Case for Dynamic Reconfigurability in Access Networks

Rajeev Roy and Wim van Etten

Telecommunication Engineering, University of Twente,
P.O. Box 217, 7500AE Enschede, The Netherlands
{r.roy,w.c.vanetten}@ewi.utwente.nl

Abstract. The paper discusses the merits of having a reconfigurable access network. The network is viewed as a stack of logical PONs in which bandwidth can be redistributed on an inter-PON scale. The redistribution allows for optimal distribution of bandwidth to the end user.

Keywords: EPON; WDM PON; dynamic reconfiguration; OLT; ONU; access networks.

1 Introduction

The BBPhotonics (BBP) project under the consortium of Freeband projects looks into the design of an extended access network. The network is a reconfigurable and resilient multi-wavelength photonic access network. The network is expected to cater to multiple communities which are geographically spaced out. The paper discusses the salient features of the network and presents a case to have reconfigurability in access networks. Section 2 introduces the network design and presents the network as a conceptual stack of quasi independent PONs. Section 3 presents a study into typical bandwidth requirements foreseen in the access in the near future. Section 4 presents two network profiles which are used to discuss the merits of a reconfigurable network. Section 5 describes performance metrics of providing bandwidth to the user by means of a static network configuration and then comparing it with the dynamic network configuration presented.

2 Network Architecture

Fig. 1 illustrates the network schematically. The Head End (HE) houses a multiple of Optical Line Termination (OLT) Units. The HE is connected to Remote Nodes (RNs) through a diverse fiber link which is resistant to up-to a single fault in the HE-RN connectivity. The RNs then connect to Customer Premises Equipment (CPEs) which house the Optical Network Units (ONUs). The OLTs used are Commercial Off the Shelf (COTS) devices with modified optics to transmit on ITU-T gridded wavelengths in the C-Band. The ONUs used are COTS devices with modified optics to receive transmission in this band. The HE also transmits gridded Continuous Wave (CW) lasers which are modulated by a CPE based Reflective Semiconductor Optical Amplifier (RSOA) and used for upstream communication [1]. The RNs house

C. Wang (Ed.): AccessNets, LNICST 6, pp. 240–250, 2009.

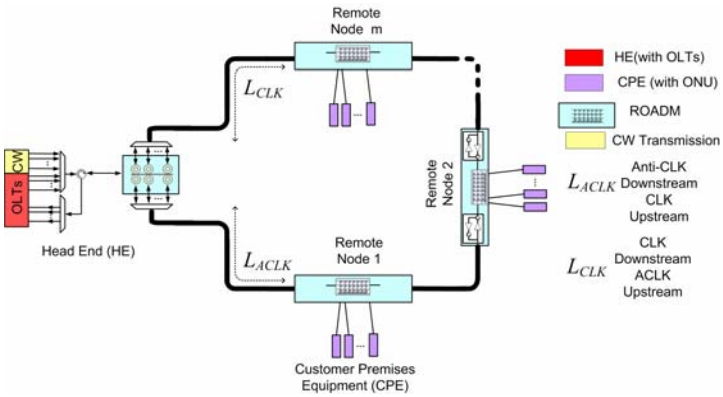


Fig. 1. Schematic of the Broadband Photonics (BBP) Network

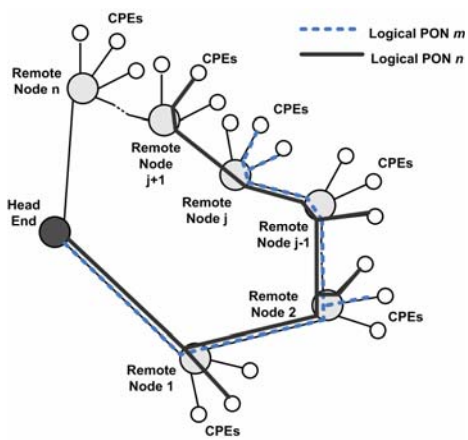


Fig. 2. Logical Connection between HE and CPEs. Two such logical PONs are illustrated.

micro-ring resonator based reconfigurable optical add/drop multiplexers (ROADMs) which are used to add/drop wavelength pairs towards the CPEs [2,3].

The logical network topology retains a tree architecture with redundancy in connectivity between the HE and the RN locations. Fig. 2 illustrates the logical connectivity between the HE and a set of CPEs connected to a set of diverse RNs. Each OLT operates on a unique wavelength add/drop pair. The RNs can be configured to add/drop any selected wavelength pair towards any ONU. The ONUs are wavelength agnostic and associate with the particular OLT operating on that wavelength pair.

Each OLT and the associated ONUs thus form a logical PON. A multiple of such logical PONs can be supported depending on the number of wavelength pairs that are supported by the network. The individual logical PONs can operate in their native format independent of the WDM overlay. The BBP network uses EPON as the underlying TDM PON specification. The concept however is flexible enough to let a mix in such operations both in terms of types of native PON operation like a mix of EPON and GPON or of speeds of operation like 1G EPON and the upcoming 10G EPON. Within the scope of each type of PON operation an optimal distribution of ONUs can be ensured to maximize the availability of bandwidth to the end user [4].

3 User Profiles and Bandwidth Requirement

The emergence of bandwidth intensive applications has driven the need for more bandwidth to the end user and hence in the access networks to a new high. In this section we estimate the bandwidth requirement of typical residential households in the near future.

3.1 User Categories

Studies of typical user profiles are available for the United Kingdom [5]. The study provides an estimation of bandwidth requirements in UK in the short and medium term (2008-2012). The study is used as a base to consider different kinds of user categories for this paper. Table 1 lists the different kinds of user categories considered.

Table 1. User Categories

Category	Description
A	Single adult, retired
B	Two adults, retired
C1	Single male, working
C2	Single female, working
D1	Two adults, empty nesters
D2	Two adults, working
E	Two adults with children
F	Single parent

3.2 Application Definitions

Triple play is the buzzword when it comes to defining applications for the access network. This refers to voice, video and data. An increasing blurring of the demarcation between them and the tendency to move towards a more converged network [6]. Table 2 lists typical applications that are considered for use by the end consumers in an access network [5, 7]. The nominal bandwidth requirement for future applications can be speculative however some applications like remote monitoring of health, remote premises monitoring and data back up seem to be uses in use in access networks.

3.3 User Application Profiles

The user bandwidth demand during the day will vary depending on the application usage. The peaking of traffic requirements for typical network exchanges is around 18:00 to 21:00 hours [8,9]. The typical applications considered to be used in this study by the different user categories in this period of interest are listed in Table 3. It should be noted that the applications listed are indicative of which applications can be expected in the "busy hour" from different category of users. Multiple instantiations

Table 2. Applications and Bandwidth requriements

Type	Application	Downstream Bandwidth (Mb/s)	Upstream Bandwidth (Mb/s)
Voice	PSTN quality call	0.032	0.032
	CD quality call	0.128	0.128
	DAB/CD quality audio streaming	0.192	
	High quality digital audio streaming	6.000	
	High quality digital audio fast download (at twice real time)	12.000	
Video	CIF quality web conferencing	0.320	0.320
	SDTV quality web conferencing	0.380	0.380
	SDTV video streaming (MPEG 4)	2.000	
	HDTV video streaming (MPEG 4)	9.000	
	HDTV download (at twice real time)	18.000	
Data	General web browsing and email download and upload	2.000	2.000
	File down/up load (10 MB in 30 s)	2.667	2.667
	File down/up load (50 MB in 30 s)	13.333	13.333
	Peer to Peer down/upload (60 MB in 30 min)	0.267	0.267
	Remote backup of data (400 GB in 30 days)		1.250
Others	Remote monitoring of health		0.00027
	Remote premises monitoring (5 channel SDTV quality CCTV)		0.69
	Online Gaming	2.000	2.000

Note: Video category calls include audio content in bandwidth calculations.

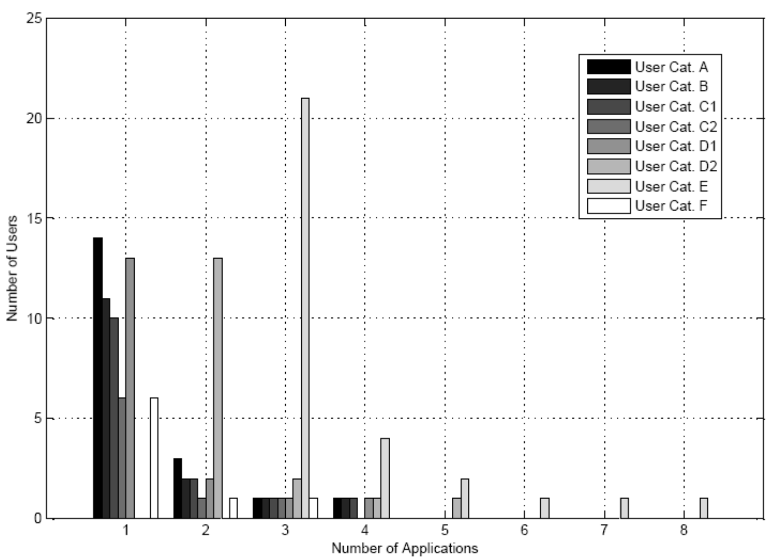


Fig. 3. Distribution of number of concurrent applications used by different user categories

of applications can be used in households with more than one person. The study presumes a generalized Pareto distribution (shape parameter =2 and scale parameter = 1) to estimate the application usage by different user categories in the period of interest. Fig.3 illustrates the number of users in the different categories and the number of applications used concurrently.

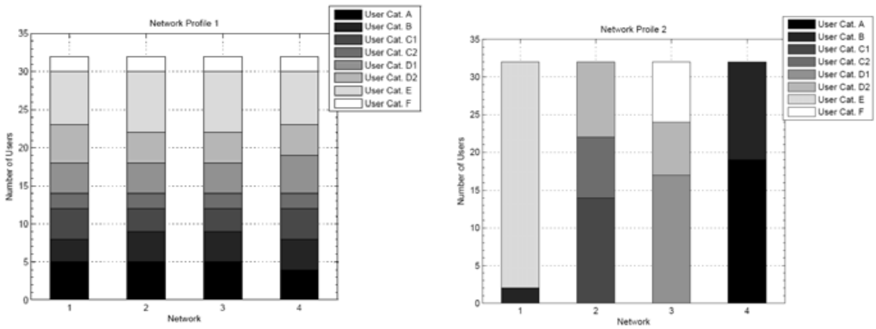
Table 3. User Category and applications used in period of interest

User Cat.	Applications	Concurrent Applications in Period of Interest							
		1	2	3	4	5	6	7	8
A	HDTV video streaming	■							
	DAB/CD quality audio strm.								
	SDTV quality web conf.								
	PSTN quality call								
B	HDTV video streaming	■							
	General web brows. & email								
	SDTV quality web conf.				■				
C1	HDTV video streaming	■							
	File dn/upload (50 MB in 30 s)								
	HQ digital audio streaming$								
	Online Gaming								
C2	HDTV video streaming	■							
	HQ digital audio streaming								
	General web brows. & email								
D1	HDTV video streaming	■	▲	▲	▲				
	General web brows. & email			■	▲				
D2	HDTV video streaming		▲	▲	▲	▲			
	File dn/upload (50 MB in 30 s)			■	■	■			
	General web brows. & email				■	▲			
E	HDTV video streaming			▲	▲	▲	▲	▲	▲
	SDTV video streaming			■	■	▲	▲	▲	▲
	File dn/upload (50 MB in 30 s)				■	■		▲	▲
	HQ digital audio streaming							■	
	DAB/CD quality audio strm.								
F	HDTV video streaming	■	▲	▲					
	SDTV quality web conf.			■					

Note: ■ One instance ; ▲ Two Instances

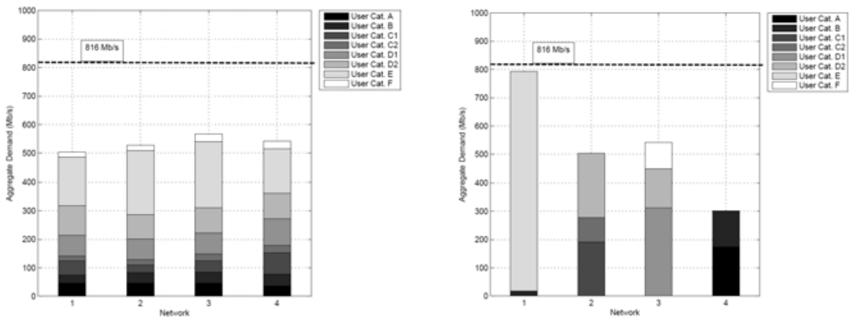
4 Network Configurations

We consider an access network in which 128 end users have to be served by a single fiber plant deployment. The users are assumed to be distributed over four distinct geographical regions with 32 users in each region. Two network profiles are considered; Network Profile 1 has uniform user category distributions while Network Profile 2 has a skewed distribution with clustering of high and low bandwidth users. Fig. 4 illustrates the user distribution the two network profiles. Fig. 5 illustrates bandwidth demand from the users in the two network profiles based on the typical application usage in the period of interest.



(A) (B)

Fig. 4. Network Profiles: (A) Network Profile 1; (B) Network Profile 2



(A) (B)

Fig. 5. Bandwidth demand in: (A) Network Profile 1 and (B) Network Profile 2

5 Static versus Dynamic Network Configuration

5.1 Static Configuration

In this network configuration we consider four PON deployments with each supporting 32 users. The IEEE Ethernet Passive Optical Network (EPON) [10] specification is considered for providing traffic in the access network. The typical throughput that can be achieved with EPON, for 32 end users in the downstream is 816.05 Mb/s [11]. The Network profile 1 would have a typical network usage of 65.5 %.Network profile 2 on the other hand shows a marked skew in the loading pattern with the 4th network group being least loaded at around 37 % while the 1st network group is loaded to around 97 %. Since the four groups are presumed to be in four distinct geographical locations, each with its own PON deployment it would not be possible to re-allocate the free capacity in other network groups to a more loaded Network group.

5.2 Sensitivity Analysis

User Category E is a typical household with multiple residents using multiple bandwidth intensive applications. A hypothetical scenario is presented by changing the distribution in the number of applications used by Category E users. Fig. 6 illustrates the change in profile of number of applications used by User Category E in four different scenarios. The distribution for the four different scenarios is created by changing the scale parameter of the generalised Pareto distribution from 1 to 4. We consider Network group 1 in Network Profile 2 to quantify the performance degradation in terms of the best download time for 50 MB files when the network is static. It is assumed that the non real time traffic such as for file down/upload is reduced to free bandwidth for streaming applications. The best download time for a 50 MB file increases from 30 s to about 80 s in the fourth scenario as illustrated in Fig. 7A. Fig. 7B illustrates additional HDTV. channels that can be supported in this configuration as a function of download time for a 50 MB file in each of the four

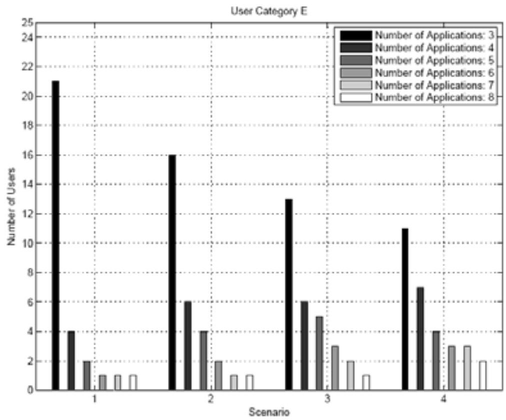
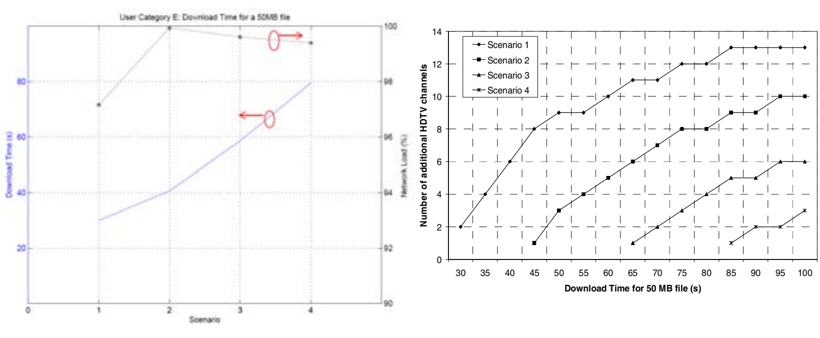


Fig. 6. Changing profile of User Category E



s

(A) (B)

Fig. 7. Evolving scenarios in Network Profile 2 for User Cat. E; (A) Download time for a 50 MB file. (B) Number of HDTV channels available as a function of download time for a 50MB file.

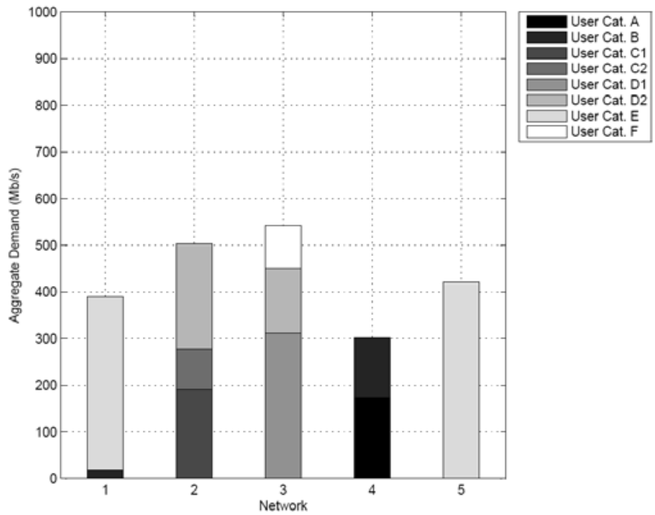


Fig. 8. Bandwidth demand in Network Profile 2 with 5 PON deployments

scenarios. The metrics of an agreeable download time is beyond the scope of this paper but it is clear that in the given profile the network cannot support an increased demand from users. In a static configuration the network provider would need to commission an additional PON deployment to provide acceptable performance for customers in Network group 1. Fig. 8 illustrates the bandwidth demand for Scenario 4 in Network Profile 2 with two PON deployments for Network group 1 (now marked as 1 and 5). These network groups are now less heavily loaded than earlier but come at an additional cost of another PON deployment and an underutilized network capacity.

5.3 Dynamic Network Configuration

A dynamic configuration should allow for reallocation of unused bandwidth from other Network groups which have less load. The BBP network is visualized as a conceptual stack of quasi independent logical PONs. In such a network it would be possible to balance out the aggregate demand over all the Network groups.

A logical PON is supported with a unique wavelength pair. The number of logical PONs that are supported depend on the number of such wavelength pairs that can be used in the network. The RNs which house the ROADM can drop any selected wavelength add/drop towards the ONUs. Since the ONUs are wavelength agnostic, they associate with any OLT which is operating on the particular wavelength pair. If the wavelength add/drop is changed to another pair, the ONUs will be associated with the corresponding OLT operating on that wavelength pair. The nominal bandwidth available to the ONU depends on the number of ONUs supported by any one logical PON. If the number of ONUs increases, the nominal bandwidth available decreases and if the number of ONUs is decreased, the nominal bandwidth available increases. Fig. 9 illustrates the concept with just two colours; the “Red” and the “Blue” logical PONs with a total of 5 ONUs. The network is depicted as a conceptual two stage

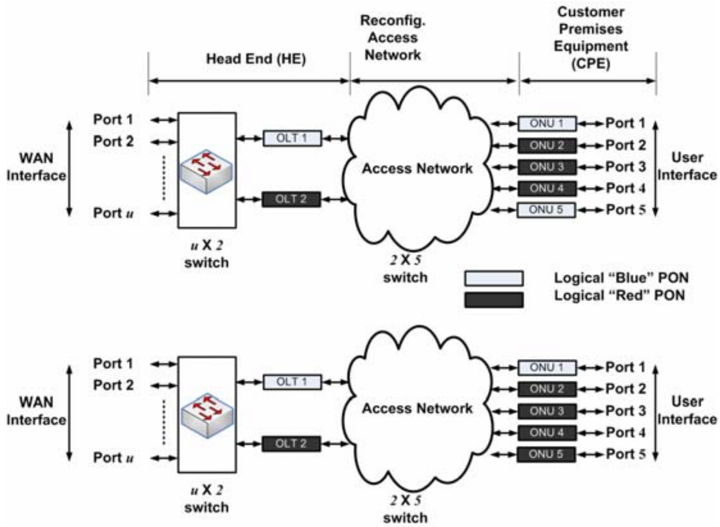


Fig. 9. Concept for inter PON re-distribution of bandwidth

cross connect, the first stage is a Gigabit Ethernet (GbE) switch (u x 2) which can switch traffic towards/from the OLTs towards the WAN while the reconfigurable network is considered as a second stage switch (2 x 5) which can switch traffic towards/from any of the ONUs to any of the OLTs. The number of ONUs supported in the "Red PON" is increased from three to four. The nominal bandwidth for the ONU in the "Red PON" now decreases while that for the single ONU in the "Blue PON" increases.

5.4 Inter-PON Bandwidth Re-allocation

The reconfiguration of the network and the consequent re-allocation of ONUs to do network load balancing can be viewed as dynamic bandwidth re-allocation on an inter PON scale. To do this a Linear programming (LP) based formulation has been proposed [4]. The technique considers optimizing the bandwidth distribution to the end user subject to constraints. The triggering of any network reconfiguration will be a planned response to user requirements and it should be possible to minimize any traffic disruptions. It is also visualized that the reconfiguration will be done on a time scale in the order of tens of minutes in which the change appears quasi static to the intra PON dynamics.

Using LP based techniques the OLT-ONU association is calculated for Network group 1 in Network Profile 2 as the demand evolves from scenario 1 to scenario 4. A detailed representation of reallocation of the ONUs of Network group 1 is illustrated in Fig. 10. The OLTs are colour coded to represent operation on four different wavelength pairs. The ONU association to the OLTs is indicated by the colour of the box in the four scenarios. In the initial state (scenario 1) all ONUs are associated with OLT1. As the network load increases, ONUs are re-allocated to OLT2. In this example the additional capacity required for network group 1 can be met with free

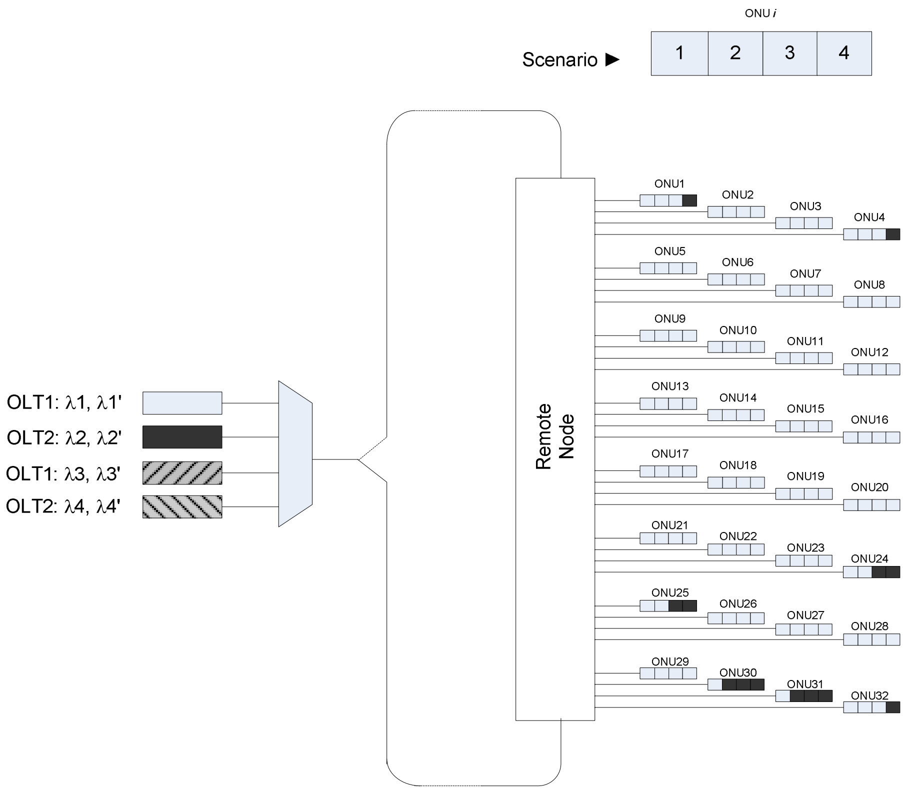


Fig. 10. Illustration of ONUs in Network group 1 being served from two OLTs (OLT1 and OLT2) over four scenarios

bandwidth from one of the other OLTs (here all the additional bandwidth requirements are met from OLT2).

6 Conclusions

A use case has been proposed to illustrate the cause for a dynamically re-configurable network in the access domain. The network allows for operation of existing PON protocols in the native format while introducing a WDM overlay over it. The concept of dynamic reconfiguration drives on the concept of being able to adapt the network configuration to make use of available resources which might otherwise not be possible. Variation in bandwidth demands can take place depending on the user profiles and user application usage profile. While the paper illustrates the concept of using a dynamically reconfigurable network in a residential setting, the concept can be extended to cases where there is a mix in residential and business customers where the diurnal variation amongst different user types will be even greater. The network concept also allows for using a single fiber plant deployment of multiple technologies of PON operations like EPON and GPON and allows for a logical upgrade path to higher speeds of operation for selected customers who might need them. The network further offers scalability in which the aggregate capacity of the network can be increased in a phased manner.

Acknowledgements

The work is funded by the Dutch Ministry of Economic Affairs through the BSIK Freeband Broadband Photonics project under contract BSIK 03025. The authors would like in particular to thank Mr. Gert Manhoudt of AimSys BV for his inputs.

References

1. Urban, P., et al.: 1.25-10 Gbit/s Reconfigurable Access Network Architecture. In: Proc. ICTON, pp. 293–296 (2007)
2. Geuzebroek, D.H., Klein, E.J., Kelderman, H., Bornholdt, C., Driessen, A.: 40 Gb/s Reconfigurable Optical Add-Drop Multiplexer based on Microring Resonators. In: Proc. ECOC, pp. 983–986 (2005)
3. Klein, E., et al.: Densely integrated microring resonator based photonic devices for use in access networks. Optics Express 15, 10345–10355 (2007)
4. Roy, R., Manhoudt, G., van Etten, W.: Bandwidth re-distribution techniques for extended EPON based multi-wavelength Networks. In: Proc. ICTON, vol. 4, pp. 80–83 (2007)
5. Predicting UK Future Residential Bandwidth Requirements, Broadband Stakeholder Group (2006), http://www.broadbanduk.org
6. Ulm, J., Weeks, B.: Next Play Evolution: Beyond Triple Play & Quad Play. In: IEEE International Symposium on Consumer Electronics, ISCE 2007, June 20-23, pp. 1–6 (2007)
7. Harrop, W., Armitage, G.: Quantifying the Broadband Access Bandwidth Demands of Typical Home Users. In: Proc. ATNAC (2006)
8. Amsterdam Internet Exchange, http://www.ams-ix.net
9. Munich Internet Exchange, http://www.inxs.de
10. IEEE 802.3-2005, Part1-Part5, Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications, Clause 56-57 and 67, IEEE Standard
11. Kramer, G.: Ethernet Passive Optical Networks. McGraw-Hill, New York (2005)
12. Lin, C.: Broadband Optical Access Networks and Fiber to the Home-Systems Technologies and Deployment Strategies. Wile