Energy consumption analysis of real metro-optical network

Josip Lorincz[1], Eldis Mujaric[2] Dinko Begusic[3]
[1, 3]FESB, University of Split, Croatia, e-mail: josip.lerinc@fesb.hr, dinko.begusic@fesb.hr
[2]Croatian Academic and Research Network – CARNet, Croatia, e-mail: eldis.mujaric@carnet.hr

***Abstract*— Significant part of the total energy consumption in distribution and core optical networks is contributed by the energy consumption of Internet Protocol (IP) routers. In this paper, an energy efficiency analysis has been performed for the case of real metro-optical network of a medium size city. Two real metro-optical network configurations, mores specifically dark fiber and the dense wavelength division multiplexing (DWDM) have been analyzed in terms of the energy efficiency. Obtained results provide insight into daily variations of routers' energy efficiency expressed in watts (W) per Mb/s of transferred traffic. In addition, cons and pros for selection of analyzed network configurations in real metro-optical implementations have been presented from the point of energy efficiency.**

Keywords*— optical, router, metro, network, energy-efficiency, dark fiber, WDM, green

I. INTRODUCTION

In this paper, energy-efficiency analyses for the real metro-optical network that is a part of e-Split project network infrastructure will be presented. The e-Split is a joint project of Croatian Academic and Research Network (CARNet) and the City of Split, Croatia. In the frame of this project, optical infrastructure based on a dark fiber has been developed. The dark fiber is a privately operated optical fiber infrastructure that is run directly by its owner, rather than by purchasing bandwidth or leasing line capacity. It is called "dark" because it is not in use until owner activates network resources [1].

Metro optical infrastructure connects CARNet member institutions in Split to the CARNet core network. Current implementation of given network infrastructure is based on dark fiber without implementation of WDM technology. WDM is a technology which multiplexes several optical carrier signals into a single fiber by using different wavelengths of light. This enables bidirectional communications over one fiber, as well as multiplication of capacity. Two most used WDM technologies are CWDM (Coarse Wavelength-Division Multiplexing) and DWDM (Dense Wavelength-Division Multiplexing). Basic CWDM characteristics are: used at distances below 50 km, without need to use optical amplifiers, up to 18 wavelengths in single fiber, 45 Gbps per single fiber, 2.5 Gbps per wavelength, less expensive than the DWDM systems.

Essential DWDM characteristics are: up to 240 wavelengths in single fiber, 32 C-band wavelengths are used in practice, 2.4 Tbps per single fiber, 10 Gbps per wavelength, at greater distance optical amplifiers are needed, more expensive then the CWDM. DWDM system (Figure 1) sends signals from several sources over a single fiber, based on signals multiplexing at the sending end and demultiplexing at the receiving end. Multiplexing is done by a multiplexer through taking optical wavelengths from multiple fibers and combining them into one light beam. At the receiving end demultiplexer has to separate out the components of the light so that they can be detected by separating the received beam into its wavelength components and coupling them to individual fibers.

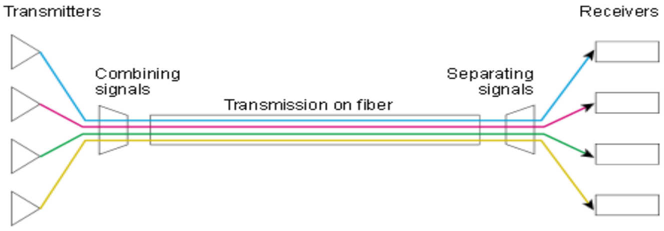

Figure 1: DWDM functional schema

In a unidirectional system, there is a multiplexer at the sending end and a demultiplexer at the receiving end. Two systems would be required at each end for bidirectional communication, and two separate fibers are needed. In case of bidirectional DWDM, multiplexer/demultiplexer must be at each end of the link because of the fact that single fiber is used for communication. Different wavelengths have to be used for full-duplex communication [2].

In the implemented real metro-optical network, ends of the optical fibers are closed with small form-factor pluggable (SFP) interfaces. The SFPs are popular industry format interface jointly developed and supported by many network component vendors. In the analyzed network, implemented SFP technology supports single wavelength transmission over single mode optical fiber.

Although expandable slots of the analyzed network equipment support WDM line cards, this technology is not used due to current user's needs which don't require WDM. However, constant increase of the network traffic transferred over implemented and analyzed metro-optical network, might demand upgrade to some of the WDM technologies in a near future. Besides operator increase in capital expenditures (CAPEX) due to implementation of additional optical elements such as multiplexers and demultiplexers, amplifiers and transceivers, upgrade to the WDM technology will also raise the operational expenditures (OPEX). This is because additional optical elements with router WDM line cards increase overall network energy consumption. This in turn increases overall operator OPEX. For that reason, differences in the energy efficiency among those two metro-optical network implementations based on single wavelength SFP and WDM technology are analyzed in the paper.

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The rest of the paper is organized as follows: related work focused on improving energy efficiency of metro-optical networks is presented in Section 2. Physical and logical topology including architecture and active equipment of the analyzed network are introduced in Section 3. Section 4 shows results of real traffic patterns detected during seven days period. Power efficiency of network architecture based on dark fiber and DWDM technology has been discussed in Sections 5 and 6, respectively. Comparison of power efficiency among the dark fiber and DWDM technologies implemented in analyzed network are given in Section 7. Finally, some concluding remarks are given in Section 8.

II. RELATED WORK

Considering continuous increase for bandwidth in the core networks and overall Internet, satisfying power demands will be a fundamental challenge in the next generation networks (NGN). Authors in [3] present methods of potential savings achievable through power-aware network design and routing. Energy consumption model of large-scale optical network is discussed in [4]. It is shown that telecoms can improve energy efficiency of the network by changing hardware characteristics of active network equipment.

In addition, it is known that routers chassis and line cards consume significantly higher amount of energy in core networks. Different fill levels of the chassis results with different energy consumption. Higher fill level will result with more energy-efficient network. Even an empty chassis with no line cards consumes a large amount of energy. Therefore, a chassis with higher fill level has lower energy consumption per transferred bit [5].

Backbone networks transport large aggregated amount of traffic. Three different network architectures based on the WDM technology are compared in terms of power consumption in [6]. Methods for minimizing energy consumption in the WDM based transport architectures are presented in [7]. Particular realizations of static optical core networks are compared with the dynamic packet switched architecture based on the WDM in [8]. Survey of the most relevant research efforts considering backbone networks power consumption reduction is given in [9].

Considering all these facts, in this paper we perform energy consumption analyses of two network architectures, which, according to our knowledge haven’t been previously analyzed. First network is static and fully operational real optical network maintained by the CARNet, and second is assumed dynamic optical network based on the xWDM technology. This network architecture might be used as future metro-optical network of e-Split project, and such network is widely implemented in large-scale interconnections, like interconnections inside large cities.

III. NETWORK ARCHITECTURE

A. *Backbone optical ring*

At the physical layer of analyzed network (Figure 2), there is the dark fiber cable with 192 fibers forming backbone optical ring which connects five network nodes (A-E) allocated inside one medium size city. Figure 2 illustrates logical and physical topology of the analyzed network based on the optical ring. The 24 fibers in the dark fiber cable are used for ensuring redundant logical connection to a main CARNet node (Node A). The dark fiber as point-to-point network architecture is chosen at the physical layer in order to satisfy requirements such as: simplicity, scalability and robustness.

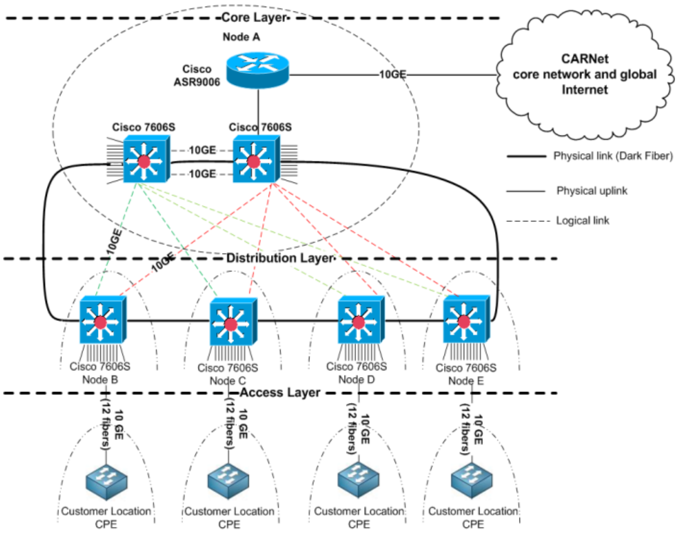


Figure 2: Analyzed network topology with dark fiber and SFPs

Every customer location is connected in the same way (Figure 2): one optical cable with 12-fibers connects the end site of the costumer to the closest shaft. From that shaft, two fibers are used to connect end site to nearest node through the backbone ring. Two fibers are patched in the shaft as redundancy in case that fiber cut occurs. The remaining eight fibers are reserved for future use in the case when more connections will be needed. Each end site is connected to the geographically closest node (Figure 2).

Implemented architecture allows simple bandwidth increase through activation of new interfaces (line cards) at the end of the dark fiber optical links. This can be performed without coordination of carrier service provider, while full monitoring of all network devices by the owner of the network will remain. Passive network equipment at every end site includes: rack, optical patch panel, power socket extension, cable ducts, shelf for active network equipment.

B. *Active network equipment*

Main network node for connecting all other CARNet’s nodes of the e-Split network to the CARNet backbone network is Node A (Figure 2). Main Node A is composed of two Cisco 7606 routers working in failover mode. All other nodes of the e-Split network have one Cisco 7606 router logical connection with the main Node A via redundant 10 Gbps links (Figure 2). Each node aggregates geographically closest end sites and each end site has access (L3) switch (such as Cisco 3560).

Cisco ASR9000 router is used in node A for interconnection with distribution layer as well as providing interconnection with main node in Zagreb (Figures 2 and 4). Node A is connected with a main node of the CARNet

TABLE 1: TECHNICAL CHARACTERISTICS OF THE DEVICES

Device (location)	CPU	RAM [Kb]
CISCO7606-S (core/distribution layer)	MPC8548_E, Version: 2.0	851,968
ASR9006 (core layer)	Intel 686 F6M14S4 processor at 2132 MHz, Revision 2.174	6,291,456

TABLE 2: CISCO ASR9006 ROUTER COMPONENTS

Card type	Model
Cisco ASR 9006 fan	ASR-9006-FAN
Route Switch Processor	A9K-RSP-4G
24-Port 10GE Packet Transport Optimized Line Card, Requires SFP+ optics	A9K-24X10GE-TR
Mod80 Modular Line Card, Packet Transport Optimized	A9K-MOD80-TR
4-Port 10GE Low Queue Line Card	A9K-4T-L

TABLE 3: CISCO 7606-S ROUTER COMPONENTS

Card Type	Model
CEF720 8 port 10GE with DFC	WS-X6708-10GE-3C
CEF720 48 port 1000Mb SFP	WS-X6748-SFP
Route Switch Processor 720	RSP720-3C-GE
Firewall service module	WS-SVC-FWM-1
4-port line card with Distributed Forwarding Card 3CXL	7600-ES+4TG3CXL
High Speed Fan Module for CISCO7606-S	FAN-MOD-6SHS

network in Zagreb city with the 10 Gbps uplink. Node in Zagreb provides access to the global Internet for all CARNet's users. Technical characteristics of the core and distribution network equipment in terms of central processing unit (CPU) types and random access memory (RAM) are shown in Table 1.

Cisco ASR9000 router components are shown in Table 2. Main part of Cisco ASR9000 router is A9K-RSP-4G Route Switch Processor comprising the following components: bidirectional nonblocking fabric, 40-GB hard drive, switch fabric, High-performance dual-core CPU, 4GB RAM and 1GB flash memory. It supports high 1/10/100-Gbps port throughputs. The A9K-MOD80-TR is modular line card, that is optimized for fast packet transport and requires modular port adapters to customize each slot. The A9K-24X10GE-TR is 24-Port 10 Gigabit Ethernet Line Card designed for various Cisco ASR platforms. It provides up to 10 Gbps of throughput per single port. Finally, the A9K-4T-L is modular 10-Gigabit Small Form-Factor Pluggable (XFP)-based line card. Short reach (SR), intermediate reach (IR), long reach (LR), CWDM, DWDM, and 10/100/1000BASE-T interfaces are supported.

Distribution layer includes Cisco 7606-S router with components shown in Table 3. The WS-X6708-10GE is 8-port Ethernet 10GBase-X module with 1 GB of RAM designed for various Cisco platforms. The WS-X6748-SFP is model of gigabit Ethernet SFP interface module. Router has two of these modules and one Route Switch Processor 720. Firewall module is stateful inspection firewall with application and protocol inspection engines. It provides up to 5.5 Gbps of throughput, 100,000 new connections per second, one million concurrent connections or 256,000 NATs (network address translations) and up to 80,000 ACL (access control list) entries. Up to four firewall services modules (FWSM) can be installed in a single chassis, providing scalability of up to 20 Gbps per chassis.

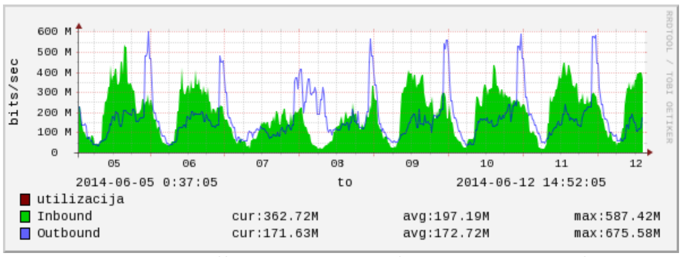


Figure 3: Real traffic load distribution for uplink router interface

IV. REAL TRAFFIC PATTERNS

For analyzed network, real inbound and outbound traffic patterns between end sites and the global Internet will be presented. One of the Cisco 7606-S routers aggregates all end sites (Figure 2) and provides connectivity to the CARNet backbone through Cisco ASR9000 router. Traffic data were obtained on uplink of this router which is link to the Cisco ASR9000 router (Figure 2). The other Cisco 7606-S router serves as backup (works in failover mode). Distribution of the real traffic load detected on the router for uplink interface is presented in Figure 3. Traffic loads presented in Figure 3 are the snapshot obtained from network traffic monitoring system. Data were taken in the interval from June 5 to June 12, 2014. Monitoring system is based on open-source Zenoss software that collects constantly (24/7) real-time data of network traffic.

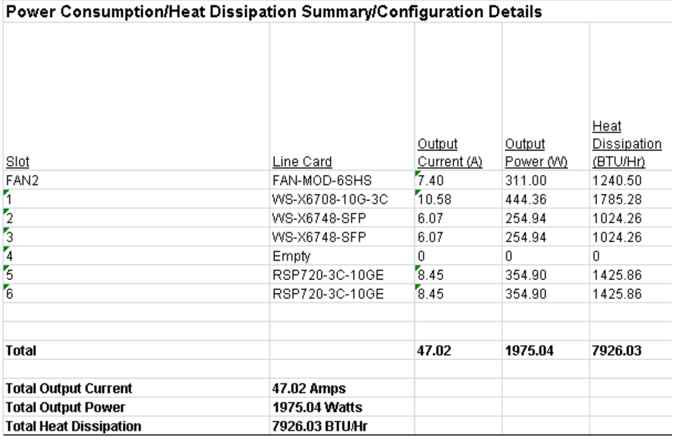
It can be noticed that traffic pattern has typical day/night pattern, which is consequence of different user's activity during day and night. End locations reaches around 1.4 Gbps at maximum in 7 days period. Around 590 Mbps is maximal inbound and around 680 Mbps is maximal outbound traffic.

V. POWER EFFICIENCY OF CORE AND DISTRIBUTION LAYERS BASED ON DARK FIBER

In order to estimate power consumption of active network equipment in the distribution and core layer, online Cisco tool known as "Cisco Power Calculator" [10] were used. Application enables users to calculate the power supply requirements for a specific configuration of network element. Firstly, power consumption of distribution and core layer of the active network equipment presented in Figure 2, which uses dark fiber and SFPs (without WDM technology) are estimated. Then, power efficiency for network presented in Figure 4, with interface modules that supports DWDM technology is simulated. The data presented in Table 4 shows: output current/power and system's heat dissipation for the Cisco 7606-S router with elements supporting dark fiber (without DWDM line cards), having configuration presented in Table 2. The same parameters for CiscoASR9000 having configuration presented in Table 3, with elements supporting dark fiber (without DWDM links) are shown in Table 5.

In order to calculate power efficiency, traffic loads from distribution and core layers of the e-Split network infrastructure were selected. In addition, typical power consumption values characteristic for network operation at standard operating temperature (20° C) for each router configuration presented in Tables 4 and 5 were used. Traffic loads data were taken in typical periods of one working day (Wed, June 11 2014.) and one weekend day (Sun, June 8

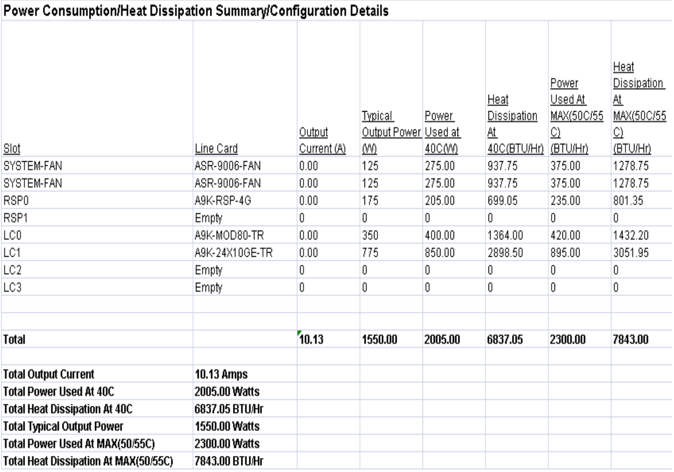
TABLE 4: POWER CONSUMPTION AND HEAT DISSIPATION FOR CISCO7606-S IN THE DARK FIBER ARCHITECTURE



Power Consumption/Heat Dissipation Summary/Configuration Details

Slot	Line Card	Output Current (A)	Output Power (W)	Heat Dissipation (BTU/Hr)
FAN2	FAN-MOD-6SHS	7.40	311.00	1240.50
1	WS-X6708-10G-3C	10.58	444.36	1785.28
2	WS-X6748-SFP	6.07	254.94	1024.26
3	WS-X6748-SFP	6.07	254.94	1024.26
4	Empty	0	0	0
5	RSP720-3C-10GE	8.45	354.90	1425.86
6	RSP720-3C-10GE	8.45	354.90	1425.86
Total		**47.02**	**1975.04**	**7926.03**
Total Output Current	**47.02 Amps**			
Total Output Power	**1975.04 Watts**			
Total Heat Dissipation	**7926.03 BTU/Hr**			

TABLE 5: POWER CONSUMPTION AND HEAT DISSIPATION FOR CISCOASR9000 IN THE DARK FIBER ARCHITECTURE



Power Consumption/Heat Dissipation Summary/Configuration Details

Slot	Line Card	Output Current (A)	Typical Output Power (W)	Power Used at 40C(W)	Heat Dissipation At 40C(BTU/Hr)	Power Used At MAX(50C/55 C) (BTU/Hr)	Heat Dissipation At MAX(50C/55 C) (BTU/Hr)
SYSTEM-FAN	ASR-9006-FAN	0.00	125	275.00	937.75	375.00	1278.75
SYSTEM-FAN	ASR-9006-FAN	0.00	125	275.00	937.75	375.00	1278.75
RSP0	A9K-RSP-4G	0.00	175	205.00	699.05	235.00	801.35
RSP1	Empty	0	0	0	0	0	0
LC0	A9K-MOD80-TR	0.00	350	400.00	1364.00	420.00	1432.20
LC1	A9K-24X10GE-TR	0.00	775	850.00	2898.50	895.00	3051.95
LC2	Empty	0	0	0	0	0	0
LC3	Empty	0	0	0	0	0	0
Total		**10.13**	**1550.00**	**2005.00**	**6837.05**	**2300.00**	**7843.00**
Total Output Current	**10.13 Amps**						
Total Power Used At 40C	**2005.00 Watts**						
Total Heat Dissipation At 40C	**6837.05 BTU/Hr**						
Total Typical Output Power	**1550.00 Watts**						
Total Power Used At MAX(50/55C)	**2300.00 Watts**						
Total Heat Dissipation At MAX(50/55C)	**7843.00 BTU/Hr**						

2014.). Inbound and outbound traffic loads were taken at the uplink interfaces of distribution router CISCO7606-S in node A, which aggregates all customer end sites, and core router ASR9006 in Node A, which provides interconnection with main node in Zagreb. Power efficiency was calculated for each traffic direction (inbound and outbound). Traffic load and power efficiency for distribution layer devices (CISCO7606-S router) at working day and weekend are shown in Table 6.

Typical traffic load and power efficiency for core layer devices (ASR9006 router) at working day and weekend are presented in Table 7. Both tables show distinctions in the inbound and outbound traffic loads during different periods of the day and week, what influences on device power efficiency. From Tables 6 and 7 can be noticed that power efficiency for inbound traffic is always larger then efficiency for outbound traffic, due to higher traffic in inbound direction caused by larger user exploitation of services form Internet.

VI. POWER EFFICIENCY OF CORE AND DISTRIBUTION LAYERS BASED ON DWDM TECHNOLOGY

In addition to the power consumption analyses of network based on dark fiber technology with the SFPs, power consumption and heat dissipation analyses for network which enables data transfer over DWDM technology has been performed. The proposed architecture for given network based on DWDM technology is shown in Figure 4. Results obtained from Cisco power calculator in terms of heat dissipation and power consumption are presented in Tables 8 and 9. Table 8 presents obtained results for the Cisco 7606-S router. Furthermore, power consumption and heat dissipation data for Cisco ASR9000 assuming hardware configuration which includes interfaces supporting the DWDM technology are presented in Table 9.

Also, for Cisco 7606-S and Cisco ASR9000 router, both having DWDM hardware components, power efficiency comparison with a real traffic load is given in Tables 10 and 11, respectively. Tables 10 and 11 show power efficiency for bidirectional traffic, which is represented as sum of inbound and outbound traffic. Due to performed analyses on the same network, it is possible to perform direct comparison among obtained results.

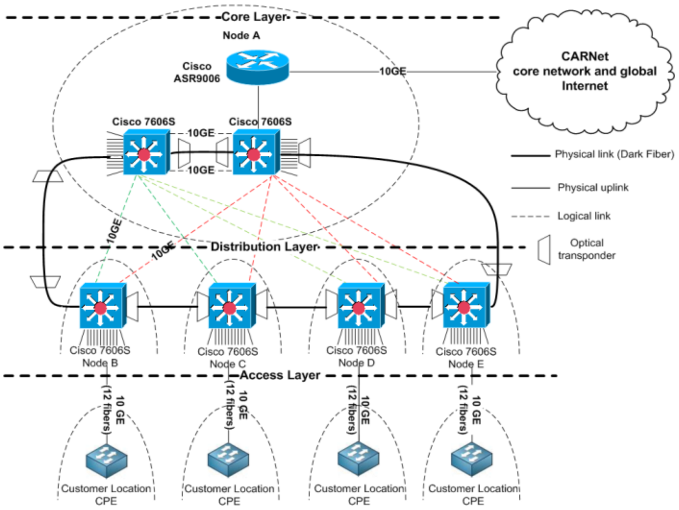


Figure 4: The proposed architecture based on DWDM

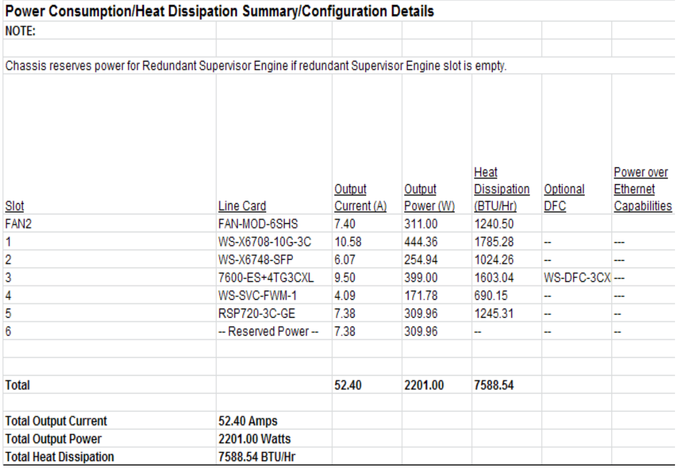
TABLE 6: TRAFFIC LOAD AND POWER EFFICIENCY FOR CISCO7606-S ROUTER ON WORK DAY AND WEEKEND

	Working day		**Weekend**	
Time (Wed, June 11)	**Traffic load (Inbound / Outbound) [Mbps]**	**Power efficiency (inbound/ outbound) [W/Mbps]**	**Traffic load (Inbound / Outbound) [Mbps]**	**Power efficiency (inbound/ outbound) [W/Mbps]**
00:00	254.3/411.39	7.76/4.8	221.91/413.53	8.9/4.77
08:00	222.95/81.99	8.86/24.09	37.03/178.14	53.34/11.09
12:00	396/127	4.99/15.55	133.73/113.91	14.77/17.34
16:00	284.97/192.4	6.93/10.27	181/151.82	10.91//13
20:00	316.64/228.87	6.24/8.63	126.81/119.18	15.57/16.57

TABLE 7: TRAFFIC LOAD AND POWER EFFICIENCY FOR CISCO ASR9006 ROUTER ON WORK DAY AND WEEKEND

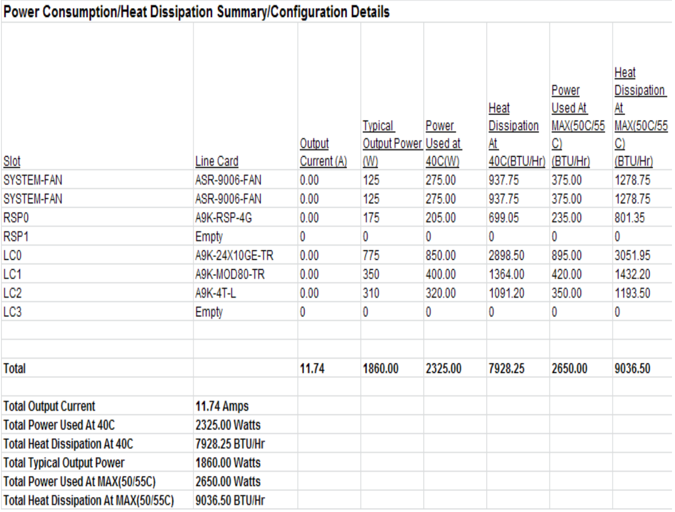
	Work day		**Weekend**	
Time (Wed, June 11)	**Traffic load (Inbound / Outbound) [Mbps]**	**Power efficiency (inbound/ outbound) [W/Mbps]**	**Traffic load (Inbound / Outbound) [Mbps]**	**Power efficiency (inbound/ outbound) [W/Mbps]]**
00:00	263.5/419	5.88/3.7	226.5/417.54	6.84/3.71
08:00	257.39/118.33	6.02/13.1	40.3/277.73	38.46/5.58
12:00	472/135.63	3.28/11.43	137.6/119.95	11.26/12.92
16:00	316/196,62	4.91/7.88	197.69/162.34	7.84/9.55
20:00	326.42/232.19	4.75/6.68	134.08/127.44	11.56/12.16

TABLE 8: POWER CONSUMPTION AND HEAT DISSIPATION FOR CISCO7606-S IN THE DWDM NETWORK



Power Consumption/Heat Dissipation Summary/Configuration Details						
NOTE:						
Chassis reserves power for Redundant Supervisor Engine if redundant Supervisor Engine slot is empty.						
Slot	Line Card	Output Current (A)	Output Power (W)	Heat Dissipation (BTU/Hr)	Optional DFC	Power over Ethernet Capabilities
FAN2	FAN-MOD-6SHS	7.40	311.00	1240.50		
1	WS-X6708-10G-3C	10.58	444.36	1785.28	--	---
2	WS-X6748-SFP	6.07	254.94	1024.26	--	---
3	7600-ES+4TG3CXL	9.50	399.00	1603.04	WS-DFC-3CX	---
4	WS-SVC-FWM-1	4.09	171.78	690.15	--	---
5	RSP720-3C-GE	7.38	309.96	1245.31	--	--
6	-- Reserved Power --	7.38	309.96	--	--	--
Total		52.40	2201.00	7588.54		
Total Output Current	52.40 Amps					
Total Output Power	2201.00 Watts					
Total Heat Dissipation	7588.54 BTU/Hr					

TABLE 9: POWER CONSUMPTION AND HEAT DISSIPATION FOR CISCOASR9000 IN THE DWDM NETWORK



Power Consumption/Heat Dissipation Summary/Configuration Details							
Slot	Line Card	Output Current (A)	Typical Output Power (W)	Power Used at 40C(W)	Heat Dissipation At 40C(BTU/Hr)	Power Used At MAX(50C/55 C) (BTU/Hr)	Heat Dissipation At MAX(50C/55 C) (BTU/Hr)
SYSTEM-FAN	ASR-9006-FAN	0.00	125	275.00	937.75	375.00	1278.75
SYSTEM-FAN	ASR-9006-FAN	0.00	125	275.00	937.75	375.00	1278.75
RSP0	A9K-RSP-4G	0.00	175	205.00	699.05	235.00	801.35
RSP1	Empty	0	0	0	0	0	0
LC0	A9K-24X10GE-TR	0.00	775	850.00	2898.50	895.00	3051.95
LC1	A9K-MOD80-TR	0.00	350	400.00	1364.00	420.00	1432.20
LC2	A9K-4T-L	0.00	310	320.00	1091.20	350.00	1193.50
LC3	Empty	0	0	0	0	0	0
Total		11.74	1860.00	2325.00	7928.25	2650.00	9036.50
Total Output Current	11.74 Amps						
Total Power Used At 40C	2325.00 Watts						
Total Heat Dissipation At 40C	7928.25 BTU/Hr						
Total Typical Output Power	1860.00 Watts						
Total Power Used At MAX(50/55C)	2650.00 Watts						
Total Heat Dissipation At MAX(50/55C)	9036.50 BTU/Hr						

VII. RESULTS COMPARISON

In the analyses, traffic load data in characteristic periods of a day (Table 6, 7 and 10, 11) are selected. It may be seen in Figure 3 that the maximum traffic loads occur around 00:00, and the minimum traffic loads occur around 08:00 AM. Bidirectional traffic load in specific timestamps and estimated power consumption are used for calculation of the power efficiency values [W/Mbps] for each network configuration (dark fiber and DWDM).

It shown in [11] that significant daily variation of traffic load has impact on instantaneous power consumption of network devices. However, our initial assumption is that typical power consumption of network device is constant in the regular network operation. This is the case when device is not loaded with a large amount of traffic, and when the value of memory and CPU utilization does not vary significantly in time. This is exact situation in our test case, since analyzed network is over capacitated for the purpose of accepting future traffic loads increase during period of next 10 years.

It can be clearly seen from Tables 6, 7 and 10, 11 that power efficiency is inversely proportional to the traffic load.

TABLE 10: CISCO7606-S POWER EFFICIENCY COMPARISON

Time (Wednesday, June 11)	Power efficiency (bidirectional dark fiber SFP interface) [W/Mbps]	Power efficiency (bidirectional DWDM interface) [W/Mbps]
00:00	1975/665.69 (2.97)	2201/665.69 (3,31)
08:00	1975/304.94 (6.48)	2201/304.94 (7.22)
12:00	1975/523.00 (3.78)	2201/523.00 (4.21)
16:00	1975/477.37 (4.14)	2201/477.37 (4.61)
20:00	1975/545.51 (3.62)	2201/545.51 (4.03)

Table 11: CISCOASR9000 POWER EFFICIENCY COMPARISON

Time (Wednesday, June 11)	Power efficiency (bidirectional dark fiber SFP interface) [W/Mbps]	Power efficiency (bidirectional DWDM interface) [W/Mbps]
00:00	1550/682.5 (2.27)	1860/682.5 (2.73)
08:00	1550/375.72 (4.13)	1860/375.72 (4.95)
12:00	1550/607.63 (2.55)	1860/607.63 (3.06)
16:00	1550/508.62 (3.05)	1860/508.62 (3.66)
20:00	1550/558.61 (2.77)	1860/558.61 (3.33)

For the higher values of the traffic load, power efficiency in W/Mbps is lower. This means that for the same consumed power, larger amount of data can be transferred.

In addition, values of power efficiency in core and distribution network based on dark fiber and DWDM technology are compared. Firstly, Cisco 7606 router in the distribution layer is analyzed. Its uplink towards the core layer has maximum traffic load around midnight. Its estimated total output power consumption with SFP line cards is 1,975 W, and the estimated total output power consumption with line card that supports DWDM is 2,201 W. Figure 5 presents data power efficiency curve interpolated for whole day.

Furthermore, Cisco ASR9006 router in the core layer was analyzed. Traffic transferred over its uplink towards the main node in Zagreb has the same shape as traffic pattern of the router in the distribution layer (maximum traffic load around midnight). It's estimated total power consumption when dark fiber and DWDM is implemented equals to 1,550 W and 1,860 W, respectively. Considering this, data power efficiency in characteristic times of the day is calculated and interpolated for whole day. Obtained results are shown in Figure 6.

Finally, we give power efficiency comparison for each device on working day and weekend (Sunday), in case of optical network based on dark fiber technology. Power efficiency comparison for Cisco 7606 and ASR 9006 on working day and weekend is shown in Figure 7 and 8, respectively. Larger differences between power efficiency on working and weekend day is consequence of significant difference in amount of traffic during this days Also, in comparison with DWDM configuration, Figures 5 and 6 shows that SFP implementation contributes to the reduction of power consumption. This is due to lower power consumption of SFP hardware components. Hence, SFP implementation is more favorable for networks with low CPU utilization and lower amounts of traffic. Based on results presented in Figures 7 and 8, it can be noticed that independently of implemented technology (SFP or DWDM), power efficiency of devices is better for working day, meaning that higher amount of traffic can be transferred for the same amount of consumed power.

Additionally, calculation of power consumption for a given network infrastructure based on dark fiber with SFPs (without

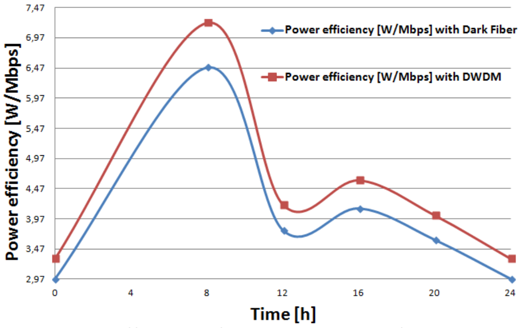


Figure 5: Power efficiency of Cisco 7606 in dark fiber and DWDM Optical networks

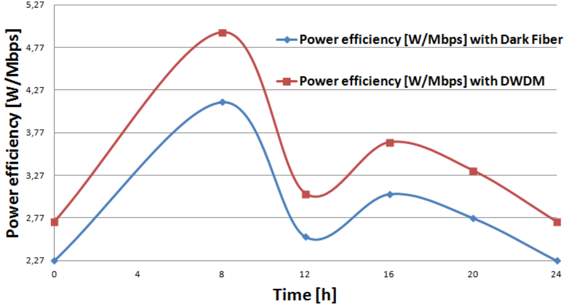


Figure 6: Power efficiency of Cisco ASR 9006 in dark fiber and DWDM optical networks

DWDM) is performed. As presented in Figure 2, network has five nodes with six Cisco 7606 routers and one ASR 9006. Each 7606 router consumes power of 1,975 W, while ASR 9006 typically consumes 1,550 W, what gives total instantaneous power consumption equal to the 13,400 W for routers in core and distribution layer of analyzed metro-optical network.

In case of the same metro-optical network with five nodes working with DWDM hardware, optical network architecture must contain ten additional 10 Gbps transponders (Figure 4) that typically consume 68.5 W each [12]. Total estimated power consumption in this case would be 14,085 W. This represents increase in power consumption of network core and distribution layer for more than 60 MWh yearly, what further gives favor on practical implementation of dark fiber.

VIII. CONCLUSION

In this paper, energy consumption analyses of the real metro-optical network based on prominent technologies such as the dark fiber and DWDM are presented. Analyses is performed for real traffic patterns, according to which, power efficiency of distribution and core level network equipment was estimated. It is shown that daily variation of traffic pattern influence on power efficiency (W/Mbps) of network devices, since higher amount of traffic can be transferred for the same amount of power consumption. Additionally, obtained results show that metro optical-networks of a small and medium size cities, based on dark fiber consumes less overall energy when compared with equal network based on the DWDM technology. Hence, dark fiber in terms of energy-efficiency is optimal solution for metro-optical networks of small and medium cities having low amount of data traffic and low network equipment CPU utilization. However, in case of large metro-optical networks where huge bandwidth demands must be satisfied, DWDM as technology has to be considered, regardless of lower energy-efficiency. Our future research activities will be focused on energy-efficiency analyses of optical amplifiers in metro-optical networks.

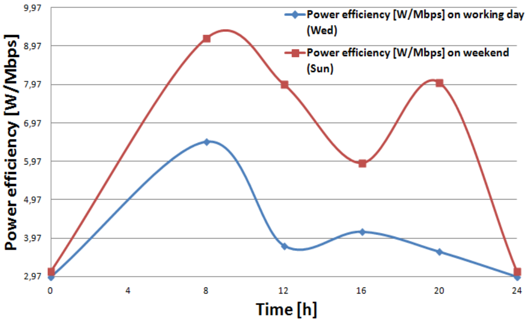


Figure 7: Cisco 7606 power efficiency comparison on working day and weekend

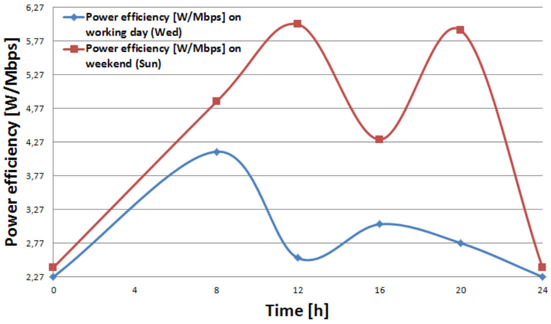


Figure 8: Cisco ASR 9006 power efficiency comparison on work day and weekend

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