Energy consumption strategies for optical network

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Environmental degradation and global warming are among the major global challenges facing us today. These challenges include improving the efficient use of energy as well as climate change. Information Communication Technologies (ICT) and the internet play a vital role in both, being part of the problem and have the potential to provide important solutions to it.

General Energy problem:

Global warming is the long-term heating of Earth's climate system observed since the pre-industrial period (between 1850 and 1900) due to human activities, primarily fossil fuel burning, which increases heat-trapping greenhouse gas levels in Earth's atmosphere. The term is frequently used interchangeably with the term climate change, though the latter refers to both human- and naturally produced warming and the effects it has on our planet. It is most commonly measured as the average increase in Earth's global surface temperature.

Since the pre-industrial period, human activities are estimated to have increased Earth's global average temperature by about 1.2 degree Celsius (2.1 degrees Fahrenheit), a number that is currently increasing by 0.2 degrees Celsius (0.36 degrees Fahrenheit) per decade. Most of the current warming trend is extremely likely (greater than 95 percent probability) the result of human activity since the 1950s and is proceeding at an unprecedented rate over decades to millennia.

Figure 1. source:NASA's Goddard Institute for Space Studies

This graph illustrates the change in global surface temperature relative to 1951-1980 average temperatures, with the year 2020 tying with 2016 for warmest on record.

GreenHouse Gases Emissions

The climate change is mainly due to the increased greenhouse gas emission. Annual anthropogenic GHG emissions have increased by 10 GtCO2eq between 2000 and 2010, with this increase directly coming from energy supply (47%), industry (30%), transport (11%) and buildings (3%) sectors.

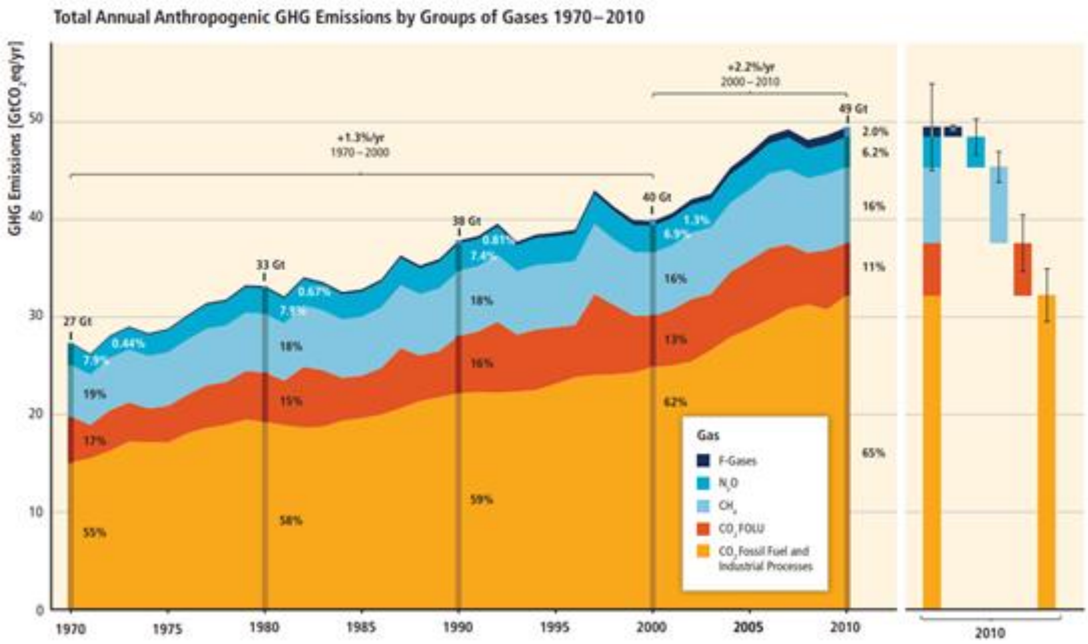


Figure 2. source:IPCC, 2014: Summary for Policymakers

Energy problem with ICT

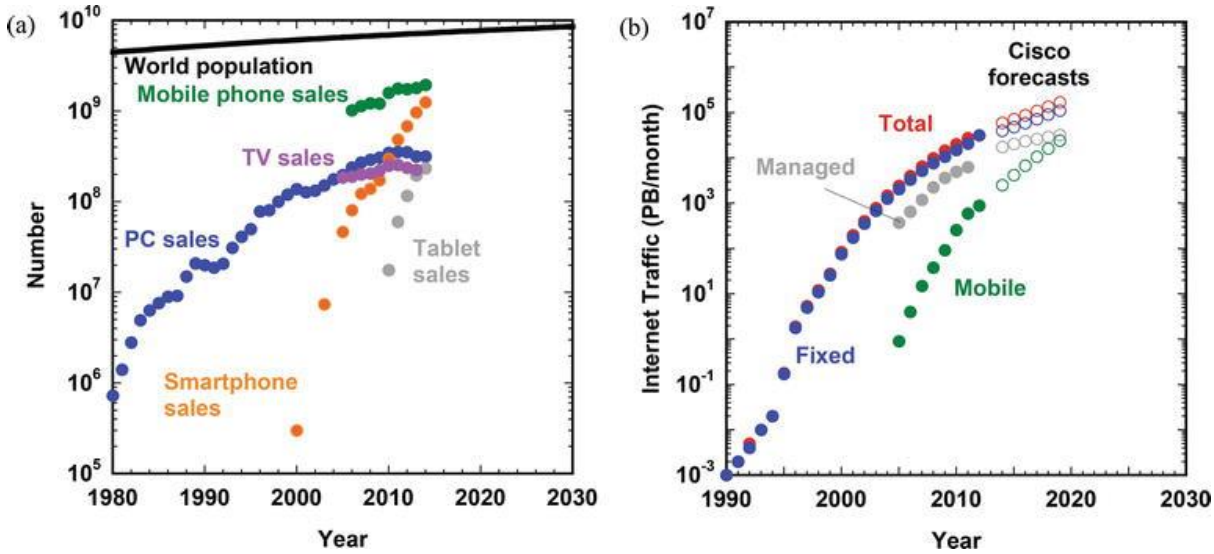
The energy consumption from the expanding use of information and communications technology (ICT) is unsustainable with present drivers, and it will impact heavily on the future climate change. However, ICT devices have the potential to contribute significantly to the reduction of CO2 emission and enhance resource efficiency in other sectors, e.g., transportation (through intelligent transportation and advanced driver assistance systems and self-driving vehicles), heating (through smart building control), and manufacturing (through digital automation based on smart autonomous sensors). To address the energy sustainability of ICT and capture the full potential of ICT in resource efficiency, a multidisciplinary ICT-energy community needs to be brought together covering devices, microarchitectures, ultra large-scale integration (ULSI), high-performance computing (HPC), energy harvesting, energy storage, system design, embedded systems, efficient electronics, static analysis, and computation.

The reliance of society on the use of information and communications technology (ICT) devices and systems is ever increasing. From the proliferation of e-mail and electronic document exchange, social media and apps to the ready use of mobile devices (already in their fourth generation), data analytics, and advanced computing to solve big challenges, there has been a transformative impact on society. However, the expanding ICT use requires increasing amounts of electricity to run and it implies fundamental transformations of energy that result in energy lost in the form of heat. Several models exist on the energy/electricity consumption of ICT, and some of them will be referenced below and in the remainder of the book. Nevertheless, a conservative estimation currently puts around 4% of all electricity consumption and over 2% of all CO_2 emissions as the result of ICT use. If entertainment, telephones, TV, and media that are now being translated onto ICT devices and systems are added, then these consumption numbers approximately double. In a recent study, the share of ICT global electricity usage by 2030 was estimated at 21% in a likely scenario and 51% in the worst-case.

By any account, the increasing energy consumption and the associated CO_2 emission of ICT devices strain the targets of low carbon, resource efficiency, and competitiveness of any modern circular economy. At present, all ICT roadmaps still use cost or performance as the main driver and improved energy management as a secondary issue, i.e., energy issues such as production, efficiency, and storage are considered only if necessary to achieve cost reduction or performance enhancement. However, if ICT is to become sustainable in terms of energy, then energy must be the key driver for all ICT devices and systems. Sustainable energy was defined by the United Nations Brundtland Commission “Our Common Future” in 1987 as requiring fuel or energy sources that have the following criteria: fuel is not significantly depleted by continuous use; no significant pollution or hazards to humans, ecology, or climate systems; no significant perpetuation of social injustice.

There are a large number of market surveys predicting the future of the ICT market and all of them suggest growth in a significant number of areas. Figure 3(a) shows the increase with time of the total number of ICT devices being sold each year. Only standard PCs and set top boxes are predicted to be static or decrease, while all other areas are predicted to grow significantly, suggesting that the number of ICT devices will continue to grow in the foreseeable future. As the number of ICT devices increases, and especially with the use of portable devices and the proliferation of the IoT, the amount of data being transmitted by the Internet and communication networks is also increasing significantly (Figure 3(b)).

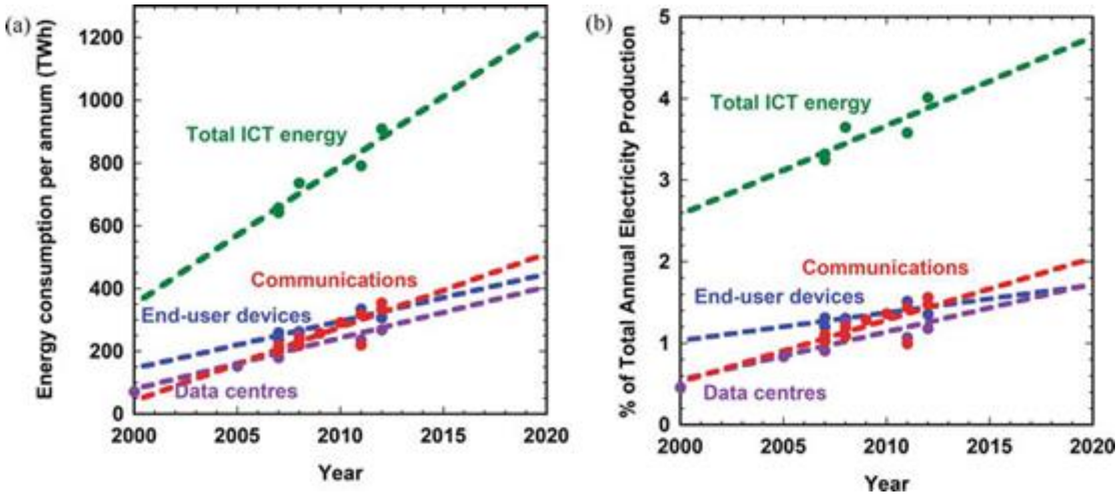
A number of studies have been looking at the energy consumption of ICT devices and systems (Figure 4). While several sources especially on web pages provide guesses of the total electricity consumption of ICT devices, there are a number of detailed studies that have tried to accurately estimate the total energy consumption and CO_2 emission. These studies have used trade data to estimate the number of devices, analyzed average use and loading of devices and considered the power scaling to provide estimates of the total electricity consumption (Figure 4) and CO_2 emission (Figure 5). In particular, there are a significant number of studies investigating the energy consumption and scaling of the Internet as the present energy consumption of telecommunications is the fastest growing part of ICT energy consumption. The key message is that in 2015, around 4% of the electricity generated worldwide is consumed by ICT devices, which results in 1 billion tonnes CO2 equivalent, that is, about 2.3% of the global emission of CO2. These studies do not include TV and media uses of ICT systems or the CO2 produced from the manufacture of the ICT devices and systems. The suggestion from reference is that TV and media has 82% of the energy consumption of ICT but 131% of the CO2 emission of ICT. As media is now being transferred to ICT devices and systems, a large part of this consumption may require being included in the total ICT consumption and emission in the future.



source:Giorgos Fagas et al., Energy Challenges for ICT, 2017

Figure 3.

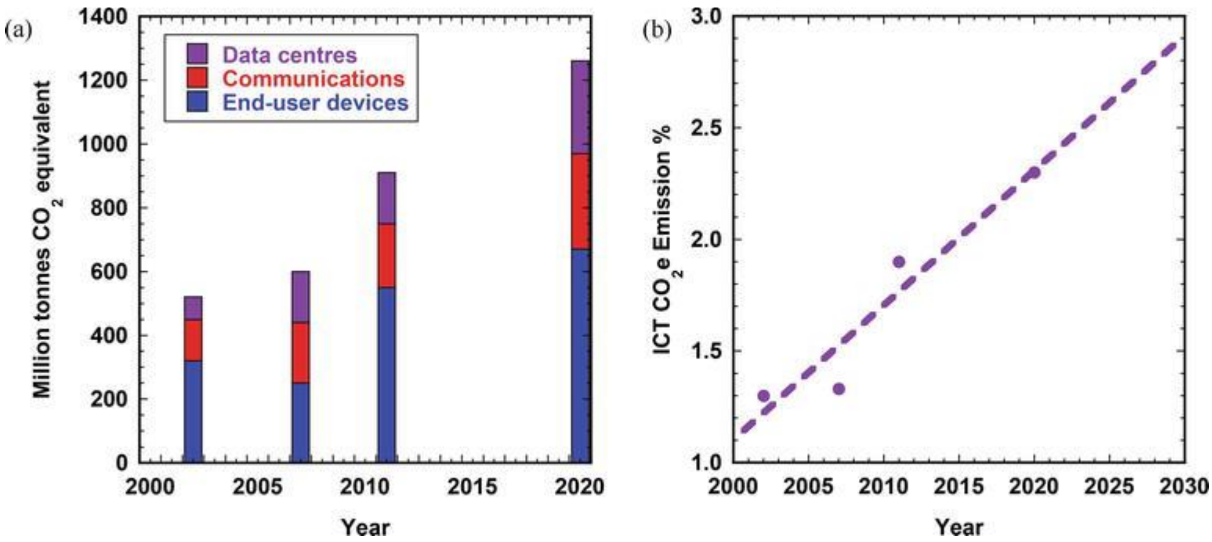
(a) The number of shipped end user device products per annum for personal computers (PCs—both desktops and laptops), mobile phones, smartphones, tablets, and TVs. (b) The average Internet traffic in terabytes per month for each year.



source:Giorgos Fagas et al., Energy Challenges for ICT, 2017

Figure 4.

(a) The estimated energy consumption per annum for data centres, PC devices (including desktops, laptops, and tablets), communications (Internet, networks, mobiles, and smartphones), and data centres (servers including cloud computing) plus the total annual ICT energy consumption. Total ICT energy does not include any entertainment and media use such as TV, HiFi, DVD, CD, or radio. The ICT energy also excludes all manufacture and disposal of ICT devices.



source:Giorgos Fagas et al., Energy Challenges for ICT, 2017

Figure 5.

(a) The amount of CO2 equivalent emitted from the manufacture and use of ICT equipment, infrastructure, and systems per annum along with predictions for 2020. (b) The percentage of ICT CO2 equivalent emissions as a percentage of total CO2 emissions.

WHY SHOULD WE BE INTERESTED IN THE ENERGY CONSUMPTION OF THE OPTICAL NETWORK?

There are many and one reasons we should be interested in the energy consumption of the optical network amongst which include:

- Accountability for Operational Expenditure (OPEX)
- GreenHouse Impact on the environment as compared to Carbon Emission.
- Managing the "Hotspots" within the Optical network systems.
- Awareness of Energy-limited capacity bottlenecks
- Enabling energy efficiencies in other sectors.

WHAT MAKES THE ENERGY CONSUMPTION GROWS - CONTRIBUTING FACTORS?

The contributing factors for ever growing energy consumption in the Optical network are but not limited to:

- Increasing user of the network
- Use of more data-intensive applications
- More often and for longer period of use
- Increasing demand thereby operators providing faster access and increase core capacity
- New applications enabled by faster access and requiring more bandwidth.

IMPORTANT OPTICAL DEVICES UNDER CONSIDERATION REGARDING ENERGY CONSUMPTION IN OPTICAL NETWORK

1. DSP vs Open Engine vs Module vs System

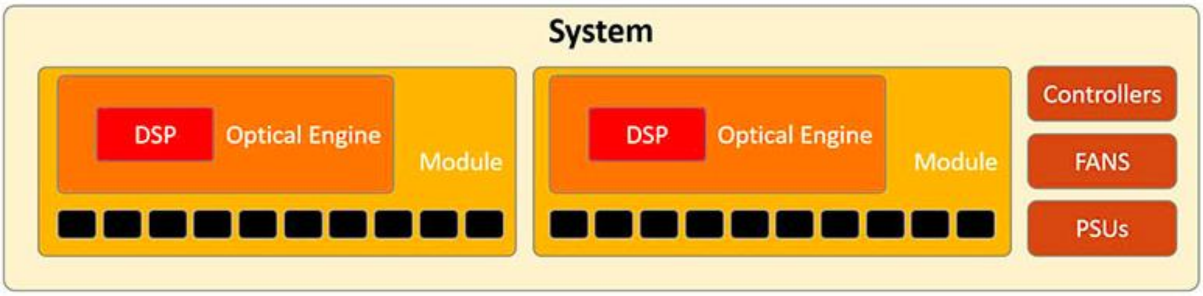


Image courtesy: Infinera.com

When some vendors provide impressive power consumption figures, they may be referring only to the DSP itself. Other vendors may define the power consumption for the complete optical engine, which includes the DSP, photonics, and analog electronics. The DSP typically accounts for around 70% of the power consumption in a high-end optical engine, though this can drop to around 50% in a coherent pluggable.

2. Typical Power vs. Maximum Power

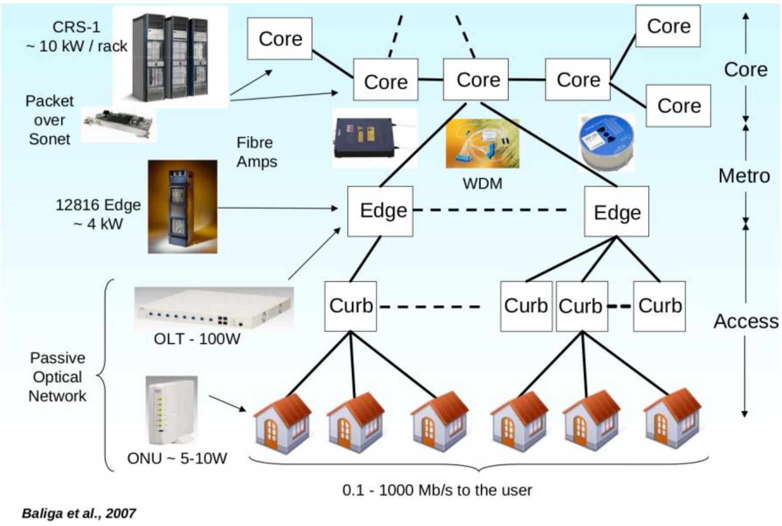


Image courtesy: Baliga et al., 2007

Like other types of equipment, optical hardware has typical and maximum power consumption. Individual copies of the same component will have a degree of variability in terms of their power consumption. Other factors that can influence power consumption include temperature, processing load, traffic load, and configuration. For example, the power consumption of fans can vary dramatically depending on how hard they have to work to keep the temperature within the required operating range.

3. Client Pluggable: Included or Not

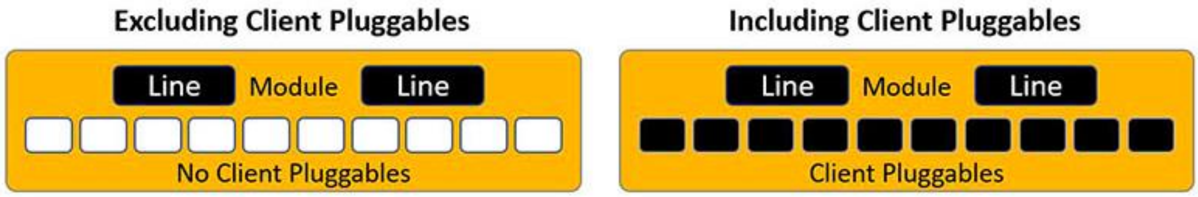


Image courtesy: Infinera.com

Another factor to consider when comparing the power consumption of modules and systems is whether client pluggables are included or not. Some vendors will quote the power consumption with no pluggables on the basis that the same types of pluggables will have the same impact on power consumption for all products.

4. Actual Bandwidth Requirement

Watts per Gb/s can provide an important tool for comparing the power consumption of devices with equivalent reach or that are all capable of meeting the reach requirement. This is normally calculated by taking the typical power consumption for the fully loaded device then dividing by the maximum capacity.

5. Distance: Watts per Gb/s per km

While watts per Gb/s is a useful tool for comparing power consumption, a vital dimension is missing distance. For example, a 400ZR pluggable with power consumption in the range of 16 to 20 watts and giving ~0.04-0.05 W per Gb/s might look much more power-efficient than an embedded optical engine with power consumption of less than 0.2 W per Gb/s.

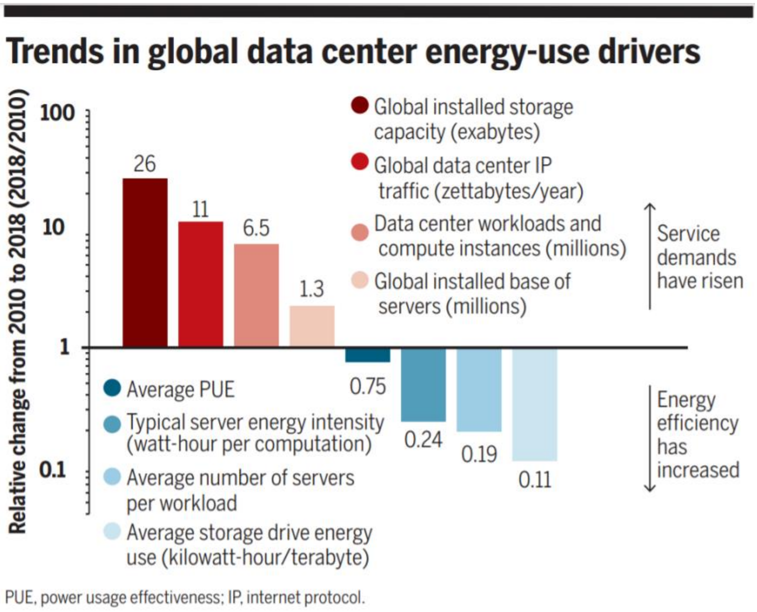
Data Center:

1. How much energy do global data centers consume per year?

By certain estimation model(based on integration of numerous recent datasets, which better characterize the installed stocks, operating characteristics, and energy use of data center IT devices, as well as structural shifts in the data center industry), between 2010 and 2018, global IP traffic—the quantity of data traversing the internet—increased more than ten-fold, while global data center storage capacity increased by a factor of 25 in parallel (Masanet et al. 2020). Over the same time period, the number of computer instances running on the world's servers—a measure of total applications hosted—increased more than six-fold (see Figure 3) (Masanet et al. 2020).

Despite rapid growth in demand for information services over the past decade, global data center energy use likely rose by only 6 percent between 2010 and 2018 (Masanet et al. 2020).

The finding that global data centers likely consumed around 205 terawatt-hours (TWh) in 2018, or 1 percent of global electricity use.



source:Masanet et al., recalibrating global data center energy-use estimates, 2020.

2. Why did the energy consumption only increase by 6% between 2010 to 2018 while the data center storage capacity increased by a factor of 25 in parallel?

Power Use Effectiveness(PUE) has been improved in recent years.

PUE is the ratio of the amount of energy used in the center by the amount to run the processors. It is a number larger than or equal to 1 and it is desirable to make it close to 1.

An Uptime Institute study in 2014 studied the PUE of cloud data centers from Google and Facebook public disclosures plus AWS internal data, all of which show PUEs under 1.2. These numbers appear to be very good, since in 2008, the Uptime Institute declared that the typical data center has an average PUE of about 2.5, but that number could be reduced to about 1.6 employing best practices

Three primary efficiency effects explain this near-plateau in energy use:

First, the energy efficiency of IT devices—and servers and storage drives in particular—has improved substantially due to steady technological progress by IT manufacturers.

Second, greater use of server virtualization software, which enables multiple applications to run on a single server to minimize memory and hardware utilization, has significantly reduced the energy intensity of each hosted application.

Third, most compute instances have migrated to large cloud- and hyperscale-class data centers, which can be intensively and effectively managed to optimize energy consumption i.e. utilize ultra-efficient cooling systems (among other important efficiency practices) to minimize energy use (Figure 2).

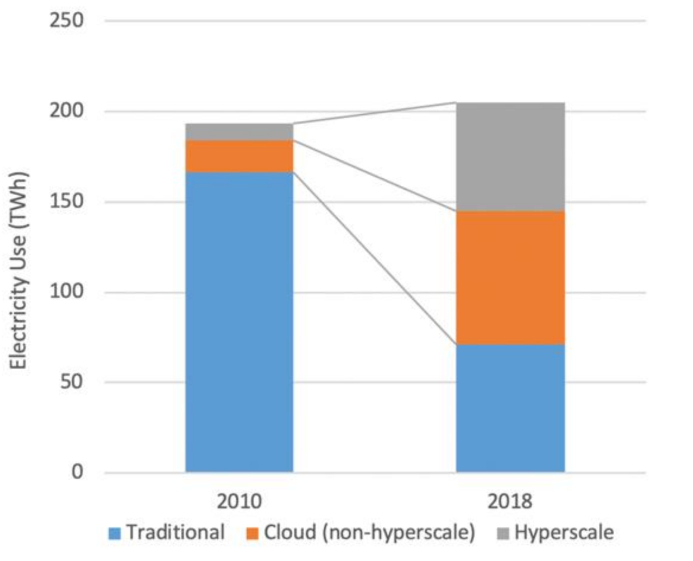


Figure 2. Estimated global data electricity use by data center type, 2010 and 2018. Source: Masanet et al. 2020.

source:Masanet et al., recalibrating global data center energy-use estimates, 2020.

3. Traditional DC vs. Cloud DC

The traditional data center is on-premises, meaning that all of its functionality is contained in a physical site within enterprise office space. A data center might be a few computers under a desk, a climate-controlled room filled with blade servers, or a whole building. It is managed by an in-house IT team employed and paid by the enterprise which owns the data center.

Meanwhile, a cloud data center (or just the ‘cloud’) serves exactly the same purpose as the traditional data center, but is physically located elsewhere, often even distributed across multiple locations. While the CDC, like the traditional data center, forms the basal IT infrastructure for an organization, it is managed off-site by a third-party company or service provider. In this case, employees and shareholders do not typically see the hardware hosting their systems or applications in person.

	Traditional Data Center	Cloud Data Center (CDC)
Location	On-premises, physically accessible	Virtualized, remote hardware
Management	Internal, business's responsibility	Outsourced to third-party provider
Administration	In-house IT professionals	Employees of the service provider
Reliability	Co-location makes failures dependent, onus is on the business for downtime and repairs	Provider is trusted to meet its promises of availability and reliability
Pricing	Business pays directly for planning, people, hardware, software, and environment	Business pays per use, by resources provisioned
Scalability	Possible, but involves challenges and delay	Completely, instantly scalable

source:https://www.talend.com/resources/cloud-vs-data-center/

4. Why does DC consume so much energy?

Data centers can be thought of as the “brains” of the internet. Their role is to process, store, and communicate the data behind the myriad information services we rely upon every day, whether it be streaming video, email, social media, online collaboration, or scientific computing.

Data centers utilize different information technology (IT) devices to provide these services, all of which are powered by electricity. Servers provide computations and logic in response to information requests, while storage drives house the files and data needed to meet those requests. Network devices connect the data center to the internet, enabling incoming and outgoing data flows. The electricity used by these IT devices is ultimately converted into heat, which must be removed from the data center by cooling equipment that also runs on electricity.

On average, servers and cooling systems account for the greatest shares of direct electricity use in data centers, followed by storage drives and network devices (Figure 1). Some of the world’s largest data centers can each contain many tens of thousands of IT devices and require more than 100 megawatts (MW) of power capacity—enough to power around 80,000 U.S. households (U.S. DOE 2020).

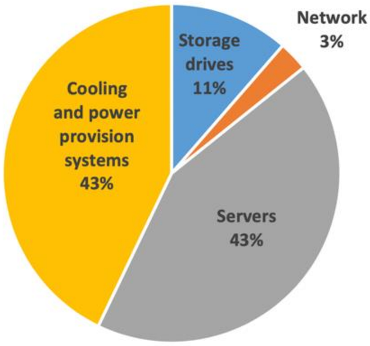


Figure 1. Fraction of U.S. data center electricity use in 2014, by end use. Source: Shehabi 2016.

source: Shehabi 2016.

5. Approaches to reduce DC energy consumption

The methods can be grouped into changes in the information technology infrastructure, airflow management, and managing air conditioning.

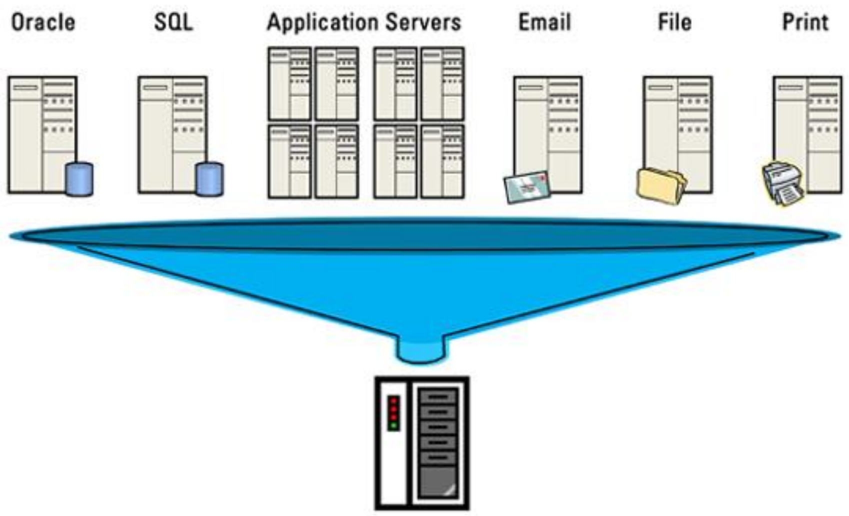
In terms of information technology, virtualizing servers, decommissioning inactive servers, consolidating lightly used servers, removing redundant data, and investing in technologies that use energy more efficiently can provide substantial improvements.

One of the improvements in terms of managing air flow is a “hot aisle/cold aisle” layout where the backs of servers face each other so that the mixing of hot and cold air is avoided. In order to further reduce mixing hot and cold air, containing or enclosing servers is recommended. Improving air flow by means of simple measures such as using structured cabling to avoid restricting air flow is recommended.

Finally, adjusting the temperature and humidity, employing air conditioning with variable speed fan drives, bringing in outside cooling air, and using the evaporative cooling capacity of a cooling tower to produce chilled water are recommended to potentially make significant changes.

Server virtualization :

Server virtualization offers a way to consolidate servers by allowing you to run multiple different workloads on one physical host server. A "virtual server" is a software implementation that executes programs like a real server. Multiple virtual servers can work simultaneously on one physical host server. Therefore, instead of operating many servers at low utilization, virtualization combines the processing power onto fewer servers that operate at higher total utilization.



source: https://www.energystar.gov/products/low_carbon_it_campaign/12_ways_save_energy_data_center

Virtualization improves scalability, reduces downtime, and enables faster deployments. In addition, it speeds up disaster recovery efforts because virtual servers can restart applications much more rapidly than physical servers. With virtualization, you can move entire systems from one physical server to another in just a few seconds to optimize workloads or to perform maintenance without causing downtime. Some virtualization solutions also have built-in resiliency features, such as high availability, load balancing and failover capabilities.

Due to these benefits, virtualization has become commonplace in large data centers. A 2011 survey of over 500 large enterprise data centers found that 92% use virtualization to some degree.5 Of those, the ratio of virtual servers to physical host servers averaged 6.3 to 1 and 39% of all servers were virtual.

decommissioning inactive servers:

Surveys of data centers often identify aged servers with no use still running–so–called "comatose" servers. Estimates of the prevalence of comatose servers vary:

Surveys have found that 8 to 10% of servers with no use are still running -- 150 of 1800 in one study; 354 of 3500 in another.

According to Kenneth Brill, executive director of the Uptime Institute, "unless you have a rigorous program of removing obsolete servers at the end of their lifecycle...is very likely that between 15% and 30% of the equipment running in your data center is comatose. It consumes electricity without doing any computing."17

A recent New York Times article described a large data center near Atlanta that found more than half of its servers were comatose.18

Server consolidation:

Server consolidation reduces total number of servers by putting more applications on fewer machines. You can consolidate servers by:

Combining applications onto a single server and a single operating system instance. Two or three lightly utilized file servers, for example, can be consolidated onto one machine.

Clustering servers.32 Server clustering reduces the number of backup or standby servers needed by a system, improves availability, and uses hardware more efficiently.

Downsizing the application portfolio. Many large organizations run a number of very similar applications, some of which are underutilized. Fewer servers are needed when redundant applications are eliminated.

Virtualize servers. Virtualization allows for consolidation of applications from different operating systems and/or hardware platforms.

Better Management of Data Storage:

The concept of energy efficient data storage is simple — use less storage to use less energy — and can result from the better data storage best practices available today through storage resource management tools. In addition, there are certain storage hardware devices that use much less energy.

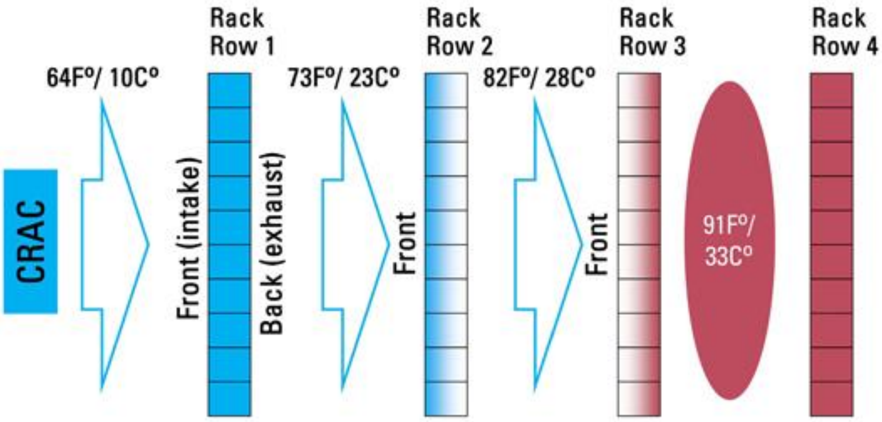
Automated Storage Provisioning, Data Compression, Deduplication.

Purchasing More Energy-Efficient Servers

New servers use more energy-efficient technology such as: More efficient power supplies, better DC voltage regulators, processors that consume less power, and cooling fans that are more energy-efficient.

Airflow Management Strategies

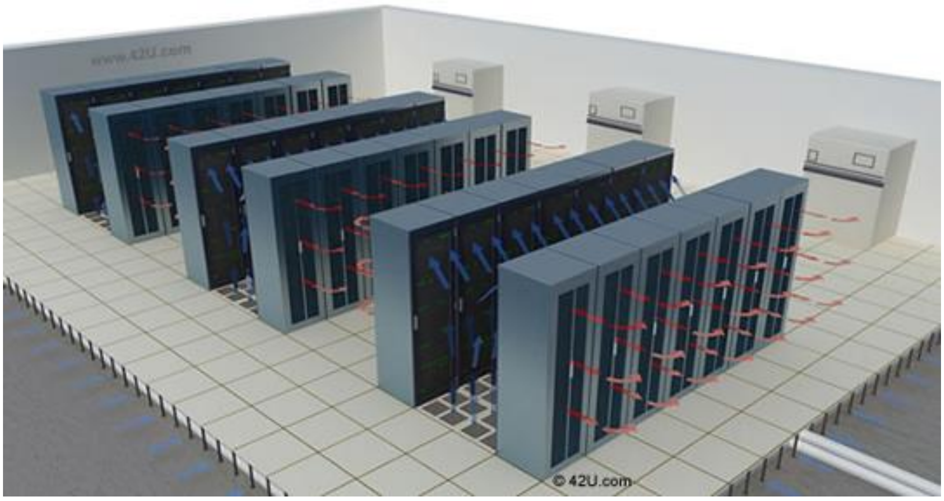
Most modern IT equipment takes in cold air via the front of the unit and exhausts hot air out of the back of the unit. If servers are logically placed in rows with the front of the racks (and servers) all facing the same direction, then one has achieved a consistent airflow direction throughout the rows of racks. However, if several parallel rows of racks are placed with the same orientation, a significant efficiency problem arises. The hot exhaust air from the first row of racks gets sucked into the "cool" air intakes of the second row of racks. With each progressive row, the air temperature increases as hot air is passed from one row of servers to the next.



source: https://www.energystar.gov/products/low_carbon_it_campaign/12_ways_save_energy_data_center

To overcome this problem, the rows of server racks should be oriented so that the fronts of the servers face each other. In addition, the backs of the server racks should also face each other. This orientation creates alternating "hot aisle/cold aisle" rows. Such a layout, if properly organized, greatly reduces energy losses and also prolongs the life of the servers.15 (See Figure 3.)

Hot aisle/cold aisle row layout should not be used with server racks equipped with solid Plexiglas or glass doors. Perforated doors are necessary for hot aisle/cold aisle implementation.

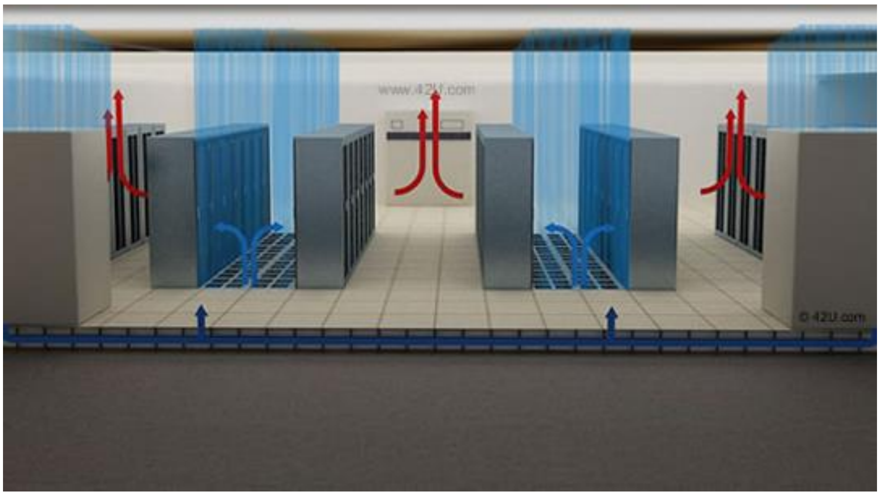


source: https://www.energystar.gov/products/low_carbon_it_campaign/12_ways_save_energy_data_center

Containment refers to the various physical barriers used in addition to a hot aisle/cold aisle arrangement that further eliminate the mixing of cold ("supply") air and hot exhaust air. Containment structures lead to higher allowable temperatures in data centers. Higher temperatures save energy because fan speeds can be lowered, chilled water temperatures can be raised, and free cooling can be utilized more often.

Figure below shows how the mixing is minimized through the use of flexible strip curtains, similar to plastic supermarket refrigeration covers. Rigid enclosures (as shown in

Figure 6) are also a possibility. Note that containment barriers can contain either the hot aisle or the cold aisle.



source: https://www.energystar.gov/products/low_carbon_it_campaign/12_ways_save_energy_data_center

Variable Speed Fan Drives

CRAC (computer room air conditioning) unit fans consume a lot of power and tend to account for 5% to 10% of a data center's total energy use.20 (Typically, only cooling compressors use more energy in a data center.) Most CRAC units are unable to vary their fan speeds with the data center server load, which tends to fluctuate. Because data center environments constantly change, variable-speed fan drives (or VSDs for short) should be used wherever possible. Retrofits of many CRAC and CRAH (computer room air handling) units are available.

Server Inlet Temperature and Humidity Adjustments

For a long time, computer room IT personnel have been limited by the traditional computer room temperature superstition. Reluctant to increase the temperature of the computer room, however, the American Society of Air-Conditioning and Refrigeration Engineers (ASHRAE) has revised the computer room temperature recommendations to 18°C to 27°C (64.4°F to 80.6°F).

In addition to temperature, ASHRAE has also increased the recommended humidity range. Thanks to such revisions, the data center will be able to create more savings in cooling costs, and it will be more in line with the conditions of natural cooling.

As far as the temperature of the computer room is concerned, if it is too conservative to maintain a low temperature in the computer room, the operating cost will remain high, resulting in poor PUE or higher cooling costs; in addition, according to a research data from Intel, the computer room environment temperature increases every time 1°C can bring 4% cooling cost savings.

Use AI to reduce the energy consumption

AI can help reduce the amount of energy they use for cooling, irrespective of location. Take, for example, one of the largest data center operators on the planet – Google. Through machine learning, it managed to reduce the amount of energy it uses for cooling by up to 40 percent. It did this by using historical data that sensors already collected (such as temperature, power and pump speeds) and then used Deepmind AI to train neural networks that made up the AI system.

Every five minutes, the cloud-based AI takes a snapshot of the cooling system from thousands of sensors and feeds it into DeepMind's deep neural networks, which predict how different combinations of potential actions will affect future energy consumption.

The AI system then identifies which actions will minimise energy usage while also satisfying a robust set of safety constraints. Those actions are sent back to the data centre, where they are verified by the local control system before being implemented.

Control costs with natural climate control

Google Inc.'s opening of a €200 million ($273 million) server hall in Hamina, Finland, over the weekend is boosting Scandinavian hopes that other big Internet companies will choose to build data centers in the region, attracted by its cold climate.

Disadvantages:

Being far from the end user creates latency, which diminishes the end user's quality of experience.

Because these areas are far from population centers, they typically don't have great network connectivity or electrical infrastructure.

Lack of proximity to IT team to do the fast repairment.

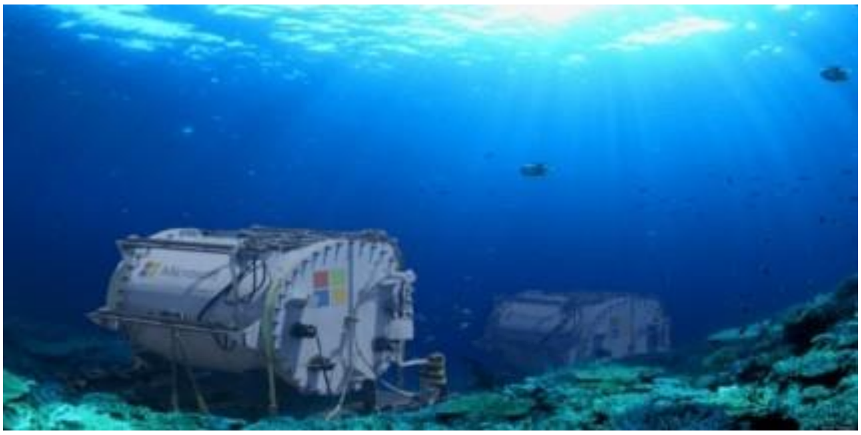
source:https://www.datacenterdynamics.com/en/news/google-invest-670m-to-build-second-facility-hamina-finlan-/

Microsoft drowned one of its data centers at sea. Bringing data centers close to hubs of computing power benefits customers, enabling smoother web surfing or game playing by cutting down the back-and-forth between users and servers. Microsoft says nearly half the world's population lives within 150 km (120 miles) of the ocean. And because oceans are uniformly cool below a certain depth, keeping the machines under the sea would cut down the cooling costs that make up a large chunk of the operating budget of data centers.

Disadvantages:

Difficult to repair.

Closed pressure vessels are expensive.



source: https://blog.cloudware.bg/en/did-microsoft-go-crazy-sinking-their-data-centers-undersea/

Reuse the heat produced from DC

There are two ways this issue is being addressed: first, by looking for ways to reduce the amount of heat that is generated in a data center environment and second, by putting it to use. Here are some of the ways the heat generated by a data center can be and, in some cases are being, utilized.

Excess heat generated from colocation facilities can be diverted to nearby homes and businesses, creating a district heat network. Thus, the waste heat is converted and utilized as a source of energy.

Excess heat can be used to heat nearby swimming pools during the winter. This may seem like a logical solution, yet, it is seldom put to use.

Ducts running out of the heat exhaust systems can be directed into nearby buildings, thus providing them with heat when colder temperatures prevail. The heat supplied can be controlled through the use of pneumatic baffles.

Telecity, a data center in Paris uses waste heat to provide heat to an on-site Climate Change Arboretum, where the effects of future climate change are studied.

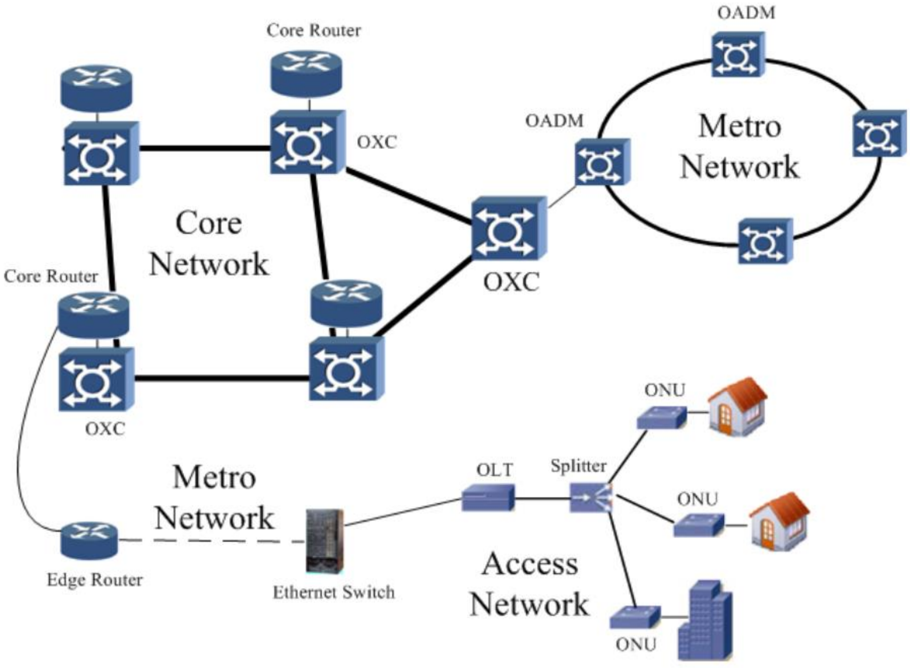
The Notre Dame Center for Research Computing uses the heat to maintain warm temperatures at a local municipal greenhouse.

Recycling the heat generated not only results in energy management and savings, but it also means that the additional investments required for reducing the amount of heat generated can now instead be utilized for the optimization of other avenues in a data center business.

source:https://www.datacenterknowledge.com/sites/datacenterknowledge.com/files/wp-content/uploads/2010/02/Telecity-Paris.jpg

Energy Issues in Core , Metro and Access Networks

An illustration of the distribution of these areas in the network is shown below:



Brief description of subsections

-core network : usually connects large cities and nations. considered as the backbone of the network , has a mesh topology. a nodal distance of >400km.

- metro network : ring topology which aggregates accesss traffic before transmission via the core. intermediate layer between access and traffic. nodal distance approximately between 60 to 200km.

-access network : this is the last mile network whihc links to the users and contains highly dynamic traffic. Spans shorter areas compared to the last two. It is also a major consumer of energy due to the presence of a huge number of active elements

Energy consumption

Energy is consumed in the various areas by the presence of these active elements shown. the following table depicts typical energy consumptions for some of these components:

Network Domain	Component	Capacity	Energy Consumption
Core Network	Core Router (Cisco CRS-1 Multi-shelf System)	92 Tbps	1020 kW [26]
	Optoelectronic Switch (Alcatel-Lucent 1675 Lambda Unite MultiService Switch)	1.2 Tbps	2.5 kW [27]
	Optical Cross-Connect (MRV Optical Cross-Connect)	N/A	228 W [28]
	WDM Transport System (Ciena CoreStream Agility Optical Transport System)	3.2 Tbps	10.8 kW [24]
	WDM transponder (Alcatel-Lucent WaveStar OLS WDM Transponder)	40 Gbps	73 W [29]
	EDFA (Cisco ONS 15501 EDFA)	N/A	8 W [29]
Metro Network	Edge Router (Cisco 12816 Edge Router)	160 Gbps	4.21 kW [30], [31]
	SONET ADM (Ciena CN 3600 Intelligent Optical Multiservice Switch)	95 Gbps	1.2 kW [32]
	OADM (Ciena Select OADM)	N/A	450 W [33]
	Network Gateway (Cisco 10008 Router)	8 Gbps	1.1 kW [31]
	Ethernet Switch (Cisco Catalyst 6513 Switch)	720 Gbps	3.21 kW [26], [31]
Access Network	OLT (NEC CM7700S OLT)	1 Gbps	100 W [34]
	ONU (Wave7 ONT-E1000i ONU)	1 Gbps	5 W [34]

Due to the number of ONUs and OLTs present in the network (considering a passive network), it can be easily seen how the access network consumes the most energy.

Addressing the Energy Consumption Problem

Generally two directions are being taken to address this problem:

1. Use of Renewable energy

   renewable energy is being harnessed to replace traditional hydrocarbon energy. This not only gives the opportunity to reduce the carbon footprint, but also it paves the road towards a sustainable and environment-friendly societal development . This involves the use of solar panels , wind turbines etc to power network components.

2. schemes to reduce the energy consumption of components.

in our work, we would proceed with the latter option as it pertains to the different subsections of the network:

1. **Core Network**

As core networks exhibit multilayer network architectures, energy consumption of the core network should be considered at both of the network layers, i.e., the optical layer and the electronic layer. Considering IP over WDM, energy consumption of its network components can be found in the switching (routing) level and also in the transmission level. In the switching (routing) level, the main energy consumers are Digital Cross-Connects (DXC) and IP routers for switching electric signals at the electronic layer, while Optical Cross-Connects (OXC) are used to switch optical signals in fibers at the optical layer. In the transmission systems, WDM is a technology which multiplexes multiple optical carrier signals on a single optical fiber by using different wavelengths of laser light to carry different signals. this consumes energy . EDFA's are also involved as shown in the diagram below. Typical values for the energy consumption can be seen in the table above.

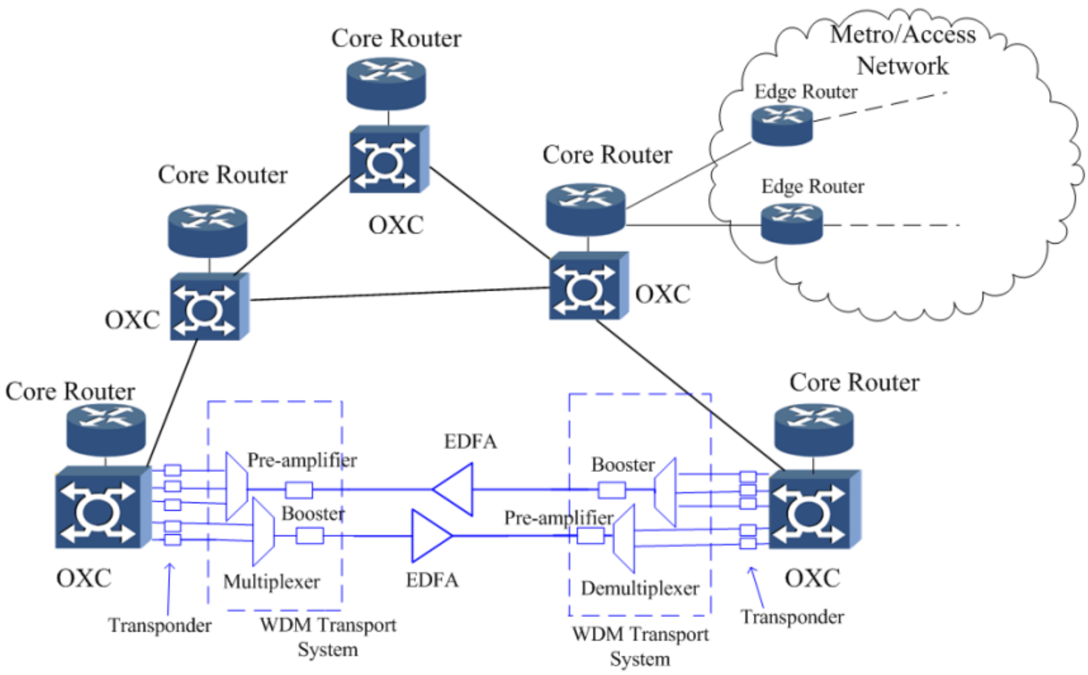


fig : Core network

how to reduce energy consumption in the Core network

Selectively Turning Off Network Elements

This approach involves shutting down links and nodes when they are idle or traffic passing through them is below a certain threshold value. Also a certain percentage of nodes can be shut down during less busy hours of the network (eg in the night).

a pertinent problem is that of maximizing the amount of nodes that can be turned off without affecting the performance of the network. This has been proven to be an NP hard problem and therefore only approximate heuristics are employed.

Energy efficient network Design

lightpath non-bypass and bypass. Under lightpath non-bypass, all the lightpaths incident to a node must be terminated, i.e., all the data carried by the lightpaths is processed and forwarded by IP routers. But the lightpath bypass approach allows IP traffic, whose destination is not

the intermediate node, to directly bypass the intermediate router via a cut-through lightpath. Results show that lightpath bypass can save more energy than non-bypass, deriving the fact that the number of IP routers can be decreased while using the lightpath-bypass scheme in designing an energy-efficient core network. a light path by pass approach endeavours to keep the network as transparent as possible as OEO conversions consume energy.

Energy Aware Routing

In energy aware routing, in the presence of multiple routes, the energy consumed by each route is taken into account and thus the route with the smallest consumption is chosen. This of course can coexist with other typical routing algorithms. the priority depends on the network designers and operators but as we are concerned with energy consumption , we would not go into much detail in that direction.

the following parameters can be considered during routing:

- route length: the longer the length, the more amplifiers needed and the more energy consumed.
- modulation format : the higher the rate, the higher the energy consumed in transmission
- switches involved in the route: the higher the number of fibers connected to the OXC, the higher the energy consumed.

A possible drawback here is we would need a global view of the network alongside real time data processing. Technologies like SDN can help with this.

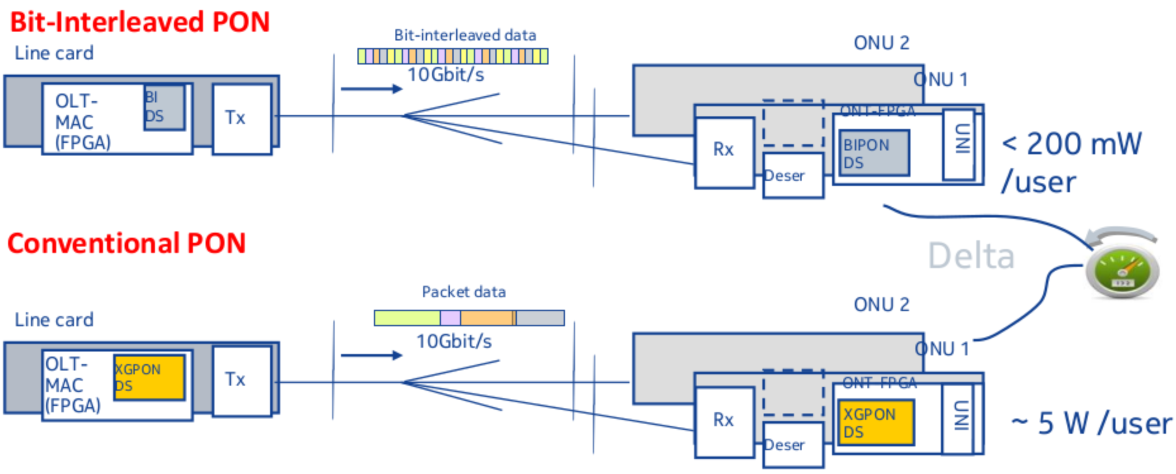
2. **Metro Network**

There is limited research on energy conservation in metro networks mostly because it accounts for a small percentage of the total energy consumption in the network. Three architectures for a unidirectional WDM ring network,can be considered i.e., FG (FirstGeneration) optical network, SH (Single-Hop) network, and MH (Multi-Hop) network. In a FG optical network, every node must electronically process all the incoming and outgoing traffic, including the in-transit traffic. In a SH optical network,

every node electronically processes only the traffic that goes into or out of the network at that node. A MH network lies somewhere between the FG and SH networks. SH has the least energy consumption.

3. **Access Network**

- Adoption of passive optical networking which would eliminate the need for energy draining active components . This is energy efficient and reduces the absolute total energy consumed.
- Bit Interleaved PON



Interleaving the bits imply that at the ONU, the sampling scheme used involves a lower rate . say we have 10gbps downlink rate with bit interleaving, this meaning each ONU receiver would be sampling at the rate of 1gbps which leads to a smaller energy consumption (5W to <200mW) compared to the conventional packet interleaving used today.

- ONT sleep mode scheduling

  The ONT goes into sleep mode after being active for a certain period of time to reduce power consumption and also to avoid the near far effect (where near ONUs with stronger transmissions produce noisy signals when not transmitting thereby crowding the weaker signals from farther ONUs). To put some perspective on energy gain:

  Active ONU power consumption : 10.5W
  ONU sleep mode power consumption : 0.8W