Equipment power consumption in optical multilayer networks – source data

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Abstract

This report contains source data to derive accountable reference power consumption values for IP-over-WDM core network equipment. The reference values are provided in the publication shown in the box below. The report is mainly based on publicly available data from product data sheets.

For additional information and referring values given in this work, please cite the corresponding paper:

W. Van Heddeghem, F. Idzikowski, W. Vereecken, D. Colle, M. Pickavet, and P. Demeester, "*Power consumption modeling in optical multilayer networks*", Photonic Network Communications (2012), DOI: 10.1007/s11107-011-0370-7

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1 Detailed power consumption data

1.1 IP/MPLS layer

The IP/MPLS layer power consumption is based on data sheets for Cisco's CRS and Juniper's T-series core routers.

1.1.1 Systems description and overview

Cisco CRS

The Cisco CRS (Carrier Routing System) core router series consists of 2 generations: the CRS-1 which was launched in 2004 and the CRS-3 which was launched in 2010.

Both generations come in three different shelf sizes: a 4-slot, 8-slot and 16-slot *line card shelf* (LCS). In addition to these three standalone shelf configurations multiple line card shelves can be connected by using one or more so-called *fabric card shelves* (FCS) to increase the total routing capacity. Each FCS can connect 9 LCS. The maximum configuration consists of 72 LCSs interconnected by 8 FCSs.

The main difference between the CRS-1 and CRS-3 generation is the slot capacity: 40 Gbps per slot for the CRS-1 and 140 Gbps for the CRS-3.

Each slot takes a *modular services card* (MSC) and a *physical layer interface module* (PLIM). The MSC is always paired with a PLIM and mainly contains the forwarding engine. The PLIM contains the physical connections to the network, for example a 1-port STM-256 PoS, or a 4-port 10 Gigabit Ethernet interface. In this document we consider the MSC as the slot card because it contains the forwarding engine, and the PLIM as the port card.

Juniper T-series

The Juniper T-series core routers, launched in 2002, come in three standalone shelf configurations: the T320 (16 x 10 Gbps slots), the T640 (8 x 40 Gbps slots), the T1600 (8 x 100 Gbps slots). In addition, multiple of these shelves can be connected by a *TX Matrix* shelf (connects up to four T640s) or a *TX Matrix Plus* shelf (connects up to 16 T1600s[1]).

Considering only the T1600, each slot can be equipped with a *flexible PIC concentrator* (FPC), which can then take – depending on the FPC type – up to four *physical interface modules* (PICs). Similar to the Cisco architecture, the FPC contains the forwarding engine. The PIC provides the physical layer-1/layer-2 connections. A PIC can contain multiple ports.

Again, in this document we consider the FPC as the slot card, and the PIC as the port card. The main difference with the CRS architecture is that for the T-series the FPC really contain PICs and thus acting as a proper slot card, whereas for the CRS, the MSC are not really slot cards containing another card.

Table 1 provides an overview of the different components and terminology used.

[1] However, the hardware guide [7] does not mention how to connect more than 4 T1600s.

Table 1 Cisco and Juniper terminology overview

This document	***Cisco***	***Juniper***
Basic node Contains everything but the slot cards and the port cards, i.e. mainly routing engine, switch fabric, internal cooling systems	*Line card shelf,* plus optionally *fabric card shelf* for multi-shelf systems	*Core router chassis,* plus optionally *TX Matrix (Plus) chassis* for multi-shelf systems
Slot card Contains the forwarding engine	*Modular Services Card (MSC)* Is always paired with a PLIM The maximum 'slot' throughput is 40 Gbps (CRS-1) and 140 Gbps (CRS-3)	*Flexible PIC Concentrator (FPC)* Depending on the FPC type: - its maximum throughput is either 4, 16, 40, 50 or 100 Gbps - can take either 1, 2 or 4 PICs
Port card Contains the physical interfaces	*Physical Layer Interface Module (PLIM)* Can contain multiple ports of the same interface	*Physical Interface Card (PIC)* Can contain multiple ports of the same interface

1.1.2 Power consumption breakdown

Table 2 shows the detailed power distribution breakdown of two configurations. We derived the typical power consumption to be 90% of the given maximum power consumption. Power values have been rounded; for Juniper power values were derived from current specifications at 48 VDC.

Table 2 Power consumption breakdown for the CRS-3 16-slot and T1600

Component	***Power Max. [Watt]***	***Power Typ. [Watt] (derived)***	***Percentage***	***Source***
Cisco CRS-3 16-slot (single shelf system)				
Chassis				
Switch fabric modules (8x206 W)	1648	1483	14%	[13]
Route processors (2x166 W)	332	299	3%	[13]
Power supply and internal cooling				
Fan controller cards (2x344 W)	688	619	6%	[13]
Line cards				
Forwarding engines (MSC, 16x446 W)	7136	6422	58%	[13]
Interfaces (PLIM, 16x150 W)	2400	2160	20%	[13]
Juniper T1600				
Chassis				
Switch fabric (5 SIBs: 5x197 W)	984	886	13%	[3]
Routing engine (1 host subsystem + RE-C1800, 125 W + 82 W)	206	185	3%	[3]
Other (2 SCG, craft interface, LCC-CB, 2x10 W + 10 W + 48 W)	77	69	1%	[3]

Component	*Power Max. [Watt]*	*Power Typ. [Watt] (derived)*	*Percentage*	*Source*
Power supply and internal cooling				
Power supply (2) + internal cooling (2x82 W + 480 W)[2]	643	579	9%	[3]
Line cards				
Forwarding engines (FPC, 8x542 W)	4339	3905	59%	[3]
Interfaces (PIC, 16x66 W; generalized maximum value)	1052	947	14%	[3]

1.1.3 Detailed power consumption values

General notes:

- Power values stated in the data sheets are the maximum power budget required per component (for power provisioning purposes), and thus represent an upper limit and not typical values of power consumption at full load. We derived the typical power consumption at full load to be 90% of the given maximum power consumption.
- The power consumption of the port cards includes the power consumption for powering the optics. Separate values are not given, except for two 10GE Cisco port cards (see the table for details).
- For a list of Juniper T-series documents and data sheets, see the *T-series Technical Documentation* webpage [1].
- For an overview of Cisco CRS components, see the list of product data sheets [9] containing power consumption values.
- For an overview of Cisco CRS system description publications, see the *Product installation guides list* [10].

Table 3 Detailed power consumption values of IP router components

Manuf.	*Description*	*Power Max. [Watt]*	*Power Typ. [Watt] (derived)*	*Source*
Basic Node				
Juniper	T320 chassis, 160 Gbps (custom calculation based on: switch fabric, routing engine, power supply, internal cooling, other)	605	545	[4]
Juniper	T640 chassis, 320 Gbps (custom calculation based on: switch fabric, routing engine, power supply, internal cooling, other)	1 114	1003	[5]
Juniper	T1600 chassis, 800 Gbps (custom calculation based on: switch fabric, routing engine, power supply, internal cooling, other)	1 910	1719	[3]

[2] The actual maximum cooling power consumption is given 22 A x 48 V = 1056 W, but this is for "high temperature environment or cooling component failure". As such, we have used a more realistic maximum power consumption of 10 A x 48 V = 480 W.

Manuf.	*Description*	*Power Max. [Watt]*	*Power Typ. [Watt] (derived)*	*Source*
Juniper	TX Matrix chassis, connects up to four T640s (custom calculation based on: switch fabric, routing engine, power supply, internal cooling, other)	3 144	2830	[6]
Juniper	TX Matrix Plus chassis, connects up to four[3] T1600s (switch fabric, routing engine, power supply, internal cooling, other) As an good approximation, half the power (3518 W) is required per two T1600s, since only 5 SIB cards are required for connecting 1 or 2 T1600s, whereas 10 SIB cards are required for connecting 3 or 4 T1600s	7 036	6332	[7]
Cisco	CRS-1 16-slot single-shelf system chassis, 640 Gbps	2 920	2628	[Idzikowski2009]
Cisco	CRS-3 16-slot single-shelf system chassis, 2240 Gbps (custom calculation based on: switch fabric modules, route processors, fan controller cards)	2 668	2401	[13]
Cisco	CRS-1 Fabric card shelf, connects up to nine CRS 16-slot systems	9 000	8100	[14]
Slot cards				
Juniper	Type-3 FPC, 40 Gbps full duplex, max. 4 PICs	437	393	[3]
Juniper	Type-4 FPC, 40 Gbps full duplex, max. 1 PIC	394	355	[3]
Juniper	Type-4 FPC, 100 Gbps full duplex, max. 2 PICs	542	488	[3]
Cisco	CRS-1 MSC 40 Gbps full duplex	350, 375	315, 338	[12], [13]
Cisco	CRS-3 MSC 140 Gbps full duplex	446	401	[11], [13]
Port Cards				
Juniper	1x Gigabit Ethernet PIC with SFP, reach 70 km	11.9	10.7	[2]
Juniper	2x Gigabit Ethernet PIC with SFP, reach 70 km	11.9	10.7	[2]
Juniper	4x Gigabit Ethernet PIC with SFP, reach 70 km	23.8	21.4	[2]
Juniper	10x Gigabit Ethernet PIC with SFP, reach 70 km	29.9	26.9	[2]
Juniper	1x 10GE Ethernet PIC with XENPAK (T1600 Router), reach 80 km	26.6	23.9	[2]
Juniper	1x 10GE Ethernet LAN/WAN PIC with XFP (T1600 Router), Type 4 FPC compatible, reach 80 km	43.0	37.8	[2]
Juniper	1x 10GE Ethernet DWDM PIC (T1600 Router), reach 80 km	26.6	23.9	[2]
Juniper	1x 10GE Ethernet DWDM OTN PIC (T1600 Router), reach 80 km	26.6	23.9	[2]
Juniper	1x 10GE Ethernet IQ2 PIC with XFP (T1600 Router), reach 80 km	56.0	50.4	[2]
Juniper	1x 10GE Ethernet Enhanced IQ2 (IQ2E) PIC with XFP (T1600 Router), reach 80 km	56.0	50.4	[2]

[3] The product brochure ([8]) mentions up to sixteen T1600s, however the hardware guide [7] only details on connecting up to four.

Manuf.	***Description***		***Power Max. [Watt]***	***Power Typ. [Watt] (derived)***	***Source***
Juniper	1x	SONET/SDH OC48/STM16 (Multi-Rate) PIC with SFP, reach 80 km	9.5	8.6	[2]
Juniper	1x	SONET/SDH OC192c/STM64 PIC (T1600 Router), reach 80 km	21.6	19.4	[2]
Juniper	1x	SONET/SDH OC192/STM64 PICs with XFP (T1600), reach 80 km	25.0	22.5	[2]
Juniper	4x	SONET/SDH OC192/STM64 PICs with XFP (T1600), Type 4 FPC compatible, reach 80 km	53.1	47.8	[2]
Juniper	1x	SONET/SDH OC768c/STM256 PIC (T1600 Router), Type 4 FPC compatible, reach 2 km	65.7	59.1	[2]
Juniper	1x	100-Gigabit Ethernet PIC, reach 10 km	not available		[2]
Cisco	16x	CRS OC-48c/STM-16c POS/DPT, reach 80 km	136, 150	122, 135	[13], [16]
Cisco	4x	CRS OC-192c/STM-64 POS/DPT, reach 80 km	138, 150	124,135	[13], [17]
Cisco	1x	CRS OC-768c/STM-256c POS, reach 2 km	65, 150	59, 135	[13], [15]
Cisco	1x	CRS-3 100 Gigabit Ethernet, reach 10 km	150	135	[13]
Cisco	14x	CRS-3 10GE LAN/WAN-PHY, reach 80 km	150 (of which 35 W for optics budget)	135	[13]
Cisco	20x	CRS-3 10GE LAN/WAN-PHY, reach 80 km	150 (of which 30 W for optics budget)	135	[13]
Cisco	8x	CRS 10GE, XFP	88	79	[13]
Cisco	8x	CRS 10GE, XENPAK, reach 80 km	110, 150	99, 135	[13], [18]
Cisco	4x	10GE Tunable WDMPHY, reach 2000 km	150	13	[19]
Cisco	1x	OC-768C/STM-256C Tunable WDMPOS, reach 1000 km	150	135	[20]
Cisco	1x	OC-768C/STM-256C DPSK+ Tunable WDMPOS, reach 2000 km	150	135	[21]

1.2 Ethernet layer

The Ethernet layer power consumption is based on data sheets for the Cisco Nexus 7018 and Juniper EX8216 switch.

1.2.1 Systems description and overview

Cisco Nexus 7018

The Cisco Nexus 7000 series switches consist of two types: the 10-slot Nexus 7010, and the 18-slot Nexus 7018. We only consider the latter. The Nexus 7018 chassis has 18 slots which can contain up to 16 I/O modules and up to 2 supervisor modules. The base system consists of 3 to 5 fabric modules and a set of fan trays.

Juniper EX8216

The Juniper EX8216 Ethernet switch is the high-capacity switch of the EX8200 series. It has 16 slots. The base systems consist of a routing engine, switch fabric cards and fan trays.

1.2.2 Power consumption breakdown

Table 4 shows the detailed power distribution breakdown of two 10G configurations. The source of the values can be found in section 1.2.3.

Table 4 Power consumption breakdown for the Cisco and Juniper Ethernet switches

Component	*Power Typ. [Watt]*	*Percentage*
Cisco Nexus 7018		
Chassis		
Switch fabric modules (5x90 W)	450	4%
Supervisor module (2x190 W)	380	3%
Fan trays (1x569 W)	569	5%
Line cards		
32 port 10G cards (16x611 W)	9776	87%
Juniper EX8216		
Chassis		
Routing engine (1), Fans (2), Fabric cards (8)	1080	18%
Line cards		
8 port 10G cards (16x299 W)	4784	82%

1.2.3 Detailed power consumption values

Table 5 lists the power consumption values of the **individual components** of the listed switches.

Table 6 lists the power consumption values of **complete systems**, for various maximum configurations.

Table 5 Detailed power consumption values of Ethernet switches components

Manuf.	*Description*	*Power Typ. [Watt]*	*Power Max. [Watt]*	*Power Used [Watt]*	*Source*
Cisco	Nexus 7000, 32-port 10-Gigabit Ethernet I/O module	611	750	611	[22]
Cisco	Nexus 7000, 8-port 10-Gigabit Ethernet I/O module with XL option	520	650	520	[22]
Cisco	Nexus 7000, 48-port 1-Gigabit Ethernet I/O module	358	400	358	[22]
Cisco	Nexus 7000, supervisor module, per module value; switch takes up to 2 modules	190	210	190	[22]
Cisco	Nexus 7018, fabric module, per module value; switch takes 3 to 5 modules	90	100	90	[22]
Cisco	Nexus 7018, fan trays (total number of fan trays)	569	1433	569	[22]
Juniper	EX8216 Base system, 1 routing engine, 8 switch fabric modules, 2 fan trays The datasheet mentions 'reserved power' and 'typical power'. However, the values for reserved power correspond to the typical values in the 'EX8200 Ethernet Line cards' datasheet. Likewise, the values for the typical power correspond to the maximum power in the mentioned datasheet.	1080	2280	1080	[23]
Juniper	EX8216 8-port 10G module (EX8200-8XS)	299	450	299	[24]
Juniper	EX8216 48-port 1G module (EX8200-48F)	185	330	185	[24]

Table 6 Detailed typical power consumption values of complete Ethernet switch configurations

Manuf.	*Description*	*Port speed (Gbps)*	*Power per port, typ. [Watt]*	*Source*
Cisco	Nexus 7018 average value per port '*A Cisco Nexus 7000 18-Slot Switch fully populated with Cisco Nexus 32-Port 1 and 10 Gigabit Ethernet Modules has the capability to deliver up to 10.2 (Tbps) of switching performance, with a typical power consumption of less than 10 W per port.*'	10	10	[25]
Cisco	Nexus 7018, maximum 10 G configuration, fully populated with 16 32-port 10G Ethernet modules + fans + 2 supervisor modules + 5 fabric modules 512 ports for a total of 11175 W typical. But slot switching capacity limited to 230 Gbps, so we assume 23 ports per slot, which gives 368 ports in total	10	30	[22]
Cisco	Nexus 7018, maximum 1 G configuration, fully populated with 16 48-port 1G Ethernet modules + fans + 2 supervisor modules + 5 fabric modules 768 ports for a total of 7127 W typical	1	9.3	[22]
Juniper	EX8216, maximum 10 G configuration, fully populated with 16 8-port 10G modules + 1 routing engine, 8 fabric cards and 2 fans 128 ports for a total of 5864 W typical	10	45.8	[23]
Juniper	EX8216, maximum 1 G configuration, fully populated with 16 48-port 1G modules + 1 routing engine, 8 fabric cards and 2 fans 768 ports for a total of 4040 W typical	1	5.3	[23]

1.2.4 Observations and reference values

The Ethernet power consumption is based on two systems: the Cisco Nexus 7018 and the Juniper EX8216. The power consumption values are based on the typical power consumption of a maximum configured system, including the power overhead of the chassis and any required control and switch fabric cards.

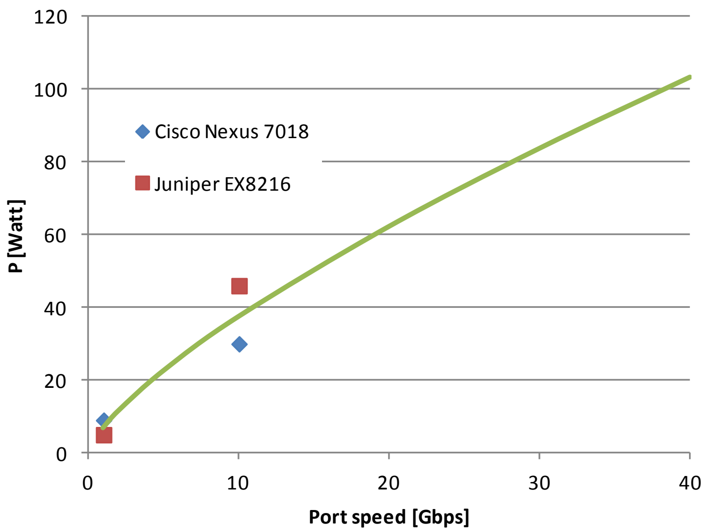

Figure 1 Power consumption of the Ethernet layer interfaces, per port

Observations:

- The typical power-per-port values, including chassis overhead, are plotted in Figure 1.
- The power values of both systems are roughly in line, as such averaging of the values makes sense.
- The reference values are given in Table 7.
- As there is no public data available for higher capacities, we assume the same exponential function: $P_2 = \left(\frac{C_2}{C_1}\right)^{0.73} \cdot P_1$.
  The value 0.73 follows from $\log_{C_{10G}/C_{1G}}\left(\frac{P_{10G}}{P_{1G}}\right) = \log_{10/1}\left(\frac{38}{7}\right)$

Table 7 Ethernet layer (bidirectional)

Type	***Remarks***	***Power consumption [Watt]***	***Power efficiency [Watt/Gbps]***
Ethernet 1 Gbps port	Includes chassis overhead	7 W	7 W/Gbps
Ethernet 10 Gbps port		38 W	3.8 W/Gbps
Ethernet 40 Gbps port		*(105 W)*	*(2.6 W/Gbps)*
Ethernet 100 Gbps port		*(205 W)*	*(2.1 W/Gbps)*
Ethernet 400 Gbps port		*(560 W)*	*(1.4 W/Gbps)*
Ethernet 1 Tbps port		*(1100 W)*	*(1.1 W/Gbps)*

1.3 OTN layer

The OTN power consumption is based on confidential information; as such the values are approximations.

The power consumption values are based on the typical power consumption of a maximum configured system, including the power overhead of the chassis and any required control and switch fabric cards.

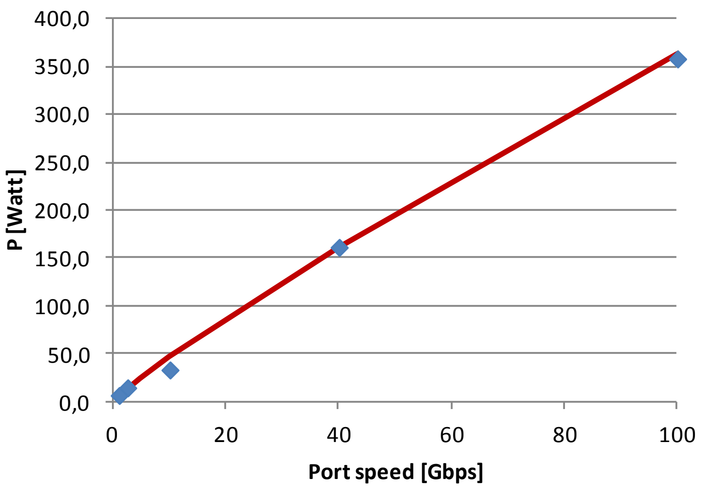

Figure 2 Power consumption of the OTN layer interfaces, per port

Observations:

- As can be seen in Figure 2, the values scale quite smoothly with the port speed.
- The values are given in Table 8.
- As there is no data available for capacities higher than 100 Gbps, we assume the same exponential function as present for the 40 Gbps to 100 Gbps cards. $P_2 = \left(\frac{C_2}{C_1}\right)^{0.89} \cdot P_1$.

  This line is also indicated in Figure 2.

Table 8 OTN layer (bidirectional)

Type	***Remarks***	***Power consumption [Watt]***	***Power Efficiency [Watt/Gbps]***
OTN 1 Gbps port	Includes chassis overhead	7 W	7 W/Gbps
OTN 2.5 Gbps port		15 W	6 W/Gbps
OTN 10 Gbps port		34 W	3.4 W/Gbps
OTN 40 Gbps port		160 W	4 W/Gbps
OTN 100 Gbps port		360 W	3.6 W/Gbps
OTN 400 Gbps port		*(1240 W)*	*(3.1 W/Gbps)*
OTN 1 Tbps port		*(2800 W)*	*(2.8 W/Gbps)*

1.4 WDM layer: transponders/muxponders

1.4.1 Detailed power consumption values

The power consumption value in the column labeled ‘Used’ is calculated by using the values in the previous 3 columns. If the value in the source was unspecified to be typical or maximum, it is assumed to be typical, and this value is shown in the used column. Otherwise the values in the typical and maximum column are averaged, with the maximum value (first) being reduced to 75%.

Table 9 Detailed power consumption values of transponders

Manuf.	*Description*	*Speed (Gbps)*	*Power [Watt]*				*Source*
			Unsp.	*Typ.*	*Max.*	*Used*	
Fujitsu	FLASHWAVE 7200, Tunable Optical Transponder Solution, ANSI shelf: 381 W typical for 16 2.5 G transponders (OC-48/STM-16) mgmt shelf: 215 W typical fully populated (381+215)/16 = 37.2 W	2.5	-	37.2	-	37.2	[26]
Fujitsu	FLASHWAVE 7200, Tunable Optical Transponder Solution, ANSI shelf: 333 W typical for 8 10G transponders (OC-192/STM-64)) mgmt shelf: 215 W typical fully populated (333+215)/8 = 68.5 W	10	-	68.5	-	68.5	[26]
Fujitsu	FLASHWAVE 7200, Tunable Optical Transponder Solution, ETSI shelf: 334 W typical for 14 2.5 G transponders + mgmt shelf: 215 W typical fully populated (334+215)/14 = 39.2 W	2.5	-	39.2	-	39.2	[26]
Fujitsu	FLASHWAVE 7200, Tunable Optical Transponder Solution, ETSI shelf: 292 W typical for 7 10G transponders + mgmt shelf: 215 W typical fully populated (292+215)/7 = 72.43 W	10	-	72.4	-	72.4	[26]
Fujitsu	FLASHWAVE 7300 WDM transponder, 10G Ethernet (“transponder, protection and regenerator system”) Muxponder capability (4x2.5 Gb). Feature list also mentions: • Performance monitoring • Out-of-Band forward error correction • Control plane routing functionality, 681 W for 18 bidir 10G + 206 W mgmt shelf = (681 + 206)/18 = 49.3 W/Gbps bidir	10	49.3	-	-	49.3	[27]
Ciena	F10-T 10G transponder module, 10G transponder for the CN 4200 FlexSelect platform family, F10-Tunable with maximum FEC (does not include XFP): 35 W	10	35	-	-	35	[28]
Ciena	F10-T 10G transponder module, 10G transponder for the CN 4200 FlexSelect platform family, F10-Tunable with maximum FEC (does not include XFP): 41 W	10	41	-	-	41	[28]
Transmode	10G Tunable OTN Transponder, ‘Max. 22 W worst case including client optics’	10	-	-	22	16.5	[29]
Transmode	10G Tunable Transponder, 25 W fully equipped	10	-	-	25	18.75	[30]
Transmode	Double 10GbE Transponder. Max. 40 W in Transponder mode (fully equipped with client and DWDM XFPs). So 20 W for one transponder.	10	-	-	20	15	[31]

Manuf.	*Description*	*Speed (Gbps)*	*Power [Watt]*				*Source*
			Unsp.	*Typ.*	*Max.*	*Used*	
Transmode	Double 10G Lite Transponder, Max. 18 W in Transponder mode (fully equipped with client and DWDM XFPs). So 9 W for one transponder.	10	-	-	9	6.75	[32]
Transmode	Tunable 10G Transponder with extended reach, '22 W (Max. consumption including transceivers)'	10	-	-	22	16.5	[33]
Transmode	7900/01 10G Transponder. Can also be used in regenerator mode, Max. 11 W	10	-	-	11	8.25	[34]
Transmode	7910/01 10G Transponder. Can also be used in regenerator mode, Max. 17 W	10	-	-	17	12.75	[35]
Transmode	MultiRate Transponder 7700 The 7700 is a fully featured 100Mb/s – 2.7Gb/s Transponder with pluggable optics on both the line and client side. 'Fully equipped: 5.5 W'	2.5	-	-	5.5	4.125	[36]
Transmode	TM-4000 40G transponder unit, Max. power consumption: 130 W	40	-	-	130	97.5	[37]
Transmode	TM-4000 40G transponder unit + chassis, Chassis has room for 8 cards. Max. chassis power consumption: 1500 W, with max. card power consumption 160 W (muxponder card). Thus: 1500 - 8x160 = 220 W chassis Thus: for 8 transponders =130 + 220/8 = 158 W	40	-	-	158	118.5	[37]
Cisco	Extended Performance 10-Gbps Full-Band Tunable Multirate Transponder Card for the Cisco ONS 15454 Multiservice Transport Platform	10	-	35	50	36.25	[38]
Cisco	ONS 15454 2.5 Gbps Multirate Transponder Card	2.5	-	25	35	25.63	[39]
Cisco	ONS 15454 10-Gbps Multirate Enhanced Transponder Card	10	-	40	50	38.75	[40]
Tellabs	40 Gigabit Transponder Module (FGTM)	40	-	167	-	167	[41]
Paper	(based on) Alcatel Lucent WaveStar OLS 1.6T ULH, WDM transponder based on Alcatel Lucent WaveStar OLS 1.6T ultra-long haul system (OLS: optical line system)	10	73	-	-	73	[Shen2009]
Paper	WDM transponder 40G, LH, Nokia Siemens estimate	40	66	-	-	66	[Palkopoulou2009]
Paper	100G transponder (QPSK modulation)	100	351	-	-	351	[Morea2011]

1.4.2 Observations and reference values

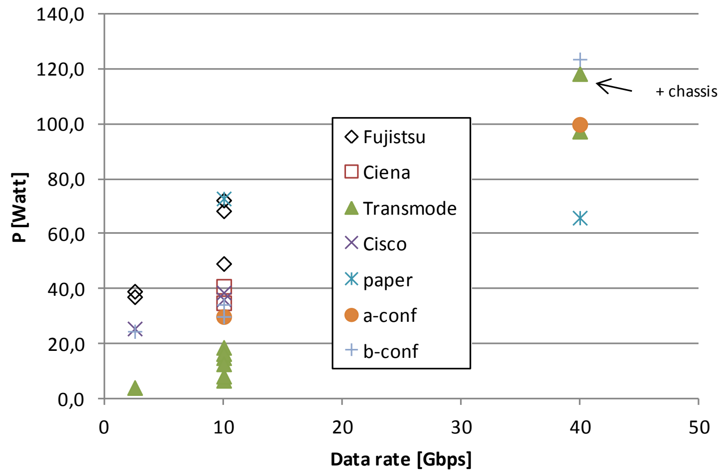

Figure 3 Transponder power consumption in function of the data rate

Observations:

- From Figure 3: Fujitsu has higher values, because these values are based on complete systems (including management shelf). The percentage of overhead ranges from 22% to 42%.
  The Transmode 40G transponder is shown once with and once without chassis overhead. This overhead represents 11% of the total power consumption.
- From confidential data (a-conf and b-conf in Figure 3), we see that the influence of the line side maximum transmission distance is of (arguably) minor influence on the power consumption. A 10G transponder with reach up to 1200 km consumes about 15% more than its 200 km version. Given the range of power consumption values for the different equipment and the fact that it is not always clear from the data sheets what the maximum supported reach is, we do not make a distinction based on the reach.

Based on the distribution in Figure 3, we assume the following **typical power consumption values**, including chassis and management overhead power consumption:

- For 2.5G transponders we assume 25 W
- For 10G transponders we assume 50 W
- For 40G transponders we assume 100 W

As there is no public vendor data available for 100G, 400G and 1T transponders, we assume the same function where the power is doubled for a forth-fold increase in capacity: $P_2 = \left(\frac{C_2}{C_1}\right)^{0.5} \cdot P_1$. We thus get:

- For 100G transponders we assume 150 W.
- For 400G transponders we assume 300 W.

For 1T transponders we assume 500 W (rounded from 474 W). In [Morea2011] a power estimation (351 W) is given for 100G coherent transponders. This seems to suggest that the digital signal processing functionality of these transponders leads to more than the double power consumption of our extrapolated estimates.

Furthermore, we assume the following guidelines:

- **Maximum power consumption** values, as opposed to typical values, can be approximated by adding 33%.
- The **chassis and management power overhead *per transponder*** is about 20% of the above quoted typical consumption values (which already includes this overhead).

1.5 WDM layer: optical amplifiers

1.5.1 Detailed power consumption values

Table 10 lists the power consumption values of **individual optical amplifiers**

Table 11 lists the power consumption values of **complete amplification systems**, for various maximum configurations.

See the note at the beginning of section 1.4 for an explanation of the different power value columns.

Table 10 Detailed power consumption values of optical amplifiers

Manuf.	*Description*	Power [Watt]				*Source*
		Unsp.	*Typ.*	*Max.*	*Used*	
Cisco	ONS 15501 EDFA optical amplifier, mode of operation: unidirectional Typ. 8 W, max. 15 W	-	16	30	19.25	[43]
conf	EDFA, 2-stage 25 W per direction	50	-	-	50	Confidential
conf	Raman amp (~10 dB gain) 50 W per direction	100	-	-	100	Confidential
Infinera	Optical Line Amplifier, EDFA Typ. 26 W per fiber (probably), so 52 W per fiber pair Max. 53 W per fiber (probably), so 106 W per fiber pair	-	52	106	65.75	[44]
Infinera	Optical Line Amplifier, RAMAN Typ. 45 W per fiber (probably), so 90 W per fiber pair Max.105 W per fiber (probably), so 210 W per fiber pair	-	90	210	123.7 5	[44]
Cisco	ONS 15454 Optical amplifier card (pre/booster) Typ. 30 W, max. 39 W. Seems unidirectional, so double	-	60	78	59.25	[47]
Cisco	ONS 15454 Optical amplifier card (inline) Typ. 19 W, max. 23 W. Seems unidirectional, so double	-	38	46	36.25	[47]
Cisco	ONS 15454 Raman C-band optical amplifier card (15454-OPT-RAMP-C) Typ. 44 W, max. 55 W	-	88	110	85.25	[48]
conf	Line amplifier card, very long span	-			80	Confidential
conf	Line amplifier card, long span	-			70	Confidential
conf	Line amplifier card, medium span	-			47	Confidential
conf	Line amplifier card, short span	-			47	Confidential
conf	Raman pump	-			100	Confidential

Manuf.	*Description*	*Power [Watt]*				*Source*
		Unsp.	*Typ.*	*Max.*	*Used*	
MRV	Fiber Driver optical amplifier module (EM316EDFA), For metro networks Power usage: max. 6 W. Seems unidirectional, so double	-	-	12	9	[50]
MRV	LambdaDriver Optical Amplifier Module. (EM800-Oax/EM1600-Oax), For long haul networks. 18 dBm output. 20 dB gain without midstage access From 3.3 W (18 dBm type) to 15 W (high-power 21 dBm type). Seems unidirectional based on accompanying figures, so double	-	-	6.6	4.95	[51]
MRV	LambdaDriver High Power Optical Amplifier Module, EDFA (EM800-Oax/EM1600-Oax), Mainly serve high wavelength count (more than 32 waves) DWDM or ultra long single span applications, with midstage access From 3.3 W (18 dBm type) to 15 W (high-power 21 dBm type). Seems unidirectional based on accompanying figures, so double	-	-	30	22.5	[52]
MRV	LambdaDriver Optical Amplifier Module, Raman. (EM1600-OAR), for long haul networks Max. 60 W. Seems unidirectional based on accompanying figure, so double.	-	-	120	90	[53]
Oclaro	PureGain PG1000, Compact EDFA Pre-Amplifier, 30 dB gain Max. power consumption is 4 W with cooling (typ. 2 W), 1.5 W uncooled (typ. 1 W). Unidirectional, so double	-	4	8	5	[54]
Oclaro	PureGain PG 1000, Compact EDFA Booster amplifier, 25 dB gain Max. power consumption is 4 W with cooling, 1.5 W uncooled. Unidirectional, so double	-	4	8	5	[55]
Oclaro	PureGain PG1600, Compact EDFA, For add drop terminals, 23 dB Gain Max. 9 W. Unidirectional, so double	-	-	18	13.5	[56]
Oclaro	PureGain PG2800 Configurable EDFA, model 2811, Inline 1 without Mid-Stage Access, 15-25 dB variable gain 9 W. Unidirectional, so double	-	-	18	13.5	[57]
Oclaro	PureGain PG2800 Configurable EDFA, model 2821, Inline 1 with Mid-Stage Access, 17-29 dB variable gain 14 W. Unidirectional, so double	-	-	28	21	[57]
Oclaro	PureGain PG3000 Performance EDFA, Inline 2 with Mid-Stage Access 24-34 dB variable gain 14 W and 20 W. Unidirectional, so double	-	28	40	29	[58]
Ciena	Fixed-gain amplifier for ActivSpan 4200 Series (OAF-00-1-C), Preamp/Booster/Inline 36 W probably maximum, 'unidirectional design', so double	-	-	72	54	[59]
Ciena	Variable-gain amplifier for ActivSpan 4200 series (OAV-OS-U-C), Preamp/Booster/Inline with Mid-stage access 48 W probably maximum, 'unidirectional design', so double	-	-	96	72	[59]
Alcatel	Alcatel LM1600 Dual stage line amplifier 26 W. Unidirectional, so double	-	-	52	39	[60]

Manuf.	*Description*	*Power [Watt]*				*Source*
		Unsp.	*Typ.*	*Max.*	*Used*	
Paper	optical amplifier "power consumption of optical amplifiers is between 3 and 12 W depending on the overall insertion loss and the length of fiber delay lines" Probably unidirectional	-	6	12	7.5	[Aleksic2009]
Paper	Each EDFA is 8 W based on Cisco ONS 15501 EDFAs Typ. 8 W, max.15 W	-	16	30	19.25	[Shen2009] [43]
Paper	EDFA booster/pre-amplifier combination (OLT) 25 W	25	-	-	25	[Grobe2011]

Table 11 Detailed power consumption values of complete amplification systems

Manuf.	*Description*	*Power [Watt]*				*Source*
		Unsp.	*Typ.*	*Max.*	*Used*	
Ciena	Common Photonic layer, fully filled Line Amplification site (88 wavelengths) = 95 W (0.1 rack) Probably bidirectional because for other 'sites' it always mentions specifically that it is 'per direction'	-	95	-	95	[42]
Infinera	Optical Line Amplifier, EDFA, including chassis, ancillary and controller (OMM) amplifier: 2x53 W = 106 W chassis, ancillary: 122 W [from email corresp.] OMM: 28 W [from email corresp.] = 256 W	-	-	256	192	[44]
Infinera	Optical Line Amplifier, RAMAN, including chassis, ancillary and controller (OMM) amplifier: 2x105 W = 210 W chassis, ancillary: 122 W [email corresp.] OMM: 28 W [email corresp.] = 360 W	-	-	360	270	[44]
Fujistsu	Flashwave 7700 ILA, "ultra long haul DWDM" 621.8 W typical for 176 channels (10G each)	-	621,8	-	622	[45]
Fujistsu	Flashwave 7600 ILA 601 W typical for 32 wavelengths (up to 10G)	-	601	-	601	[46]
Cisco	ONS 15454 multiservice transport platform, EDFA, specified typical power consumption	-	200	307	215	[49]
Cisco	ONS 15454 multiservice transport platform, Raman, specified typical power consumption	-	288	415	300	[49]
conf	Line amplifier card, **very long span** Maximum number of amp cards per shelf/rack + controller cards and fans	-	-	-	119	Confidential
conf	Line amplifier card, **long span** Maximum number of amp cards per shelf/rack + controller cards and fans	-	-	-	108	Confidential
conf	Line amplifier card, **medium span** Maximum number of amp cards per shelf/rack + controller cards and fans	-	-	-	66	Confidential
Alcatel	Alcatel LM1600, Dual stage line amplifier Max number of amp cards per shelf, including mandatory cards (controller, fans, alarm, …)	-	-	103	77	[60]

1.5.2 Observations and reference values

- Line rate does not have an influence on power consumption of optical amplifiers. There is also no consistent difference in booster, pre- or line amplifiers (see MRV and confidential vendor).
- The power consumption of optical amplifiers increases with longer span lengths (based on the detailed data available from the confidential vendor).
- The optical amplifier type (EDFA or Raman) has a large influence. The Infinera RAMAN optical amplifiers consume without management almost exactly twice as much as the EDFA optical amplifiers. This is also the case for the confidential vendor RAMAN amplifier.
- Management is also a big contributor: for Infinera (quite reliable values thanks to email correspondence with Infinera): management is fixed at 140 W, and one bidirectional amplifier is 106 W (EDFA) or 210 W (Raman). For the confidential vendor, the management adds about 20 W to each bidirectional amplifier in a fully-configured chassis.

1.6 WDM layer: WDM terminals

Table 12 lists the power consumption values of WDM terminals. See the note at the beginning of section 1.4 for an explanation of the different power value columns.

Table 12 Detailed power consumption values of WDM terminals

Manuf.	*Description*	*Power [Watt]*				*Source*
		Unsp.	*Typ.*	*Max.*	*Used*	
Cisco	15454 MSTP WDM terminal, 40 channels, no transponders included 1 x 40DMX + 1 x OPT-BST + 1 x OPT-PRE = 80 W (typ.), 117 W (max.) Overhead: 150 W (typ.) Total: 230 W (typ.)	-	230	-	230	[61], [47]
Cisco	15454 MSTP WDM terminal, 80 channels, no transponders included 2 x 40DMX + 1 x OPT-BST + 1 x OPT-PRE = 100 W (typical), 150 W (max.) Overhead: 150 W (typ.) Total: 250 W (typ.)	-	250	-	250	[61], [47]
Alcatel	LM1600-based MUX/DEMUX 96 channels (12x8 MUX/DEMUX), 10G each. Including amplifiers, no transponders included custom calculation (1 controller card, 1 fan, 1 ALCT, 1 alarm card, 1 PSU + 12 CMDX + 1 BMDX + 2 amplifiers)	-	-	344	258	[60]
Alcatel	LM1600-based MUX/DEMUX 80 channels (12x8 MUX/DEMUX), 10G each. Including amplifiers, no transponders included custom calculation (1 controller card, 1 fan, 1 ALCT, 1 alarm card, 1 PSU + 10 CMDX + 1 BMDX + 2 amplifiers)	-	-	314	236	[60]
Fujistsu	Flashwave 7700 terminal, "ultra long haul DWDM" 810.6 W typical for 176 channels (10G each)	-	811	-	811	[45]

1.7 WDM layer: OXC/OADM

1.7.1 Detailed power consumption values

The calculations for OXCs and OADMs are based on the Cisco OSN 15454 system. Data sheets used include [61], [62] and [63].

Table 13 Detailed power consumption values of OXC/OADMs

Manuf.	*Component*	*Power Typ. [Watt]*	*Source*
Cisco	**ROADM 40-channel** (based on: Cisco 40-Channel Reconfigurable Optical Add/Drop Multiplexing Portfolio for 15454 MSTP)		
	Switching		
	Wavelength Selective Switch (2 x 40WSS @ 63 W)	126 W	[61]
	Demultiplexer (2 x 40DMX @ 20 W)	40 W	[61]
	Booster amplifier (2 x OPT-BST @ 30 W)	60 W	[47]
	Pre- amplifier (2 x OPT-PRE @ 30 W)	60 W	[47]
	Overhead	150 W	custom estimation
Cisco	**OXC 40-channel, N-degree, D- add/drop-degree** (based on: Cisco 40-Channel Reconfigurable Optical Add/Drop Multiplexing Portfolio for 15454 MSTP)		
	Switching		
	Wavelength cross-connect (N x 40WXC)	N x 25 W	[61]
	Booster amplifier (N x OPT-BST)	N x 30 W	[61]
	Pre- amplifier (N x OPT-PRE)	N x 30 W	[61]
	Add/Drop		
	Multiplexer (D x 40MUX)	D x 20 W	[61]
	Demultiplexer (D x 40DMX)	D x 20 W	[61]
	Overhead	150 W	custom estimation
Cisco	**ROADM 80-channel** (based on: Cisco 40-Channel Reconfigurable Optical Add/Drop Multiplexing Portfolio for 15454 MSTP)		
	Switching		
	Wavelength Selective Switch (4 x 40WSS @ 63 W)	252 W	[61]
	Demultiplexer (4 x 40DMX @ 20 W)	80 W	[61]
	Booster amplifier (2 x OPT-BST @ 30 W)	60 W	[61]
	Pre- amplifier (2 x OPT-PRE @ 30 W)	60 W	[61]
	Overhead	150 W	custom estimation

Manuf.	*Component*	*Power Typ. [Watt]*	*Source*
Cisco	**OXC 80-channel, N-degree, D- add/drop-degree** (based on**:** Cisco 80-Channel Wavelength Cross-Connect Card for the Cisco ONS 15454 Multiservice Transport Platform)		
	Switching		
	Wavelength cross-connect (N x 80WXC)	N x 20 W	[63]
	Booster amplifier (N x OPT-BST)	N x 30 W	[61]
	Pre- amplifier (N x OPT-PRE)	N x 30 W	[61]
	Add/Drop		
	Multiplexer (D x 2 x 40MUX)	D x 40 W	[61]
	Demultiplexer (D x 2 x 40DMX)	D x 40 W	[61]
	Overhead	150 W	custom estimation

1.7.2 Observations

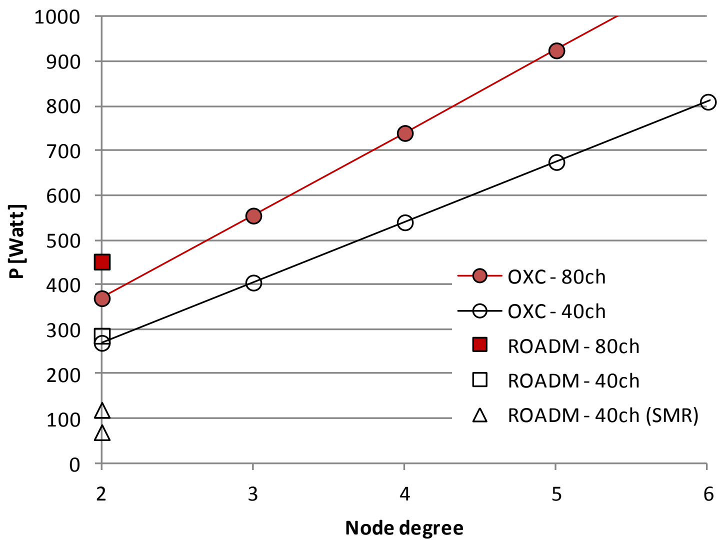

Figure 4 Typical power consumption of ROADMs and OXCs (add/dropping for each degree), not including overhead power

As public data about complete OXC systems is sparse, the data is based solely on the Cisco OSN 15454 system.

ROADM functionality is constructed by combining of a number of building blocks: wavelength selective switch (WSS) cards, MUX/DEMUX cards and pre/booster amplifier cards. Single module cards that contain all of this functionality are also available, and are labeled SMR (single module ROADM).

OXC functionality is constructed from wavelength cross-connect (WXC) cards, pre and booster amplifiers cards. For each degree to be added/dropped, MUX/DEMUX cards are required.

Observations:

- From Figure 4: ROADMs consume slightly more power than 2-degree OXCs. This is because the WSS cards used in the ROADMs consume more than the WXC cards used in the OXCs.
- From Figure 4: the SMRs consume significantly less than the combined systems.
- From Figure 4: OXC power consumption scales nicely with the degree (apart from the overhead power consumption, which is not shown in the figure)
- The overhead for both ROADMs and OXCs is estimated to be around 150 W per node. This is based on (a) the remaining difference with the typical power consumption values cited (by the datasheet) for a 2-degree 80-channel ROADM node (452 W, see Table 13), as well as (b) the combined power consumption of the fan module, power module and controller card.

2 Acronyms

ALCT	Automatic Laser ConTrol
ANSI	American National Standards Institute
BMDX	Band MUX/DEMUX
CMDX	Channel MUX/DEMUX
CRS	Carrier Routing System
DMX	Demultiplexer
DEMUX	Demultiplexer
DPSK	Differential Phase Shift Keying
DPT	Dynamic Packet Transport
DWDM	Dense Wavelength Division Multiplexing
EDFA	Erbium-Doped Fiber Amplifier
ETSI	European Telecommunications Standards Institute
FCS	Fabric Card Shelf
FEC	Forward Error Correction
FGTM	Forty Gigabit Transponder Module
FGTM-M	Forty Gigabit Transponder Module-Multiplexer
FPC	Flexible PIC Concentrator
ILA	In-Line Amplifier
IP	Internet Protocol
LCC-CB	Line Card Chassis Control Board
LCS	Line Card Shelf
LH	Long Haul
MPLS	Multiprotocol Label Switching
MSC	Modular Services Card
MSTP	Multiservice Transport Platform
MUX	Multiplexer
OADM	Optical Add/Drop Multiplexer
OC	Optical Carrier
OLA	Optical Line Amplifier
OLS	Optical Line System
OLT	Optical Line Terminal
OMM	OTC Management Module
OPT-BST	Optical Booster Amplifier
OPT-PRE	Optical Preamplifier
OTC	Optical Transport Chassis

OTN	Optical Transport Network
OXC	Optical Cross Connect
PIC	Physical Interface Card
PLIM	Physical Layer Interface Module
PoS	Packet over SONET
QPSK	Quadrature Phase Shift Keying
ROADM	Reconfigurable OADM
SCG	SONET Clock Generator
SDH	Synchronous Digital Hierarchy
SFP	Small Form-factor Pluggable
SIB	Switch Interface Board
SONET	Synchronous Optical NETworking
STM	Synchronous Transport Module
ULH	Ultra Long Haul
WDM	Wavelength Division Multiplexing
WXC	Wavelength Cross-Connect
XFP	10 Gigabit Small Form Factor Pluggable

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