4DIl_15oyPW9n39uT9fnGc/view?usp=sharing">https://drive.google.com/file/d/1gith5v8W2x4DIl_15oyPW9n39uT9fnGc/view?usp=sharing</a>

### Mark Tinka

Mark's support in crafting the questionnaire precluded any discussion on clarity of the questions. The results were within scope of discussion; a first reading drew some scepticism, due to the dominance of ADSL2+ in SGA's sample, both as the largest and fastest-growing access technology. The ensuing exchange with SGA's representatives accentuated the importance of balancing quantitative surveys with qualitative surveys. Therefrom, it emerged that with **regional and Tier 1 CSPs** dominating SGA's, and with further suggestion that these were indeed incumbents in their markets, the SGA sample includes CSPs who are still reaping returns from their investment. One particular extract of the thread is particularly pointed.

*"So, I've read their-response - I suppose it makes sense, because AT&T and Verizon, especially, are legacy operators with tons of copper in the ground that they are, most likely, still monetizing.*

*While they are likely to have all of that legacy infrastructure that comprises a huge part of their inventory, it does not necessarily mean that the world is not moving on to fibre, Ethernet and DWDM.*

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<sup>12</sup> <https://www.linkedin.com/in/philip-smith-154502/>

<sup>13</sup> <https://www.linkedin.com/in/danielking/>

<sup>14</sup> <https://www.linkedin.com/in/haider-khalid/>

*I think SGA would need to consider, for the future, how to obtain data from a wider set of operators (of varying sizes and scope), because a lot of the next-generation deployments don't generally tend to happen (fast enough) at the legacy incumbents. That, I think, is why the data is quite different from the \*NOG responses, because the \*NOG responses cover a substantially wider base of operators, most of whom are not normally representing legacy incumbents."*

This observation is reinforced by Dave Eilert's, who, in the context of reference to SONET/SDH, had reminded me about the need to exploit investment in infrastructure. Indeed, SONET/SDH is still in use by 10% and 24% of NOG and SGA sample respondents, respectively.

**Key takeaways:**

1. Return on investment is a key criterion in determination of the rate of penetration of replacement technologies. The observation here arose in the context of an access technology (copper-based ADSL2+).
2. The SGA sample's response is representative of incumbents with legacy infrastructure still being monetized.

Philip Smith

While Philip drew attention, as respondent anonymous\_2 did, to uncertainty with the representativeness of the results, he asserted that the results did not jar with his understanding of current metro area networks and developments thereof. Moreover, in the process of evaluating the credibility of the data, a fresh perspective on the two groups was offered: NOG respondents are likely to include those with a higher degree of autonomy in taking decisions than those from the large incumbents. The salient extract is reproduced below.

*"Yes, SGA has given you a guarantee of the biggest providers, probably what we'd call the national telecoms (in the old days). My feeling from the industry is that those folks will have much less scope to do what "they want to do", in that technical decisions about network deployments will be made by their vendors. I remember similar in my Cisco days – the biggest deployments by big operators (at least for access) were by and large handed over to the vendors to make a proposal and then implement ... So even if the CTO of a "Tier-1" responded, they'd have not a lot of say in what is made available or what the future strategy might be, apart from choosing the options their vendors present to them.*

*Doing the survey by open request to the NOG community will mean you'll get the smaller operators and the operators who are not driven by their vendors - the big private operators for example. Is it representative? Well, who knows, but we are stuck with those who are willing to volunteer their time.'*



*Again, I've helped these providers over the years, and they are much more determined to do what is right for the customer, the best and most reliable implementation, most cost effective for them to implement and operate'...*

*So, I'd summarise that you have two valid data sources in your survey here, but from parts of the community that have different/opposite outlooks on how they deploy infrastructure. Both are valid. TBH I'm more comfortable with access infrastructure that has been designed by the provider than one that is delivered by t-e vendor - my bias after years and years of working helping build Internet service provider networks ... Thanks for sharing—all this - it was an interesting read. I can't think of anything that would invalidate (or cause question) on either the NOG or SGA survey. They are going to be as representative as you can get with a voluntary response."*

I also invoked Philip's support on the issue of interpretation of the problematic term "routed optical networks". In view of the significance of the technology stack's impact, I have deferred citing his contribution to resolution of the issue, to the analysis.

#### **Key takeaways:**

1. Given the observed difference between the two samples, the results match expectations.

Daniel King

Limitations and ambiguities in the questionnaire were addressed directly, as follows.

*"Nothing obvious. I suppose a few questions on planned network evolution might have been interesting; for instance... Juniper is proposing Seamless Segment Routing; they are keen to continue the end-to-end inter-domain/AS principle of seamless MPLS with lightweight traffic engineering features of SR. I know at least two mobile operators working with Juniper on this architecture – although several standards gaps exist, such as BGP-CT maturity."*

Indeed, Daniel's observation is correct; however, since the scope of research was the data plane, and the questionnaire required 10 – 12 minutes [12] of a respondent's time, I felt the need to avoid digressing.

I also asked how well the results match his perception of trends.

*"The service distribution of the existing customer base and current/predicted service growth meets my expectation. Although, I have not discussed specific customer service demand with an operator for several years. However, the results match the recent trend of standardisation activity, including discussion in the ETSI Fifth Generation Fixed Network (F5G)."*

Given Daniel's background as witnessed by [his participation in several RFCs](#)<sup>15</sup>, I asked for his opinion on the widespread choice of seamless MPLS as a layer 2+ aggregation technology.

*"Service evolution for residential customers has recently transitioned from a "Broadband Era" (XG PON), to "Ultra Fast Broadband" (NG-PON), and we are now in a "Gigaband Era" (50G EPON). It is worth noting that the operators not only wanted to increase the number of users supported and provided more bandwidth, but an operator must also be able to dedicate bandwidth for 5G fronthaul and provide backward compatibility with EPON/10G-EPON and GPON/XG PON, whilst reducing operation costs (especially reducing overall system power consumption and cooling costs).*

*Why is seamless MPLS so popular with your respondents? Transceivers now support a higher power budget, reach, flexible grid transmission, and system power cost. Still, they can also be used in multi-layer packet routers that already have MPLS fast-path forwarding ASIC/FPGA's. In addition, these GPON/EPON transceivers provide a server layer for seamless MPLS architectures – which can be managed using a single control plane to simplify operations and reduce costs - supporting ultra-fast end-to-end Internet services across a range of residential, business and vertical user and application requirements (BW, protection and latency).*

*Importantly, to reduce operational costs, setting up fine-grained services across multiple domains (end-to-end) whilst collapsing control plane architecture is a huge advantage. Ultimately, I think energy efficiency constitutes an increasingly significant challenge for network operators; not only does it directly reduce the operational expenditures of operators, but it also lowers both carbon emissions and environmental impact."*

#### **Key takeaways:**

1. Multi-layer packet routers are facilitating delivery of differentiated end-to-end services – and these services' availability benefits from the smaller domains facilitated by seamless MPLS.
2. The results match expectations.
3. The questions are clear.

[Haider Khalid – report](#)

In addition to the face-to-face interview, Haider accepted to dwell further on the content and wrote a brief report [8]. The key takeaways from the report are reproduced below.

#### **Key takeaways:**

1. UNI and NNI are easily recognizable terms; U1 and A10 are not.

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<sup>15</sup> <https://datatracker.ietf.org/person/d.king@lancaster.ac.uk>

2. In similar vein: provider edge (PE) is recognizable as the edge of access. This calls to mind the Stage 2 segmentation model [9].
3. The results match expectations. Haider cited the following as particular cases of the agreement between results and expectations:
  - a. distribution of deployment of access technologies;
  - b. Ethernet as a “major layer 2 backhaul”;
  - c. MPLS as dominant switching technology, especially when core is taken into account, and
  - d. location of video BNGs as close as possible to the end-user, to save bandwidth.
4. No ambiguities in the questions were detected (though the graphs presented to Haider for his analysis, were found lacking in clarity).
5. Limitations observed concerned the desire to extend into questions on SDN. Here, my defence is the same as that offered with regard to Daniel King’s observation on scope of the quantitative survey.

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