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Power consumption of network elements in IP over WDM networks

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Abstract

This report collects numbers (available in the literature and in the product data sheets) on power consumption of various network elements in IP over WDM networks.

Contents

1 Introduction

Power consumption has become a significant issue in the last few years. According to [42], the network equipment of ICT (Information and Communication Technologies) consumes 22 GW, which relates to over 1% of the the global electricity consumption worldwide. This value is confirmed in [61], which reports that the Internet consumed about 1-2% of the total electricity consumption in the U.S. in the year 2000 The total annual electricity consumption of various networking devices (Hubs, LAN, WAN switches, Routers) in the U.S. in the year 2000 sums up to 6.05 TWh [32]. Since there is quite a lot of research on the topic of energy efficient networks going on (e.g [2, 11, 13, 44]) and ICT are expected to consume more and more of the primary energy [42], we decided to collect numbers on power consumption available in the literature (research papers and vendor data sheets). It can be used as a database for further research. We mainly focus on the IP over WDM networks in our work.

2 Related work

Before collecting numbers on power consumption, we survey the literature on various approaches on how to estimate power consumption of a network. The goal of this survey is to identify network elements that contribute to the network power consumption.

Extensive work of the group of prof. Tucker [2, 3, 5, 62, 63] is summarised in [4]. It considers power consumed in the Access, Metro and Edge, Video Distribution as well as Core Networks. Only the last ones fall into the scope of our survey. A single-rack CISCO CRS-1 core router consuming approximately 10.9 kW (fully configured with line cards with traffic running [8]) is used (switching capacity of 640 Gbps, proportional to sixteen 40 Gbps line cards). The per customer power consumed by the core node P_c equals the core router power consumption (10.9 kW) scaled by the number of core node hops plus one, and the number of customers that the router can support with minimum capacity available to a customer from the public Internet ($\frac{A_I}{640}$, where A_I is the minimum capacity available to a customer from the public Internet, and 640 is the router capacity in Gbps). Moreover, the core router power consumption is doubled three times. Firstly due to the future growth of traffic peak demand, secondly due to the power requirements for cooling, and finally for redundancy. [4] proposes also estimates for the power consumed by the core terrestrial WDM links ($P_{core\_terrest}$) as well as the undersea WDM systems ($P_{undersea}$). They are both proportional to the number of customers that the router can support with minimum capacity available to a customer from the public Internet ($\frac{A_I}{40}$ for terrestrial WDM systems (40 Gbps link capacity) and $\frac{A_I}{10}$ for undersea WDM systems (10 Gbps link capacity)) scaled by the proportion of traffic going to neighbouring nodes through the alternative WDM system (terrestrial or undersea correspondingly) and cumulative power per channel. The cumulative power per channel includes power consumed by two terminal systems and intermediate line amplifiers (one every 100 km) for terrestrial links, and two terminal systems and repeaters (one every 50 km) for undersea links. Both estimates $P_{core\_terrest}$ and $P_{undersea}$ are doubled twice due to cooling (terrestrial), provisioning for future growth of the traffic demand (undersea) and redundancy (both). In former work [3], Baliga, Hinton and Tucker considered the core node power consumption P_c and power consumption of WDM links P_{wdm}. Both metrics assume that for every Watt of power consumed, another Watt of power is required for cooling. The P_c moreover assumes that core routers are built such that they are able to cope with future traffic growth and so are usually built such that they can handle double the current peak traffic demand. The proposed metric does not distinguish the single elements of a router, but a router as a whole (power and bi-directional capacity of Cisco CRS-1 router [8] in its maximum configuration is 1020 kW and 92 Tbps respectively). The number of homes, the peak access rate in each direction, and the oversubscription rate are the parameters that need to be adjusted according to the considered network to calculate P_c. The scaling parameters for P_{wdm} are related to the power consumed by the WDM terminal systems connecting the edge nodes to the core node (64 wavelengths), multiple wavelength amplifiers, as well as the WDM terminal systems connecting the core nodes (176 wavelengths), and the Intermediate Line Amplifiers (ILA). 40 Gbps transmission rate of one WDM channel is assumed.

The other metric P_{wdm} is also a function of the number of homes, the peak access rate in each direction, and the oversubscription rate. Additionally, since Passive Optical Network (PON) is assumed as the Access Network, the number of Optical Network Units (ONUs) that connect to one Optical Line Terminal (OLT), when the oversubscription rate is 0 is taken into account.

Chabarek et al. in [11] consider the router power consumption PC. It is determined by its configuration and current use, i.e. chassis type used and number of active line cards. The power consumed by the active line cards is dependent on the traffic utilization on each line card and the cost of each line card in a base configuration.

In [12] the power consumption of a link between two routers is calculated proportionally to the number of amplifiers needed to regenerate the signal (one every 70 km), the power consumption of a single amplifier, the static power consumption of router interfaces, and the number of wavelength channels needed per link. The number of nodes and links in the network contributing to the power consumption is also considered in [12]. The authors calculate the energy spent for each bit by the network. In [13], the power of the network is given as the sum of nodes' and links' power, where power of both the nodes and the links is constant.

3 Power consumption in IP over WDM networks

Having surveyed which network elements are considered in the power consumption estimates available in the literature, we now present a collection of power values of the corresponding network elements in the IP and WDM layers.

3.1 IP layer

We consider the following network elements of a router (a node in the electrical layer):

- line (slot) cards with port cards
- chassis
- route processor

Cooling is considered separately in Section 3.3.

The router chassis according to [11] dominates the power consumption of a router. It is essential to have as few chassis as possible equipped with possibly biggest (necessary) number of line cards.

Tables 1 - 3 show the collected numbers on power consumption of line cards, chassis and route processors of some routers available in the market.

Table 1: Power consumption of line cards in the IP layer

Device	**Router**	**Power [Watts]**	**Ref.**
4 port GE	Cisco GSR 12008s	92 (no traffic), 106 (maximum)	[11, 43]
1 port OC-12/POS	Cisco GSR 12008s	72 (no traffic)	[11]
1 port OC-48/POS	Cisco GSR 12008s	70 (no traffic)	[11]
1 port Fast Ethernet	Cisco 7507	26 (no traffic)	[11]
1 port Gigabit Ethernet	Cisco 7507	30 (no traffic)	[11]
1 port 1.544 Mb/s DS1	Cisco 7507	49 (no traffic)	[11]
10-Gigabit Ethernet Physical Layer Interface Module with eight optics modules + Modular Services Card	Cisco CRS-1	150 + 350 = 500	[41, 50]
10-Gigabit Ethernet WDM-PHY Physical Layer Interface Module + Modular Services Card	Cisco CRS-1	150 + 350 = 500	[41, 50]
OC-768c/STM-256c POS Physical Layer Interface Module + Modular Services Card	Cisco CRS-1	75 + 350 = 425	[40, 50]
OC-768c/STM-256c WDM-POS Physical Layer Interface Module + Modular Services Card	Cisco CRS-1	150 + 350 = 500	[40, 50]
OC-192c/STM-64c POS/DPT Physical Layer Interface Module + Modular Services Card	Cisco CRS-1	138 + 350 = 488	[40, 50]
OC-48c/STM-16c POS/DPT Physical Layer Interface Module + Modular Services Card	Cisco CRS-1	150 + 350 = 488 (maximum) or 136 + 350 = 486 (derated)	[40, 50]
unspecified	Cisco CRS-1	approx. 500	[38]
unspecified	Cisco CRS-1 (8-slot)	1000 on average	[61]
10 Gb/s	unspecified	200	[39]
unspecified	unspecified	100	[12]
10-Gigabit Ethernet DWDM OTN PIC	Juniper T1600, T640, T320	26.6	[29, 30, 31]
10-Gigabit Ethernet DWDM PIC	Juniper T1600, T640, T320	26.6	[29, 30, 31]
10-Gigabit Ethernet LAN/WAN PIC with XFP	Juniper T1600, T640	43	[29, 31]
10-Gigabit Ethernet PIC with XENPAK	Juniper T1600, T640, T320	26.6	[29, 30, 31]

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Table 1 – continued from previous page

Device	**Router**	**Power [Watts]**	**Ref.**
10Gigabit Ethernet Enhanced IQ2 (IQ2E) PIC with XFP	Juniper T1600, T640, T320	56	[29, 30, 31]
10Gigabit Ethernet IQ2 PIC with XFP	Juniper T1600, T640, T320	56	[29, 30, 31]
SONET/SDH OC768c/STM256 PIC	Juniper T1600, T640	65.7	[29, 31]
SONET/SDH OC192/STM64 PICs with XFP	Juniper T1600, T640	25 (one-port), 53.1 (two-port)	[29, 31]
SONET/SDH OC192/STM64 PIC with XFP	Juniper T320	25 (one-port)	[30]
SONET/SDH OC192c/STM64 PIC	Juniper T1600, T640, T320	21.6	[29, 30, 31]

Table 2: Power consumption of chassis in the IP layer

Device	**Router**	**Power [Watts]**	**Ref.**
5 configurable interface slots, 3 rack chassis	Cisco 7507	max. 945, typical 650	[52]
8 slots	Cisco GSR 12008	1620	[46]
16-Slot Single-Shelf System	Cisco CRS-1	max. 10920 fully configured	[8]
8-Slot Single-Shelf System	Cisco CRS-1	max. 5992 fully configured	[8]
4-Slot Single-Shelf System	Cisco CRS-1	4326@16200 BTU/HR[1]	[8]
Fabric Card Chassis	Cisco CRS-1	max. 9100@31050 BTU/HR	[8]
72 line card shelves interconnected by 8 fabric shelves	Cisco CRS-1	1020000	[2, 3, 8]
single-rack (640 Gbps)	Cisco CRS-1	10900	[4]
Juniper T320 (320 Gbps)	Juniper T Series	2880 (agency label, max), 2314 (theoretical aggregate)	[27]
Juniper T640 (640 Gbps)	Juniper T Series	7296 (agency label, max), 4517 (theoretical aggregate)	[27]
Juniper T1600 (1.6 Tbps)	Juniper T Series	8352 (agency label, max), 7008 (theoretical aggregate)	[27]
Juniper TX Matrix with 4 x T640 (2.5 Tbps)	Juniper T Series	4560 (agency label, max), 2976 (theoretical aggregate)	[27]
Juniper TX Matrix Plus with 16 x T1600 (25.6 Tbps)	Juniper T Series	12750 (preeliminary)	[27]

[1] $BTU = BritishThermalUnit = 0.2931Wh; BTU/HR \simeq 0.293W$

Table 3: Power consumption of route processors in the IP layer

Device	Router	Power [Watts]	Ref.
8-Slot Line-Card Chassis Route Processor	Cisco CRS-1	96	[60]
16-Slot Line-Card Chassis Route Processor	Cisco CRS-1	166	[58]
16-Slot Line-Card Chassis Route Processor B	Cisco CRS-1	140	[59]

According to [2, 3, 8], each complete CRS-1 system consumes 1020 kW, which shows a significant potential of energy savings.

The power consumption of CRS-1 chassis (single- and multi-shelves of different capacities in terms of 40 Gbps line cards) is presented in Table 4. According to [8], the power consumption of a 16-Slot Single-Shelf-System (built from the single line card chassis (shelf)) fully configured with line cards with traffic running is equal to 10.92 kW. Since the power of each line card is 500 W [38, 41, 50], we assume that the power of an idle 16-slot Single-Shelf-System without line cards is equal to 2.92 kW.

In order to increase the capacity of the CRS-1 Carrier Routing system, the above mentioned line card shelves can be interconnected into a Multishelf System using fabric card shelves. Each fabric card shelf can accommodate up to 9 line card shelves. Altogether a Multishelf System can contain up to 72 line card shelves interconnected by eight fabric card shelves (we skip some configurations of the Multishelf System in Table 4). Power of a fabric card shelf (chassis) is equal to 9.1 kW @ 31.050 BTU/hr [8].

Table 4: Power consumption of chassis in multi-shelf systems of Cisco CRS-1 Carrier Routing System using 16-Slot Single-Shelf Systems [8]

Shelftype	Number of 40 Gbps line card slots	Number of fabric card shelves needed	Power [kW]
SH-IP-640	16	0	$1 \cdot 2.92 + 0 \cdot 9.1 = 2.92$
SH-IP-1280	32	1	$2 \cdot 2.92 + 1 \cdot 9.1 = 14.94$
SH-IP-1920	48	1	$3 \cdot 2.92 + 1 \cdot 9.1 = 17.86$
SH-IP-2560	64	1	$4 \cdot 2.92 + 1 \cdot 9.1 = 20.78$
SH-IP-3200	80	1	$5 \cdot 2.92 + 1 \cdot 9.1 = 23.7$
SH-IP-3840	96	1	$6 \cdot 2.92 + 1 \cdot 9.1 = 26.62$
SH-IP-4480	112	1	$7 \cdot 2.92 + 1 \cdot 9.1 = 29.54$
SH-IP-5120	128	1	$8 \cdot 2.92 + 1 \cdot 9.1 = 32.46$
SH-IP-5760	144	1	$9 \cdot 2.92 + 1 \cdot 9.1 = 35.38$
SH-IP-6400	160	2	$10 \cdot 2.92 + 2 \cdot 9.1 = 47.40$
SH-IP-7040	176	2	$11 \cdot 2.92 + 2 \cdot 9.1 = 50.32$
...	...	...	...
SH-IP-11520	288	2	$18 \cdot 2.92 + 2 \cdot 9.1 = 70.76$
SH-IP-12160	304	3	$19 \cdot 2.92 + 3 \cdot 9.1 = 82.78$

Continued on next page

Table 4 – continued from previous page

Shelftype	**Number of 40 Gbps line card slots**	**Number of fabric card shelves needed**	**Power [Watts]**
...	...	...	...
SH-IP-17280	432	3	$27 \cdot 2.92 + 3 \cdot 9.1 = 106.14$
SH-IP-17920	448	4	$28 \cdot 2.92 + 4 \cdot 9.1 = 118.16$
...	...	...	...
SH-IP-23040	576	4	$36 \cdot 2.92 + 4 \cdot 9.1 = 141.52$
SH-IP-23680	592	5	$37 \cdot 2.92 + 5 \cdot 9.1 = 118.16$
...	...	...	...
SH-IP-28800	720	5	$45 \cdot 2.92 + 5 \cdot 9.1 = 176.90$
SH-IP-29440	736	6	$46 \cdot 2.92 + 6 \cdot 9.1 = 188.92$
...	...	...	...
SH-IP-34560	864	6	$54 \cdot 2.92 + 6 \cdot 9.1 = 212.28$
SH-IP-35200	880	7	$55 \cdot 2.92 + 7 \cdot 9.1 = 224.30$
...	...	...	...
SH-IP-40320	1008	7	$63 \cdot 2.92 + 7 \cdot 9.1 = 247.66$
SH-IP-40960	1024	8	$64 \cdot 2.92 + 8 \cdot 9.1 = 259.68$
...	...	...	...
SH-IP-46080	1152	8	$72 \cdot 2.92 + 8 \cdot 9.1 = 283.04$

As for the Juniper T Series Core routers, apart from the Physical Interfaces Cards (PICs) mentioned in Table 1, the power consumption of various other PICs can be found in [29, 30, 31]. It needs to be mentioned that the PICs are Short Reach (SR) [29], which explains that their power consumption is lower by an order of magnitude compared to their CISCO counterparts. Moreover, Juniper does not mention an equivalent of CISCO's Modular Services Card. However, in the appendices of the hardware guides [33, 34, 35, 36] they give detailed current values to estimate power consumption of certain configuration of Juniper routers. We assume for both CISCO and Juniper that the power values indicated in the data sheets [8, 27] include the power consumed by line cards, although it is not clearly explained there (especially in [27]).

Table 5 shows power consumption of Juniper T1600 core router(s) interconnected by a Tx Matrix Plus. The TX Matrix Plus can interconnect up to 16 T1600 chassis, which correspond to 256 40 Gbps ports [27]. Power consumption of a single Juniper T1600 core router equals 7008 W. We calculate the power of a T1600 chassis by subtracting power of 16 OC768c/STM64c PICs (65.7 W [29]) from this value, which results in 5956.8 W. For completeness, we repeat from Table 2 that the power consumption of a TX Matrix Plus is 12750 W.

Table 5: Power consumption of chassis in multi-shelf systems of Juniper T1600 core routers using Juniper TX Matrix [27]

Shelftype	**Number of 40 Gbps line card slots**	**Number of fabric card shelves needed**	**Power [kW]**
SH-IP-640	16	0	$1 \cdot 5.9568 + 0 \cdot 12.75 = 5.9568$
SH-IP-1280	32	1	$2 \cdot 5.9568 + 1 \cdot 12.75 = 24.6636$
SH-IP-1920	48	1	$3 \cdot 5.9568 + 1 \cdot 12.75 = 30.6204$

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Table 5 – continued from previous page

Shelftype	Number of 40 Gbps line card slots	Number of fabric card shelves needed	Power [Watts]
SH-IP-2560	64	1	$4 \cdot 5.9568 + 1 \cdot 12.75 = 36.5772$
SH-IP-3200	80	1	$5 \cdot 5.9568 + 1 \cdot 12.75 = 42.534$
SH-IP-3840	96	1	$6 \cdot 5.9568 + 1 \cdot 12.75 = 48.4908$
SH-IP-4480	112	1	$7 \cdot 5.9568 + 1 \cdot 12.75 = 54.4476$
SH-IP-5120	128	1	$8 \cdot 5.9568 + 1 \cdot 12.75 = 60.4044$
SH-IP-5760	144	1	$9 \cdot 5.9568 + 1 \cdot 12.75 = 66.3612$
SH-IP-6400	160	1	$10 \cdot 5.9568 + 1 \cdot 12.75 = 72.318$
SH-IP-7040	176	1	$11 \cdot 5.9568 + 1 \cdot 12.75 = 78.2748$
SH-IP-7680	192	1	$12 \cdot 5.9568 + 1 \cdot 12.75 = 84.2316$
SH-IP-8320	208	1	$13 \cdot 5.9568 + 1 \cdot 12.75 = 90.1884$
SH-IP-8960	224	1	$14 \cdot 5.9568 + 1 \cdot 12.75 = 96.1452$
SH-IP-9600	240	1	$15 \cdot 5.9568 + 1 \cdot 12.75 = 102.102$
SH-IP-10240	256	1	$16 \cdot 5.9568 + 1 \cdot 12.75 = 108.0588$

We plot the power versus capacity curves in Fig. 1. It turns out that although the Juniper T1600 + TX Matrix Plus do not provide as high capacities as the CISCO CRS-1 provides, it consumes less power per bps (according to [10], Juniper T1600 holds the energy efficiency record in IP/MPLS routing as for the year 2008). It is mainly caused by the fact that the Juniper solution uses just one central switching and routing element that interconnects up to 16 T1600 chassis into a single routing entity [27]. Morever, Juniper uses Short Reach interfaces, which consume much less power. Interestingly, the 16-Slot Single-Shelf System turns out to be most energy-efficient (W/Gbps). The 4- and 8-Slot counterparts are competitive only at low capacities corresponding to a few line cards.

As for the route processors, Juniper T1600 and Tx Matrix Plus use Intel Celeron and Pentium IV as Routing Engine Options (RE-A-1600-2048, RE-A-1600-2048, RE-TXP-SFC-DUO-2600), however, to the best of our knowledge, power they consume has not been detailed by Juniper.

3.2 WDM layer

We have a broad variety of network elements in the WDM layer:

- Transponders/muxponders
- Regenerators
- WDM terminals (including mux, demux and amplifiers)
- Optical line amplifiers (OLAs)
- Optical Switches (OADMs, OXCs)

Tables 6 - 10 contain the numbers on power consumption of some specific network elements in the WDM layer. It is problematic to interpret those numbers though, since it is often a manufacturer's secret, what the network elements really contain.

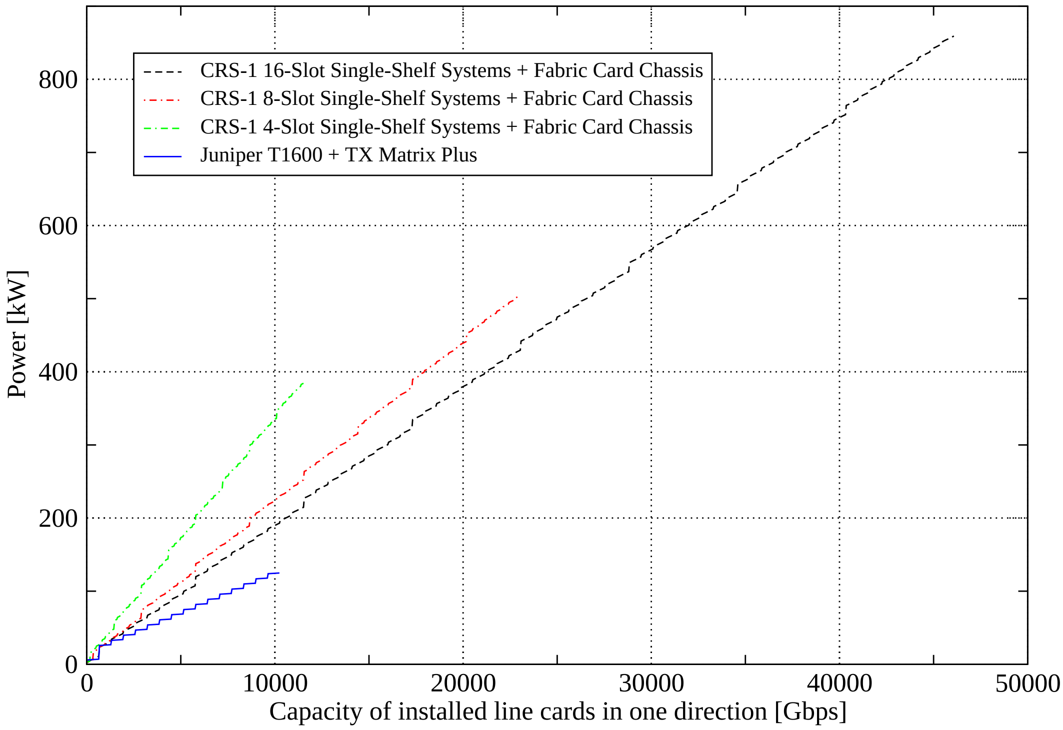

Figure 1: Router power consumption versus capacity (as unidirectional capacity of installed 40 Gbps OC-768c/STM-256c line cards) for Cisco CRS-1 single and multi shelf systems as well as Juniper T1600 interconnected by Juniper TX Matrix Plus

Table 6: Power consumption of transponders / muxponders in WDM layer

Device	Power [Watts]	Ref.
2.5-GBPS Multirate Transponder Card for the CISCO ONS 15454 Multiservice Transport Platform	Typical 25, maximum 35	[49]
10-GBPS Multirate Transponder Card for the CISCO ONS 15454 Multiservice Transport Platform	Typical 45, maximum 50	[53]
4 x 2.5-GBPS Muxponder Card for the CISCO ONS 15454 Multiservice Transport Platform	Typical 45, maximum 50	[54]

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Table 6 – continued from previous page

Device	Power [Watts]	Ref.
10-Gbps Full-Band Tunable Multirate Enhanced Transponder Card for the Cisco ONS 15454 Multiservice Transport Platform	Typical 35, maximum 50	[57]
Cisco 2-Channel SFP WDM Transponder	maximum 9.7	[56]
Lucent Metropolis Multi-Rate Transponder for Service Providers	7RU shelf: 50 per fan, 330 max (fully populated shelf)	[51]
Ciena F10-T 10G Transponder Module For the CN 4200 FlexSelect Advanced Services Platform Family	35 (with maximum FEC), 41 (tunable, with maximum FEC)	[25]
Fujitsu Flashwave 7200 - Transponder, Protection, Regenerator System	ANSI shelf: 381 typical for 16 OC-48/STM-16 transponders, 333 typical for 8 OC-192/STM-64 transponders; ETSI shelf: 334 typical for 11 OC-48/STM-16 transponders, 292 typical for 7 OC-192/STM-64 transponders	[14]
Fujitsu Flashwave 7300 - Transponder, Protection, Regenerator System	681 for 18 bidirectional OC-192s/STM-64s	[15]
Alcatel-Lucent Wave Star OLS 1.6T ultra-long-haul systems	73	[61]
Fujitsu Flashwave 7500 small system (compact ROADM for Mid-Size Applications)	<440@1500 BTU/HR (OLC shelf (full))	[20]

Table 7: Power consumption of regenerators in WDM layer

Device	Power [Watts]	Ref.
Cisco Optical Regenerator (OC-48/STM-16 Bidirectional)	max. 100@342 BTU/HR	[47]
JDSU WaveShifter 200 ER 3R	typical 4.5, max. 6	[45]
iLynx STM-16 / OC-48 Regenerator	nominal 8	[19]

Table 8: Power consumption of WDM terminals in WDM layer

Device	Power [Watts]	Ref.
connecting edge nodes to the core node	1500 W for every 64 wavelengths	[2, 3]
connecting core nodes (Fujitsu Flashwave 7700)	811 W for every 176 channels	[2, 3, 17, 63]
undersea terminal system	9000 W 4 fiber pairs with 64 wavelengths at 10 Gbps	[4]

Table 9: Power consumption of Optical Line Amplifiers in WDM layer

Device	Power [Watts]	Ref.
multiple wavelength amplifier (1 amplifier per ca. 200 km)	6 W per fiber	[2, 3]
CISCO ONS 15501 Erbium Doped Fiber Amplifier (EDFA)	15 maximum, 8 typical	[18, 61]
intermediate line amplifier (1 ILA per ca. 108 km), Fujitsu Flashwave 7700	622 W for every 176 channels	[2, 3, 17, 63]
Fujitsu Flashwave 7600 (in-line amplifier)	601 W typical for 32 wavelengths	[16]
Lucent Metropolis Multi-wavelength Optical Amplifier (1 OA per 140 km in single span, 1 OA per 100 km in multiple spans)	typical 6, max. 25	[48]
JDSU OA 400 Amplifier Series - Compact, Low Cost Single-Channel or Narrow Band Amplifiers	4.5	[55]
infinera Optical Line Amplifier	205 (typical)	[22]
single amplifier (every 70 km)	1000	[12]
undersea repeater	40 (every 50 km)	[4]

Table 10: Power consumption of optical switches in WDM layer

Device	Power [Watts]	Ref.
Ciena Configurable OADM For CoreStream Agility Optical Transport System	typical 250	[24]
Fujitsu Flashwave 7500 Metro/Regional ROADM Platform	<360@1228 BTU/HR (Optical/HUB shelf); <680@2318 BTU/HR (2D-ROADM shelf); <930@3170 BTU/HR (Tributary shelf)	[26]
Fujitsu Flashwave 7500 small system (compact ROADM for Mid-Size Applications)	<240@820 BTU/HR (OADM shelf (typical))	[20]
Fujitsu Flashwave 7600 (Regional Long Haul DWDM Solution)	443 typical for 32 wavelengths	[16]
Finisar Dynamic Wavelength Processor DWP 100 Wavelength Selective Switch	typical 20	[6]
Finisar Dynamic Wavelength Processor DWP 50 Wavelength Selective Switch	typical 20	[7]
Remote Optical Add/Drop Multiplexer/Photonic Cross Connect (Implemented current equipment)	40 / 100 Gbps at 10 Gbps in 50 GHz spacing	[37]

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Table 10 – continued from previous page

Device	Power [Watts]	Ref.
Remote Optical Add/Drop Multiplexer/Photonic Cross Connect (Next generation equipment)	10 / 100 Gbps at 40 Gbps in 50 GHz spacing	[37]
Infinera DTN Switched WDM System (ROADM)	1500 (typical, fully loaded), 2730 (max)	[9]
128 x 128 Calient OXC	$<$100	[4]
Calient DiamondWave FiberConnect - Fiber Optic Cross-Connection System	0.47 per connection (fully loaded)	[23]
Calient DiamondWave PXC - photonic switching system for metro and long-haul network environment (128x128 or 256x256)	0.47 per connection (fully loaded)	[21]
MRV OCC - Optical Cross Connect - Single-Mode Fiber Optic Switch	$<$750 (fully loaded)	[28]

Significant differences of power consumption of comparable network elements can be observed. E.g. an OC-48/STM-16 regenerator by Cisco [47] consumes max. 100 W, while nominal power consumption of the iLynx OC-48/STM-16 is 8 W [19]. Another example is the power of a transponder, which ranges from 9.7 W for Cisco 2-Channel SFP WDM Transponder [56] to 73 W for Alcatel-Lucent Wave Star OLS 1.6T ultra-long-haul systems [61]. These differences may be caused by the differences in technologies used for deployment of the network elements, as well as the technological improvement of energy-efficiency over time.

3.3 Other aspects regarding energy consumption

Network elements not only consume energy, but also generate heat. Following [2], we account one Watt spent on cooling for every Watt spent by any of the network devices.

Another issue is the dependency of the energy consumption on the network load. According to [11], traffic has an impact on the power consumption, however the costs of powering the chassis and the line cards dominate the overall power profile of a network. In the scenario considered in [11], traffic (of various characteristics) increased the power consumption of Cisco GSR 12000 with a 4-port Gigabit Ethernet engine 3 line card and a 1-port OC-48/POS line card (the line cards contain transceivers [1, 43, 46]) by about 20 Watts (out of the 756 Watts consumed in the idle case), which corresponds to only 2.65% of the power consumed by the router.

4 Summary

We provide a collection of power numbers (together with direct references) of various network elements in IP over WDM networks in this report. There is a big variety of network elements for IP over WDM networks, which show different levels of power consumption. As expected, the optical elements consume less energy than the electrical ones. However, differences of power consumption of comparable network elements may be significant (e.g. ROADMs or regenerators). Although many network elements are numerously represented (like transponders or line cards), there are also some elements (especially the emerging ones, like optical cross connects), for which only some unprecise data is available. Moreover, the information provided in the data sheets and in the literature may sometimes be misleading, since it is often unclear how the power was measured (which configuration, idle or active state, with or without traffic etc.)

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