PON versus AON: Which is the best solution to offload core network by peer-to-peer traffic localization

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Abstract

Video streaming and video-on-demand are gaining popularity nowadays which dictates a need of bandwidth upgrade for Internet users. Many next generation optical access network architectures have been proposed to meet high capacity requirement on a per-user basis. However, the capacity upgrade in access networks, may lead to a huge traffic growth in the aggregation/core network. One way to avoid this problem is to keep the traffic locally (i.e., inside the access network area) as much as possible. It can be obtained by using locality-aware peer-to-peer (P2P) applications for content distribution and has the potential to offload the core segment. However, various optical access network architectures accommodate the P2P traffic in different ways. Thus, it is important to study these differences in order to identify the best architecture option for capacity offloading in the core network, energy efficiency and network resource utilization. By deploying a proper architecture in the access segment along with an efficient traffic locality aware strategy, the extra investment and capacity upgrade of the expensive core network resources needed to support the future traffic expansion can be minimized. However, to the best of our knowledge this kind of assessment is so far not available. Therefore, in this paper, we analyze the efficiency of supporting locality-aware P2P video distribution algorithm in three main types of optical access network architectures, i.e., active optical network (AON), wavelength division multiplexing passive optical network (WDM PON) and time/wavelength division multiplexing PON (TWDM PON). Our goal is to provide important design guidelines for the next generation broadband access architectures, while minimizing the need for the core network upgrade. We obtain this objective by utilizing the unique characteristics of each access network architecture in accommodating P2P video delivery applications. We have done an extensive literature study and for the first time we have compared performance of these architectures with respect to the amount of the traffic on the links in different aggregation levels, power consumption taking into account sleep mode functionality at the user premises, and required switching capacity in the nodes. Our results reveal that both active and passive architectures have good ability to localize P2P traffic, whereas they show distinct performance with respect to the other aforementioned aspects. This is caused by the different number of aggregation levels, link capacity, and resource allocation protocols. Considering the overall performance evaluation, it is shown that TWDM PON is the most promising option for the future broadband access, where locality-aware P2P video distribution is applied, thanks to its low energy consumption and required switching capacity of the network equipment needed to deliver this service. This conclusion is against the general intuition because of the PON’s centralized control plane and passive

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1. Introduction

The growing interest for the video streaming and multimedia applications offered on the Internet, results in a rapidly increasing bandwidth demand of the individual users that affect both access and core networks. In this regard optical fiber is considered as the most promising transmission medium for the future Internet and hence access networks based on optical fiber are considered as the most promising candidates for the current and future deployments [1]. In addition to the high bandwidth on a per-user basis, future access networks are expected to cover much larger service areas and support higher number of customers. This allows for co-locating several central offices in one central access node (CAN), offering a great potential to save the operational expenditures [2] and reduction of the aggregation network [3,4]. There are basically two main groups of optical access architectures, namely active optical network (AON) and passive optical network (PON). A large number of comparative studies have been conducted to find the best solution for the future access network based on the optical technology by evaluating the cost and performance of various candidates, such as power consumption and reliability performance. Papers [5–7] analyze power consumptions of several access architectures offering fiber to the home (FTTH), where active and passive solutions are compared for. The results show that PONs are more energy efficient than AONs, as no active equipment is required in the outside plant. Papers [8,9] present techno-economic studies considering next generation AONs and PONs which could offer 1 Gbps and more as peak data rate per subscriber. The authors claim that AON is cheaper than PON with 10 Gbps transceivers in terms of deployment cost, though the power consumption of AON is higher. On the contrary, authors of [4] present a comprehensive techno-economic study comparing the different flavors of AON and PON for FTTH. According to the outcomes of this study, which includes both operational and capital expenditures, PON is a cost efficient alternative for future broadband access. Moreover, the reliability performance and protection cost of several passive and active optical architectures are assessed in [10,11], confirming that PON performs better than AON from the resilience point of view.

Meanwhile, it should be noticed that bandwidth growth in the access network may lead to a need for an upgrade in the aggregation/core network [12], e.g. the growth of average bandwidth per user from 1 Mbps to 100 Mbps in the future access networks may result in 100 times larger capacity demand in the core network. Consequently, in the near future the core segment may become the bottleneck for the bandwidth upgrade per user. One way to address this problem is to keep the traffic locally in the access network area as much as possible. It would prevent “feeding” the core network with all the traffic from the access segment. Based on the study presented in [13], the sum of all forms of video traffic including TV, client-server based video downloads and peer-to-peer (P2P) will exceed 91 percent of global consumer traffic by 2014. Therefore, our intuition is that it may be possible to remove the bottleneck from the core network by keeping the video traffic inside the access network [14].

A number of solutions have been introduced recently, proposing data storage in the micro-caches close to the end users [15] or even in the end user premises [16] to push the aggregation/core traffic towards network edges via localized P2P video distribution. Using P2P application, it is possible to move caches from the core edge to the user premises, and utilize the upstream bandwidth of the customers that is normally wasted in today’s applications. This can potentially reduce the bandwidth required in the aggregation and core links. Based on the study done in [17], in 2013 the total localized P2P video content was exceeding 20 Exabytes per month. This brings a great potential of localizing the video traffic.

Accordingly, the next generation optical access network does not only need to be able to provide high capacity per user in a cost efficient way, but also should support the locality of traffic to prevent overloading the core network. The advantages of using localized P2P video delivery method over the future access networks are addressed in several works considering offloading core network traffic and power efficiency. Studies presented in [12,18], evaluate the advantages of P2P applications over traditional content delivery network (CDN) and data-center in long reach PONs (LR-PONs). The results show that P2P can achieve significant bandwidth savings by keeping most of the traffic inside the access section of the network. Work in [12] also addresses the benefits of large service areas covered by the future fiber access networks on the traffic locality as a result of supporting much larger number of users. The impact of symmetric bandwidth in long reach time division multiplexing PON (TDM PON) on the locality of P2P traffic as well as possible energy saving is assessed in [18].

Up to 2012, the deployments of Ethernet Passive Optical Networks (EPONs) covered more than 60 million households, where more than 20 million subscribed the EPON services. On the other hand, over 80% of P2P traffic, which is mainly related to the video delivery applications, can be handled locally within the same Internet provider’s network. Therefore, authors in [19] proposed a P2P locality-aware architecture for EPON where the optical network unit (ONU) at the user premise needs to be modified. The results in this paper show that their proposed architecture can provide good system performance in terms of packet...
delay and bandwidth utilization in the access network. Moreover, authors in [20], propose two architectures handling the P2P traffic in radio over fiber networks. The first architecture utilizes a dedicated wavelength for P2P and the second one reuses the downstream wavelength for the P2P connectivity. The experimental measurements verify that their proposed systems can achieve good performance with no noticeable degradation of the transmitted signals. However, the cost of adding extra wavelength or hardware could be an issue for cost-sensitive access networks.

Energy efficiency of P2P video distribution services as one of the most important factors of the future internet design is analyzed in [21–25]. Paper [21] proposes a locality aware peer selection scheme for P2P algorithm aiming to reach lowest possible energy consumption in the access network considering gigabit capable PON (GPON) as broadband access technology. The simulation results show a clear reduction of energy consumption by using proposed method compared to the client-server based video delivery techniques. Papers [22,23] propose sleep mode functionality for set-top boxes (STBs) in the user premises while they are offline, to decrease the power consumption. Paper [24] also introduces a distributed optimization algorithm to be deployed on the STBs, which put unused STBs in sleep mode without degrading the quality of service. Paper [25] proposes an energy-efficient scheme based on P2P over a time and wavelength division multiplexing (TWDM) PON which combines adaptive link rate and network coding techniques. Simulation results show that the power consumption of the devices can be decreased using proposed architecture in the presence of P2P traffic.

The above findings confirm the benefits of P2P applications running in PONs for offloading the traffic in the core and aggregation network using the upstream bandwidth of the end users. However, various access architectures might perform differently in accommodating local traffic. For example, paper [26] examines the P2P localization capability within the access network considering both next generation high capacity PONs and currently deployed GPON. Results show that nearly all of the unicast video traffic can be kept within access network via localized P2P using next generation PONs (NG-PONs), while GPON shows less benefit in offloading the core traffic compared to NG-PONs. Moreover, highly centralized architectures (e.g. wavelength division multiplexing (WDM) based PONs with node consolidation) can potentially decrease the operational cost of the network but may bring difficulties to manage the local traffic due to the long distances (e.g., 60 km and beyond) between end users and the first aggregation level. On the other hand, active switches located in the outside plant (e.g., in street cabinet) in AON might improve the traffic locality compared to the PON architecture by moving switching capacity close to the user. However, it is done on expense of increased power consumption as well as management and maintenance effort required in the field as presented in [7].

The benefits of using PON for P2P traffic in the integrated optical wireless access networks, referred to as FiWi networks are identified and assessed in [27]. This study shows that by sending P2P traffic through a wireless-optical-wireless path instead of several hops in pure wireless network, the throughput can be improved. Authors in [28] propose a comprehensive probabilistic analysis for evaluating the packet throughput and delay performance of next-generation PONs. Their model can be applied for several access architectures based on PONs. This study is further extended in [29] to evaluate the performance of several optical access network architectures backhauling future wireless local area network (WLAN) where P2P traffic is carried. The results show that WDM PON and TWDM PON outperform TDM PON considering the delay performance. The authors demonstrate the benefits of transmitting the P2P traffic over the PON in comparison with the case where users are directly connected through wireless mesh network, with several hops between source and destination nodes.

To this end, the studies prove the benefit of using P2P in the future fiber access networks for the energy efficiency and core capacity saving. However, to the best of our knowledge, the impact of traffic dynamism of P2P applications caused by the resource allocation algorithms such as time division multiple access (TDMA) and physical topology of various access architectures on the power consumption and network resource utilization have not been studied yet. Therefore, in this work we are trying to find the best candidate for the future fiber access networks aiming to maximize the core bandwidth saving by analyzing the consumed power and network resources of P2P video distribution in the access network. We believe that our study represent a more comprehensive view towards finding the suitable architecture for the future optical access networks and can extend the existing comparative studies of various optical access network architectures considering cost, power consumption and network reliability. We investigate the performance of several candidates for the future optical access networks in terms of traffic distribution, switching capacity and power consumption taking into account the traffic dynamism via localized P2P traffic. For our study, we developed a tailored simulation tool based on network simulator 2 (NS2). NS2 is an event-driven and real-time network simulator which makes it possible to simulate dynamic behavior of flow and congestion control scheme at packet level. It enables us to see the influence of layer two protocols on the network resource usage that is not possible to obtain by the simple flow based simulators (such as the one used in [12]). The remainder of the paper is organized as follows. In Section 2, three optical access network architectures evaluated in this paper are introduced. Section 3 presents the setup details and the network scenarios used for our simulations. Section 4 shows the performance evaluation results in terms of the amount of traffic on the links, energy consumption and switching capacity required in each architecture considering P2P application to offload the core network. It also includes a short summary of the comparison between different architectures. Finally, conclusions are drawn in Section 5.

2. Next generation optical access network architectures

In [30] a set of next generation optical access network architectures covering large service areas and providing high bandwidth per user have been proposed. As mentioned
previously, two main categories of optical access technologies in regard to the type of remote nodes (RNs), i.e., active and passive, have been identified. The latter category consists of several kinds of PON utilizing WDM technology to increase capacity, including pure WDM PON (where a dedicated wavelength is assigned to a single end user) and hybrid PON, complemented by the other multiplexing techniques (e.g., TDM), which can further enlarge the number of clients per PON. In this paper, we focus on three optical access network alternatives, namely, AON, WDM PON and TWDM PON [31].

Fig. 1 shows the three considered optical network architectures mapping to three network segments, i.e. core, aggregation and access. In all the cases, point of presence (PoP) represents the border of the core network and all the traffic passing the router located in this node are considered as the core traffic. The router located in PoP is connected to N central access nodes containing Ethernet switches and optical line terminals (OLTs). The network segment between PoP and CAN is referred to as the aggregation network, and the section from CAN up to the ONU at the user side represents the access network. Due to the node consolidation that is expected in the future, in the next generation access networks the OLTs will move from the central offices to the CANs that are closer to the core edges compared to the today’s network. The fiber section between CAN and RN is named as feeder fiber (FF), and the one connecting users to RN is referred to as distribution fiber (DF).

In AON (see Fig. 1(a)), several ONUs are connected to the OLT through the Ethernet switch located in the RN (e.g. in the street cabinet). In this case, the communication between the users connected to the same RN could be kept locally and the corresponding traffic does not have to travel all the way up to the OLT and then be switched back to another user in the same access area. The Ethernet switch offers one extra aggregation level inside AON. In this architecture, ONUs are equipped with 100 Mbps Ethernet ports.

For PON architectures OLTs are connected to the users via a passive optical distribution network (ODN). Therefore their first aggregation point is at the CAN through an Ethernet switch. WDM PON (Fig. 1(b)) has an arrayed waveguide grating (AWG) in the RN linking M1 users to each OLT. Each ONU has a dedicated wavelength channel working at 1 Gbps data rate in both downstream and upstream directions. Thus, the ONUs are connected to the OLT via logical point-to-point connections in the wavelength layer. In case of TWDM PON (Fig. 1(c)), one power splitter is located at the RN to have high flexibility in wavelength allocation. Each PON consists of 4 wavelength with 10 Gbps transceivers which are broadcasted to all the users of this PON. Each 32 users share one wavelength in the time domain. In TWDM PON an arbitration mechanism (e.g. TDMA protocol) is required for bandwidth allocation in the upstream direction to ensure that only a single user is allowed to transmit data at a given point in time for a certain wavelength. The considered TWDM PON uses the static wavelength allocation and the standard GPON protocol to perform the bandwidth allocation among the users assigned to the same wavelength. ONUs are equipped with the tunable transmitters and receivers in order to select the assigned wavelength and they can provide peak rate up to the 10 Gb/s in downstream and upstream direction. TWDM PON is
promoted by FSAN as the NG-PON2 architecture for future upgrade of access network [25].

3. Network scenarios and simulation setup

We consider a video-on-demand (VoD) delivery network where a set of movies can be shared by the users. Our study is carried out by utilizing a specially tailored NS2 based discrete event driven simulator [32]. NS2 is one of the most popular simulators used in academia. Since it is an open source simulator, it is constantly updated by a large user base. It has already implemented several network protocols such as transmission control protocol (TCP), Internet protocol (IP), router queue management mechanisms, routing algorithms, etc. Therefore, using our NS2 based simulator with built-in network protocols such as TCP/IP, TDMA, Ethernet, etc., makes it possible to process dynamic traffic distribution and hence accurately measure bandwidth usage on each link in any arbitrary short period of time. This also allows us to measure an exact amount of packets passing each node, to perform a detailed evaluation of required switching capacity in the switches.

In the simulation each user is equipped with a STB with enough storage capacity connected to each ONU. In the initial stage of the simulation, some of the customers have already watched the movies and cached them, making the content ready to share with other peers (P2P users). We consider a set of movies to be downloaded by different customers using P2P application. The movies are considered with duration of less than 2 min in order to keep the simulation time at a reasonable level. Typically the users watch the movies in the evenings after coming back from work, which occurs during a short period of the whole day (e.g. between 5 pm and 7 pm in the evening). Therefore, we assume the users start watching movies randomly during the first 30 s of our simulation, which corresponds to the peak hours (2 h) in the evening. A detailed description of the number of movies and popularity model considered for the simulations can be found in [33]. The simulations run for 3 min after which all the peers have finished their download and the links become idle. The simulation results change proportionally if the duration of movies are decreased or increased.

In a P2P application the tracker (a node who has a list of all users with their table of content and IP addresses) has the responsibility to find peers for a given content. In our simulations tracker uses a locality awareness scheme introduced in [16] for the peer selection. The source node sends a request to the tracker which is located in the core edge and is responsible for finding peers for any requested content. The goal of this algorithm is to find enough peers in the vicinity of the source node to limit the P2P traffic passing the aggregation/core network as much as possible. When a peering query arrives, the tracker sends back a list of IP addresses of peers using a recursive search in its database. The list is ordered according to the distance from the requesting node which is the number of aggregation level hops the traffic needs to pass. Tracker starts to look up for the content in the nodes connected to the same source node at the certain aggregation switch. If it cannot find enough peers in this level, the search is extended to the higher levels. This process stops if either the enough peers are found or the whole network is explored. In case of AON, when a user requests to download a movie, the tracker starts the process by searching the peers connected to the same Ethernet switch at the RN for the required content. If it cannot find a sufficient number of peers in this level, the tracker checks the contents at the ONUs connected to the same OLT but different RNs.

The considered input parameters for all three optical access architectures are presented in Table 1. The bit rate presented here is for one wavelength in case of WDM PON and TWDM PON. To be able to have a fair comparison among architectures, we consider the same total number of users (i.e. 768) in all the scenarios. This value is used as the basis to define the number of nodes in each level. Moreover, this value is also the largest one allowing to keep the simulation time on an acceptable level. It can be seen that the average data rate on a per user basis is quite different among three considered architectures. It is determined by the considered resource sharing mechanisms. The bit rate on DF link in AON is assumed to be 100 Mbps instead of 1 Gbps because of the capacity limitation at its feeder fiber.

4. Simulation results

4.1. Amount of traffic on the links

This section presents the simulation results showing the amount of P2P traffic in different links. The total amount of traffic on aggregation fibers are similar in all the three considered architectures, which means that they have almost equal capability to offload traffic in aggregation/core networks by employing P2P applications. However, they perform differently in terms of instant traffic intensity (the bandwidth usage on each link in an arbitrary short period of time that in our case is equal to 1 ms). The architecture option significantly affects the energy consumption and required switching capacity, which are discussed in Sections 4.2 and 4.3.

Table 1
Input parameters of the considered architectures as well as capacity in each fiber section.

<table>
<thead>
<tr>
<th>Architectures</th>
<th>No. of CANs</th>
<th>No. of OLTs per CAN</th>
<th>( M_1 )</th>
<th>( M_2 )</th>
<th>Bit rate</th>
<th>Average bandwidth per user (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Aggregation. fiber (Gbps)</td>
</tr>
<tr>
<td>AON</td>
<td>3</td>
<td>1</td>
<td>8</td>
<td>32</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>TWDM PON</td>
<td>3</td>
<td>2</td>
<td>128</td>
<td>–</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>WDM PON</td>
<td>3</td>
<td>2</td>
<td>128</td>
<td>–</td>
<td>40</td>
<td>1</td>
</tr>
</tbody>
</table>

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Fig. 2(a)–(c) show the instant P2P traffic sampled in each microsecond (for one wavelength in case of PONs) in downstream direction on the aggregation fiber, FF and DF, respectively. As there is no intermediate aggregation node between ONUs and CAN for two evaluated PON variants, the traffic on the FF and DF are exactly the same. As it can be seen in the figures, despite the fact that the same numbers of users are downloading the same content, the traffic distribution is completely different among the architectures. It is mainly because of the variations in the topologies and the applied resource sharing mechanisms.

In TWDM PON, the downstream aggregated traffic for the users assigned with the same wavelength passes through FF and DF, due to the broadcast property of the splitter. Therefore, as it can be seen in Fig. 2(b) and (c), the amount of traffic in TWDM PON is significantly higher compared to the AON and WDM PON, especially on the DF link. Moreover, because of the control overhead for the TDMA protocol in TWDM PON, there is still some traffic on the links after the peak for P2P. However, in the aggregation link (see Fig. 2(a)), the amount of traffic in TWDM PON is slightly lower than in AON. It proves that AON does not have any obvious benefit compared to TWDM PON to offload traffic from the aggregation/core networks. Besides, it should also be noted that the bandwidth of the FF and DF in TWDM PON is 10 Gbps, so the P2P traffic observed in these links occupy less than 10% of the total capacity of the links. In WDM PON, traffic is obviously more bursty compared to the other two architectures, due to the fact that its point-to-point connectivity leads to the highest sustainable data rate per user. Consequently, the peers are able to download their data much faster. However, as most of the nodes download their data at the same time in the beginning of simulation, a large peak can be observed in the aggregation link (Fig. 2(a)) for a short period of time.

AON has relatively stable instant traffic on all the downstream links. In DF, the maximal instant traffic is the lowest in AON compared to the other considered architectures, thanks to an additional aggregation level at the RN compared to PON solutions.

The instant P2P traffic on the DF in the upstream direction (i.e., sent from ONU) is depicted in Fig. 3. The trend of instant upstream traffic on the feeder and aggregation fibers is very similar as for the downstream traffic shown in Fig. 2(a) and (b). The total amount of P2P data over DF for the entire simulation time in upstream direction is nearly the same for all the architectures, since it only depends on the amount of data that each user is sending, which is assumed to be similar for all the considered architectures. However, they perform totally different in terms of the instant traffic on the links. The amount of upstream traffic for TWDM PON has a more uniform distribution due to the periodically assigned time slots determined by the TDMA protocol. On the other hand, in WDM PON all the upstream traffic is sent immediately using the high capacity link available for the
user. The traffic in AON is also varied a lot during the time but it has obviously lower peaks and lasts longer because of the smaller capacity of the link.

4.2. Switching capacity

Ethernet switches in AON and TDMA protocol in TWDM PON cause that these two architectures have a more scattered and less bursty traffic flow on different links compared to the WDM PON, where a point-to-point logical connection between the ONUs and the OLT, allows much higher capacity on a per-user basis. In our simulations we considered Ethernet switches with 100 Gbps switching capacity to ensure that there is no packet loss in the nodes. Fig. 4, shows the maximum instant amount of P2P traffic that needs to be switched in different locations of the network, which implies the switching capacity required to handle the peak traffic. It can be seen that WDM PON needs nearly three times larger switching capacity to handle the same total amount of P2P traffic compared to the other two architectures. This is a consequence of the large bursts of data that are transmitted in WDM PONs. On the other hand, AON and TWDM PON require similar total switching capacity. As AON has one more aggregation level compared to the other two architectures, switching function should be also located at RN, which may lead to higher operational complexity due to the active components in the ODN. Furthermore, it can be seen that the maximal instant amount of traffic passing through the PoP router is the lowest in TWDM PON, which means that for this architecture the lowest switching capacity is required at the edge of the core network to deal with the P2P traffic.

4.3. Power consumption

As shown in Section 4.1, there are some time slots during the transmission of P2P traffic in which the links are idle, offering the possibility to turn off the transceivers if an energy efficient scheme is applied. In this section, we evaluate the power consumed by the active components in the access network from CAN down to the ONUs to carry out P2P traffic and investigate the potential energy saving by using low-power mode.

Table 2 shows the input values used for power consumption calculation [34]. The power consumption of each device is divided in two categories: the constant offset power, which is not affected by the traffic, and the power that is traffic dependent. The later part can be saved by switching off the transceivers when there is no traffic on the link. This leads to two modes of operation for each component, namely active and sleep. It should be noted that the sleep mode for Ethernet switch in AON and OLT

<table>
<thead>
<tr>
<th>ONU power consumption (W)</th>
<th>OLT power consumption per user (W)</th>
<th>RN(32 user)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active mode</td>
<td>Sleep mode</td>
<td>Active mode</td>
</tr>
<tr>
<td>TWDM PON</td>
<td>5.5</td>
<td>3</td>
</tr>
<tr>
<td>WDM PON</td>
<td>4.7</td>
<td>3</td>
</tr>
<tr>
<td>AON</td>
<td>3.5</td>
<td>3</td>
</tr>
</tbody>
</table>

Fig. 3. Instant traffic in upstream direction on distribution fiber.

Fig. 4. Switching capacity required in different locations.

Fig. 5. Power consumption for the considered architectures.

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in TWDM PON is not considered as these two components are shared by several end users and it is difficult to switched them off.

The energy consumed by the ONU is typically paid by the users in contrast to the equipment belonging to the network provider. Therefore, we present the results of power consumption in two categories, namely power consumed by the user and network provider (NP) equipment, respectively. Fig. 5 shows the power consumption calculated for all the users connected to one CAN. The bars with the darker color represent the power consumption without considering the sleep mode in the components and the bars with the lighter color indicate the average power consumption during the simulation where the transceivers can be turned off, if there is no traffic on the link. As expected, WDM PON could obtain the highest power reduction if the sleep mode is employed, due to the fact that the peers finish downloading their data relatively fast and therefore the transceivers can be in the sleep mode for a longer time. AON has the highest power consumption in the field (NP power) caused by the active Ethernet switches in the RN, though it has the lowest power consumption on the user side. TWDM PON is the most power efficient architecture from the operators’ points of view, showing the lowest power consumed by the network equipment. This is because of deploying the passive equipment in the field as well as sharing OLT transceivers among all the users sharing the same wavelength, which is different from WDM PON having one dedicated transceiver at OLT for each user. However, user premises in TWDM PON have the highest power consumption, as ONUs should be able to support the TDMA protocol as well as working at the high bit rate (i.e., 10 Gbps).

### 4.4. Performance evaluation summary

Table 3 summarizes the performance evaluation of three architectures regarding the offloading capability, switching capacity and power consumption based on the aforementioned results. The aim of this section is to present a qualitative summary of the performance evaluation for considered optical access network candidates. It has been shown that all three architectures have a similar ability to keep the traffic locally by using P2P application. However, they perform differently with respect to the other performance criteria because of distinct profiles of the instant traffic on FF and DF. TWDM PON consumes less power and needs lower switching capacity for network equipment to handle the same P2P traffic than the other two considered architectures.

<table>
<thead>
<tr>
<th>Architecture</th>
<th>Offloading capability</th>
<th>Required switching capacity</th>
<th>Power saving</th>
<th>Power consumed by network provider</th>
</tr>
</thead>
<tbody>
<tr>
<td>AON</td>
<td>Very good</td>
<td>Low</td>
<td>Poor</td>
<td>High</td>
</tr>
<tr>
<td>TWDM PON</td>
<td>Very good</td>
<td>Low</td>
<td>Good</td>
<td>Low</td>
</tr>
<tr>
<td>WDM PON</td>
<td>Very good</td>
<td>High</td>
<td>Very good</td>
<td>Medium</td>
</tr>
</tbody>
</table>

5. Conclusion

In this paper, we have carried out an extensive literature study on P2P traffic served by different access network architectures and for the first time we quantitatively compared three optical access architectures supporting locality-aware P2P application, aiming at offloading the traffic in the aggregation/core network. The packet level analyses show the dynamicity of the traffic on each link caused by different medium access control protocols required for the various optical access architectures. The comparison has been performed not only in terms of amount of P2P traffic in the access and aggregation segments but also the switching capacity required and the power consumed in each architecture.

The results show that all the assessed architectures are equally good in offloading the aggregation/core traffic by using locality awareness scheme to handle the P2P traffic. WDM PON has the highest ability of power saving using sleep mode in the OLTs and ONUs. TWDM PON has the lowest power consumption in the field, though it is difficult to further reduce it by employing any energy efficient scheme. The required switching capacity is much larger in WDM PON than in AON or TWDM PON. On the other hand, AON needs higher number of switches located in the RNs, which may increase the operational complexity. Although, PONs are not optimized for the localized traffic delivery due to their passive infrastructure without switching capability in the field, notably TWDM PON shows the best performance regarding the overall aspects when localizing video traffic via P2P, thanks to its low switching capacity and energy consumption required for the network equipment.

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**References**

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