Energy Efficiency in Datacenters
MSc Module: Green ICT

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Lecture Notes on Green ICT
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Introduction

- Green ICT – Telecommunication Networks and Data Center Carbon Footprint
- Architecture of a Data Center
- Energy Efficient Techniques
- Metrics Related to Green Operation of Data Centers
- Monitoring Energy Efficiency
- Demo of International Hellenic University (IHU) Data Center
Green ICT

Green ICT refers to strategies and actions that target energy efficiency in the IT sector. This is directly translated to reduced CO2 emissions by the sector. It incorporates strategies to improve energy efficiency but also it can include strategies by companies using eco products and recycling.

- Energy Efficiency
  - Data Centers
  - Green IT services
  - Telecommunication Networks
- Penetration of Renewable Energy Sources
- Eco-Friendly Products
- Eco-Friendly Packaging
- E-Waste
- Recycling

EU has targeted a 20% reduction of CO2 emissions by 2020. Telecommunication industry is responsible for the 5% of worldwide energy demands and CO2 emissions. Energy efficiency and carbon emissions reduction has become a critical issue in telecommunication industry for the following reasons:

- ICT and 2020 goal
- Increase in telecommunication demands (subscribers, services, data rates)
- Deployment of networks to off grid areas
- Increased cost of electricity
Green ICT

ICT are involved in this initiative in 3 ways

- **Direct**
  - Reduction of ICTs own energy requirements
- **Indirect**
  - Using ICTs for carbon displacement
- **Systematic Way**
  - Using ICT to provide reduction of energy to other sectors of the economy

- Efficient electronic equipments (processors, monitors, OLEDs,...)
- Green Telecommunication Networks
- Optimized Technologies
  - etc...
- Dematerialization
- Teleconference
- Online taxation and billing
  - etc...
- Smart House
- Smartgrid
- Intelligent Transportation Systems
  - etc...

The goal is to reduce the required Watts per User or Watts per bitrate in Telecommunication Networks
Green ICT – Power Consumption

The energy consumption in broadband wired and wireless networks presents a crucial difference.

90% of cellular power consumption is the operator OPEX
10% at user end

30% of broadband power consumption is the operator OPEX
70% is distributed
Green ICT – Towards Energy Efficiency

- Low Power Electronics
- Efficient Battery Technology
- Not ‘Always on’ devices
- Recycling
- Wireless
  - Optimized Transmission and Access Techniques
    - (modulation schemes, coding schemes, etc.)
  - Distributed Antennas
  - Multi-Carrier
  - Adaptive Channel Allocation
- Wired
  - Optical Fibers (FTTH PON, FTTCab)
  - Power Management

- Network Planning and Dimensioning
- Power Management Techniques
- Base Station Technology
  - (equipment and installation types)
- Intelligent Site Solutions
  - (tower mounted radio, etc.)
- Renewable Energy Sources
- Remote Monitoring
- Protocols
- IP Communications

- Efficient Communication for Basic needs
- High Sharing Ratio of Servers
- Efficient Equipment (MSCs, GSNs, SGSNs, MMGs...)
- Optical Fibers
- Protocols
- IP Communications

- Eco Server (Green Data Centers)
- Energy Management
- Optical Fibers
- Digital Compression, IP Communications
- Virtualization

Green ICT – IEEE Guidelines

- Energy-efficient circuit and device
- Energy-efficient transmission switching and routing technologies
- Energy-efficient base station architectures and networking
- Energy-efficiency in wired and wireless access networks
- Energy-efficiency in home and enterprise networking
- Energy efficiency of data centers and intelligent cloud computing
- Protocols and protocol extensions to enable energy efficient networks
- Network-wide cross-layer optimizations to minimize energy consumption
- Network load balance and smart information storage in distributed networks
- Instrumentation for energy consumption measurement
- Remote power management for wireless terminals and access networks
- Hierarchical and distributed techniques for energy management
- Smart Grid
- Information theory on energy efficiency
Green Datacenters Initiatives

- The Green Grid Association
- Department of Energy DOE USA→Datacenter Energy Efficiency Program
- Green IT Promotion Council Japan
- APC
- Cisco
- Intel
- IBM
- hp
- CERN
- GOOGLE
- COST 804 Action Energy Efficiency in Large Scale Distributed Systems

Green ICT – DataCenters

The data center is the most active element of an ICT infrastructure that provides computations and storage resources and supports different applications. The data center infrastructure is central to the ICT architecture, from which all content is sourced or passes through. Worldwide, data centres consume around 40,000,000 MWhr of electricity per year and a big portion of this consumption is wasted due to inefficiencies and non-optimized designs.
The energy consumption of datacenters worldwide is reaching the 0.5-1% of global electricity demands. A large datacenter consumes energy approximately equal to 25000 households! In total datacenter carbon footprint and electricity consumption is larger than the demands of Argentina, Netherlands!

The number of datacenters are continuously increasing. It is expected that with higher data transfer needs will be created with smartgrids. Datacenters will constitute an even higher portion of electricity demands globally!

The strategy towards Energy Efficiency of datacenters does not only yield environmental protection and low carbon economy but also presents crucial advantages as:

- **Reduce** operational expenditure (OPEX) of the companies
- **Increase** the lifetime of IT devices
- **Reduce** the need for equipment maintenance
- **Reduce** carbon emission that will include taxation in the near future

Reasons for Adopting Green Solutions

- Reduce company energy costs
- Extend useful life of hardware
- Reduce IT maintenance activities
- Save money through waste disposal of non-atomic hardware
- Improve corporate image
- Reduce emissions thereby reducing respiratory problems, acid rain, ozone and global climate change
- Reduce energy consumption for fear or not having sufficient energy from local utilities to meet needs
- Free up space on the datacenter floor
- None of the above-not using green computing policies, solutions or systems

Percentage of respondents

(Source: "Survey the green tech landscape", Green-IT Insight, an InfoWorld Research Report conducted by IDC Research Services Group, November 21, 2007, InfoWorld)
Green ICT – DataCenters towards EE

- In typical datacenters, the Ten year Cost of Ownership (TCO) is a factor of two major components. The costs related to purchasing and maintaining equipment of the datacenter and the electricity costs for operating the equipments.

- A 20% of TCO is related to electricity costs!

The figure presents the TCO of cooling and power equipment of a datacenter.

Datacenter Architecture

- Data centers incorporate critical and non critical equipments
  - Critical equipments are related to devices that are responsible for data delivery and are usually named as IT equipments.
  - Non critical equipments are devices responsible for cooling and power delivery and are named as Non Critical Physical Infrastructure or Network Critical Physical Infrastructure (NCPI).

- The overall design of a data center can be classified in 4 categories (Tier I-IV) each one presenting advantages and disadvantages related to power consumption and availability. In most cases availability and safety issues yield to redundant N+1, N+2 or 2N data center designs and this has a serious effect on power consumption.
Datacenter Architecture

| Tier I | 1. Single non-redundant distribution path serving the IT equipment  
| Tier II | 1. Fulfills all Tier 1 requirements  
| Tier III | 1. Fulfills all Tier 1 & Tier 2 requirements  
| Tier IV | 1. Fulfills all Tier 1, Tier 2 and Tier 3 requirements  

- **Heat Rejection**: is usually placed outside the main infrastructure and incorporates chillers, drycoolers and present an N+1 design.
- **Pump Room**: they are used to pump chilled water between drycoolers and CRACs and present an N+1 design (one pump in standby).
- **Switchgear**: it provides direct distribution to mechanical equipment and electrical equipment via the UPS.
- **UPS**: Uninterruptible Power Supply modules provide power supply and are usually designed with multiple redundant configurations for safety.
- **EG**: Emergency Generators supply with the necessary power the data center in case of a breakdown. Usually diesel generators

...
Datacenter Architecture

- **PDU** - Power Distribution Units for power delivery to the IT. Usually dual PDUs (2N) for redundancy and safety.
- **CRAC** - Computer Room Air Conditioners provide cooling and air flow in the IT equipments. Usually air discharge is in upflow or downflow configuration.
- **IT Room** - incorporates computers and servers placed in blades, routers, switches, cabinets or suites in a grid formation. Provides data manipulation and transfer.

![Datacenter Architecture Diagram]

**Power Delivery Infrastructure for a Typical Large Data Center (30K sq ft of raised-floor and above)**

- Several pounds of copper
- Power Distribution Unit (PDU)
- Uninterruptible Power Supply (UPS) modules
- UPS batteries
- Transfer panel switch
- Diesel generators
- Diesel tanks
- Power feed substation
Power Consumption in Datacenters

- The power delivery in a typical data center is presented in the following figure.

- The power is divided in a **in-series** path and a **in-parallel** path. The power enters the data center from the main utility (electric grid, generator), $P_M$ or the Renewable Energy Supply (RES) utility, $P_G$, and feeds the switchgear in series.
- Within the switchgear, transformers scale down the voltage. This voltage flows in the UPS that is also fed by the EG in case of a utility failure.
Power Consumption in Datacenters

- The UPS incorporates batteries for emergency power supply and process the voltage with a double AC-DC-AC conversion to protect from utility failures and smooth transition to the EG system. **AC-DC-AC conversion wastes energy!**

- The output of the UPS feeds the PDU's that are placed within the main data center room. The PDU's break the high voltage from the UPS into many low voltage circuits to supply the electronic equipments.

- Finally, power is consumed for the IT processes namely as storage, networking, CPU and in general data manipulation.

- The parallel path feeds the cooling system that is important for the heat protection of a data center. The cooling system incorporates air-condition fans and/or liquid chillers.

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Power Consumption in Datacenters

- Power is wasted in different stages of datacenter operation. A typical breakdown of datacenter energy overheads is

  - NCPI equipments are responsible for approximately the 70% of energy consumption. 45% are due to cooling infrastructure and 25% for power delivery units.

  - 30% of total energy is delivered to IT equipments for critical operations. (*System refers to motherboards, fans,...*)
Power Consumption in Datacenters

- Power Pattern of a 30% efficient datacenter

Type of Losses in Datacenters

- The losses and the power consumption (energy efficiency too!) of a datacenter are not constant with time but they vary according to:
  
  - **Input load to datacenter**
  
  - **Environmental parameters** (outdoor temperature, humidity, ...)

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According to the input workload the losses of NCPI equipments can be categorized as follows:

- **No load losses**: Losses that are fixed even if the datacenter has no workload. The loss percentage increases with decrease of load. Usually related to NCPI equipment!

- **Proportional losses**: Losses that depend linearly on workload. The loss percentage is constant with load.

- **Square law losses**: Losses that depend on the square of the workload. These losses appear at high workloads (over 90%).

**Type of Losses in Datacenters – ex. UPS**

Proportional Losses\(\rightarrow\)  
\[ P_n = P_{\text{no,Load}} + \left( P_{\text{max}} - P_{\text{no,Load}} \right)/100 \cdot n \]
Type of Losses in Datacenters – Electricity Costs

- Even for no IT load the annual electricity costs of 1MWatt datacenter is about 500,000 US dollars!

Reasons of Losses in Datacenters

- **NCPI Equipments**
  - Power units (UPS, transformers, etc.) usually operate far below their maximum capacity
  - Air conditioning equipment consume extra power to deliver cool air flow at long distances
  - Blockages between air conditioners and equipments that yield inefficient operation
  - No closed coupling cooling
  - No efficient lighting
  - N+1, 2N redundancy
  - No energy management – scheduling of equipments
Reasons of Losses in Datacenters

- **IT Equipments**
  - Inefficient servers (single core instead of multi-core equipments)
  - No energy proportional computing infrastructure
  - Oversized IT equipments according to actual needs ➔ Need for virtualization
  - Old fashioned equipment with power waste in their power supply units (heat waste)

Energy Efficiency in Datacenters

**Lets separate two confusing terms!**

- **Energy efficiency** ➔ Keep the same level or higher level of useful work with less consumed energy. Usually expressed as the ratio (Gbps/Watt)

- **Power Conservation (energy savings)** ➔ Reduce the energy demands without taking into account useful work. In ICT this is not preferred since it usually reduces QoS!

The energy efficiency of a data center is a complicated non constant parameter that depends on the input workload and environmental conditions.
**Energy Efficiency in Datacenters-Benefits**

- Reduce electricity costs and OPEX
- Improve corporate image
- Provide sustainability
- Extend useful life of hardware
- Reduce IT maintenance activities
- Reduce carbon emissions and prevent climate change
- Provide foundations for the penetration of renewable energy sources in IT systems

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**Energy Efficiency in Datacenters-Strategy**

Efficiency at individual parts is an important step for ‘greening’ the data center but optimization is achieved when the efficiency aims to the overall data center design!!
Energy Efficiency Strategies

- The transformation of a datacenter to a ‘Green’ one is a complex task that incorporates high CAPEX. Efficiency can be achieved through:
  - Optimization of the operation of the datacenter (operational costs) → it is referred to the changes on the operation of the datacenter towards a greener operation
  - Optimal planning actions → it is referred to actions that are required to plan a more efficient datacenter

Energy Efficiency Strategies – Operational Costs

- Optimization of operational costs → The operational costs are associated to the optimization of individual equipments like the IT equipments and NCPI.

- IT Equipments → Achieving efficiency at the IT level can be considered as the most important strategy for a green data center since for every Watt saved in computation, two additional Watts are saved- one Watt in power conversion and one Watt for cooling!
  - Retiring. Some data centers have application servers which are operating but have no users. This includes no load losses into the datacenter degrading the performance in terms of energy efficiency. Retirement of these equipments is important! Today, almost 40% of deployed servers have been operating in place for four years or longer (extending the actual lifetime of a server). That represents over 12 million single core–based servers still in use that reduce overall efficiency of the datacenter. Old fashioned servers have also inefficient power supplies (70% efficiency~30% is lost in heat!)
Energy Efficiency Strategies – Operational Costs

➢ IT Equipments (cont.)

✓ Migrating to more energy efficient platforms.
  ➢ Use of blade servers that produce less heat in a smaller area around it. Non-blade systems require bulky, hot and space-inefficient components, and may duplicate these across many computers that may or may not perform at capacity. Blade systems have important benefits in terms
  ➢ Power Supply ➔ The blade enclosure’s power supply provides a single power source for all blades within the enclosure instead of redundant power supply units.
  ➢ Cooling unit ➔ The blade’s shared power and cooling means that it does not generate as much heat as traditional servers. Newer blade-enclosure designs feature high-speed, adjustable fans and control logic that tune the cooling to the system’s requirements, or even liquid cooling systems.
  ➢ Networking of Blades ➔ Provides one or more network buses to which the blade will connect, reducing the cost of connecting the individual devices. This also means that the probability of wiring blockage to air flow of cooling systems in the datacenter is minimized.

➢ More Efficient Server. Make processors consume less energy and use the energy as efficiently as possible (multi core processors and power states in the processors)

✓ Energy Proportional Computing. Many servers operate at a fraction of their maximum processing capacity. Efficiency can be achieved when the server scales down its power use when the workload is below its maximum capacity. A research over 5000 google’s servers shows that the activity profile for most of the time is limited to 20-30% of the servers’ maximum capacity.
Energy Efficiency Strategies – Operational Costs

IT Equipments (cont.)

Energy Proportional Computing. The solution is to introduce p_state operation at the server equipment. The benefit is that at low input load the no-load losses are small where for higher input loads the server operates with high energy efficiency. The more the states used, the more energy efficiency is achieved.

A Simple Example

Let's consider a very simplified scenario. A server can operate at 3 different power states P1=50W, P2=150W and P3=300W according to normalized CPU utilisation R (0<R<1), P1 for 0<R<R1, P2 for R1<R<R2 and P3 R2<R<R3. An old fashioned server has a linear power consumption pattern ~ P_s=100+300R. It was found that 40% of time the server operates with input load smaller to R1=0.3 (30%CPU utilization), 30% of time with input load bigger than R1 and smaller to R2=0.6 (60% CPU utilization) and 30% of time with input load bigger than R2 and smaller to R3=1 (100% CPU utilization).

Assumption

CPU utilization is assumed uniformly distributed between the regions, for the p_state server a stair power consumption model is assumed.

Compute the average power for each server.

Server 1
Pt=0.4*P1+0.3*P2+0.3*P3=155Watts

Server 2
Pt=0.4(100+300(0.3/2)+0.3(100+300(0.3+(0.6-0.3)/2))+0.3(100+300(0.6+(1-0.6)/2)))=230Watts

Savings are approximately 75Watts. For a datacenter with 100 servers the savings are 7.5kWatts.
Energy Efficiency Strategies – Operational Costs

- **NCPI Equipments** → Efficiency of NCPI equipments is another step for the green operation of data center. This is highlighted by the DCiE or PUE metric.
  - **Replacing.** Chillers and UPS that are in use for more than 10 years. New technologies can perform in a more energy efficient way!
  - **Free cooling.** Free cooling is a very important technique to dramatically reduce PUE of the datacenter. Google’s datacenters placed in Alaska report a PUE equal to 1.3!! This is because low outdoor temperature provide free cooling at the datacenter.

- **Liquid Heat Removal.** Liquid heat removal is much more efficient than air!
- **Air conditioners.** Use of airconditioners that can operate at economizer mode! Take advantage of low outdoor temperature!

**Free cooling map by the Green Grid**
Energy Efficiency Strategies – Operational Costs

NCPI Equipments (cont.)

- **Power Delivery.** Use more efficient UPS for low loads of datacenter. Use less conversion stages with more efficient equipment.

![Diagram of energy efficiency strategies](image)

- **Efficiency:** \( \text{Efficiency} = \frac{\text{KWh used}}{\text{KWh supplied}} \)

- **Coefficient of performance:** \( \text{Coefficient of performance} = \frac{\text{KW local removed}}{\text{KW used}} \)

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UPS and PDU

- IT loads vary up to 2X
- Any individual PDU may need to handle more than one-tenth of load
Energy Efficiency Strategies – Planning Actions

- **Planning Actions** The individual equipment optimization is a crucial step for the data center to operate in a green manner but it is inadequate to transform the overall system operation. Planning actions for the efficiency of the overall system are required and can be achieved by introducing new technologies and management techniques.
  - *Reduce cooling needs.* Optimum equipment installation can yield to great savings.
    - Organizing IT equipment into a hot aisle and cold aisle configuration.

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Energy Efficiency Strategies – Planning Actions

- **Planning Actions** cont.
  - *Reduce cooling needs* Cont.
    - Minimize blockage by wiring and secondary equipments that influence airflow and cooling and heat removal.
    - Use raised floor environments.
    - Use equipments with higher thermal tolerance and so reduce the need of cooling
    - Place equipment and air conditioning units using sophisticated fluid dynamics models.
Exploitation of Virtualization. Virtualization and consolidation is a necessary step to overcome underutilization of the IT equipments of the data center. Virtualization enables multiple low-utilization OS images to occupy a single physical server. Virtualization allows applications to be consolidated on a smaller number of servers, through elimination of many low utilization servers dedicated to single applications or operating system versions.

Exploitation of Virtualization Cont. Explore fundamental resource allocation schemes under different objectives:

a) Schemes that abide to resource virtualization and concentrate requests on a subset of available resources
b) Schemes that aim at load balancing by evenly spreading the load across resources.

Energy efficiency is achieved when we concentrate requests on a subset of available resources. The reason is that we minimize the no-load losses!!!

The problem is an association graph where the target is to minimize underutilized equipment.

Assume that each server has a power consumption pattern that comprises a no load loss $c_0$ and a linear increase of power consumption according to each request $r_i$ ($r_i$ is an on/off identifier for each request) with a factor $d$. We assume that the requests are identical by each client. The power consumption of the server is

$$P = c_0 + d \sum_{i=1}^{N} r_i$$

where $N$ is the total number of requests the server serves.
Energy Efficiency Strategies – Planning Actions

Planning Actions – cont.

Rightsizing. Data centers suffer low utilization fractions relative to their maximum capacity. 70% of today’s data centers operate at less than 45% of their maximum capacity limits.

Why oversizing occurs?

- The cost for not providing sufficient space for a data center is enormous and must be eliminated.
- It is a tremendous cost and risk to increase the capacity during datacenter lifecycle.
- It is difficult to predict the final room size so one wants always to be above the threshold for safety reasons.

Power Consumption

\[ P_{tot} = \sum_{j=1}^{2} P_{Sj} = \]
\[ = c_0 + d \sum_{i=1}^{2} r_i + c_0 + d \sum_{i=1}^{2} r_i = \]
\[ = 2c_0 + 4d \]

No. Virtualization

\[ P_{tot} = \sum_{j=1}^{4} P_{Sj} = \]
\[ = c_0 + d \sum_{i=1}^{4} r_i + c_0 + d \sum_{i=1}^{4} r_i +.. = \]
\[ = 4c_0 + 4d \]

~waste is 2c_0
Energy Efficiency Strategies – Planning Actions

- Planning Actions cont.
  - Rightsizing cont.
    - Underutilization means that all the equipments in the datacenter operate at low input workloads and this means that they operate in low energy efficiency regions. The effect of no load losses is more significant. Power is wasted!

- Ways to avoid underutilization
  - Investigation about the estimated workload and future applications of the data center
  - Avoid underutilization of data center assuming that this will increase the reliability
  - Development of sophisticated prediction workload models
  - Adaptable infrastructure. Increase datacenter capacity according to needs

![Graph showing waste due to oversizing](image1.png)

![Graph showing room capacity](image2.png)
Energy Efficiency Strategies – Planning Actions

- **Planning Actions** → cont.
  - **Remote Monitoring.** Remote monitoring provides the necessary information for optimal planning actions. The design includes all IT and NCPI equipment. The outcome is an intelligent monitoring system that can provide real-time critical information by means of sensor networks implementation.

  A set of logical divisions can be extracted and a set of tasks are assigned as shown in the figure. The goal is that crucial information of the real data center will be gathered that will improve the development of efficiency predictions models and will guide to optimal planning actions. Furthermore, better management of the system is possible. “You cannot manage something that you cannot measure!”

- **Network Load Management/Network Topology.** Load balancing and sophisticated routing algorithms can provide important goals in terms of energy efficiency. Some applications are
  - Routing and load balancing algorithm to enhance free cooling. Increase load to datacenters placed at areas with low temperatures. This can be dynamic during a daily basis according to time difference
  - Routing and load balancing algorithm to reduce underutilization. Increase load to underutilized datacenters
  - Routing and load balancing algorithm for low cost electricity. Increase load to datacenters that operate in regions with low electricity prices.

Savings can be of order of Millions $ per year!
Energy Efficiency Strategies – Planning Actions

- Planning Actions – cont.
  - Network Load Management/Network Topology. Network load management techniques are implemented to provide workload balance to specific data centers in a network. The main aim is to reduce the workload of data centers that are underutilized and deliver the workload to other data centers to operate them near their maximum capacity.

The model utilizes the available data derived from the remote monitoring system and the required data for energy efficiency metric computation and performs workload management in the network devices to provide maximum energy efficiency. In addition, a real-time feedback system that informs about environmental conditions and availability/production of renewable energy is coupled to the algorithm.
Energy Efficiency Strategies – Planning Actions

- Planning Actions – cont.
  - Avoid data duplication. Data duplication produces high power consumption in storage devices. The fact that most of the data is duplicated, for safety reasons, reduces the energy efficiency of the system. Storage virtualization is one approach to overcome this phenomenon.

- Renewable Energy Sources. In order to increase the efficiency of a data center one approach is to reduce the needs of input power from the utility, ‘dirty’ power.

This can be achieved by applying alternative energy supply in the data center. RES is a small fraction of the actual required power to operate a datacenter. But it can be profitable for small traffic demands where the requirements are reduced. The effect of the penetration of alternative energy source is also more obvious in the DPPE and CUE metrics that will be investigated in the following sections.
Planning Actions – cont.

Tri-Generator. Tri generator systems (also known as Combined Heat and Power CHP). Tri-Generation is the use of heat engine or a power station to produce electricity and useful heat or cold air simultaneously. The benefits are more obvious if one considers that datacenters are placed in buildings that in many occasions incorporate offices that require heat or cold air flow.

- Standardization. Standardization of energy efficiency metrics can stimulate industries to achieve high energy efficiency values.
The energy efficiency metrics are used to quantify the performance of the datacenter and compare different technologies.

In Telecommunication sector energy efficiency is related to the ratios

\[
\text{Energy Efficiency} \sim \frac{\text{Joule}}{\text{bit}} \sim \frac{\text{Watt}}{\text{Gbps}} \sim \frac{\text{Watt}}{\text{user}} \sim \frac{\text{Watt}}{\text{bitrate / Hz}} \text{ (spectral efficiency)}
\]

→ spectral efficiency is usually used for modulation and coding techniques
→ Joule/bit are used for electronic equipments
Energy Efficiency Metrics - dBε

- An absolute energy efficiency metric is dBε

\[ dBε = 10 \log_{10} \left( \frac{\text{Power} / \text{bitrate}}{kT \ln 2} \right) \]

where \( k \) is the Boltzman’s constant and \( T \) is the absolute temperature (300K). Value \( kT\ln2 \) represents the minimum energy dissipated per bit of information.

- The smaller the dBε value is, the greater the achieved efficiency!

A small scale datacenter requires average power equal to 10kWatt. The effective bit rate is 100Mb/sec. Compute the energy efficiency metric dBε...

\[
\begin{align*}
\text{dBε} &= 10 \log_{10} \left( \frac{10 \times 10^3}{(100 \times 10^6) / (1.38 \times 10^{-23} \times 300 \times \log 2)} \right) \\
&= 165.4
\end{align*}
\]

<table>
<thead>
<tr>
<th>System</th>
<th>Power</th>
<th>Effective bit rate</th>
<th>Energy/bit [J/b]</th>
<th>dBε</th>
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<td>BT Network</td>
<td>10Watt</td>
<td>22Tb/s</td>
<td>4.5x10^4</td>
<td>162</td>
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<tr>
<td>Dell Laptop</td>
<td>20Watt</td>
<td>1.8GHz (clock)</td>
<td>4.2x10^9</td>
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<td>155mWatt</td>
<td>10Mb/s</td>
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<td>1 photon bit</td>
<td>1.23x10^-3 Watt</td>
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<td>0.12x10^-13</td>
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</table>
Energy Efficiency Metrics - PUE

- Power Usage Effectiveness (PUE) is the metric that characterizes the efficiency of the NCPI equipment. PUE is the inverse of Data Center Infrastructure Efficiency (DCiE) metric.

\[
\text{DCiE} = \frac{\text{Power to IT}}{\text{Power to Datacenter}} \times 100
\]

\[
PUE = \frac{1}{\text{DCiE}} = \frac{\text{Power to Datacenter}}{\text{Power to IT}} = \text{CLF} + \text{PLF} + 1
\]

**Cooling Load Factor** normalized to IT Load. Losses associated to power consumed by chillers, air conditioners, pumps,..

**Power Load Factor** normalized to IT Load. Losses associated to power dissipated by switchgear, UPS, PDU

- A study over 24 different datacenters operating in different regions is presented below.

- PUE equal to 1.83 means that 1.83 times more energy is consumed in total by the datacenter than the amount of energy delivered to IT equipments.

The mean value of the measured PUE is 1.83 or 0.53 (53%) DCiE. This means that almost 53% of the power that enters the data center is wasted for cooling and power delivery in the non-critical components. The rest 47% is used for data processing.
Energy Efficiency Metrics - PUE

- PUE and DCiE mainly depends on
  - Input workload → high input workload leads to an efficient datacenter in terms of PUE.
  - Environmental conditions → cool outside temperature means less power waste due to cooling

![Graph showing PUE and DCiE for input workload.

![Graph showing PUE and DCiE over different environmental and workload conditions.]}
CO2 and Costs related to Metrics (simplified computations)

- The carbon emissions due to the operation of datacenters are related to the consumed 'dirty' energy (energy not produced by renewable sources).

- The grid electricity is responsible for CO₂ emissions depending on the used material for energy conversion. In order to provide a measure of carbon emissions, the energy is converted to gr of CO₂. This is subject to each country energy sources. The relationship is \( Q=1\text{KWh} \times X_{\text{grCO}_2} \). For anthracite electricity production \( X=870 \), for gas electricity production \( X=370 \) and for petroleum it is \( X=950 \).

- Therefore, the carbon footprint of a data center is computed according

\[
K_{\text{CO}_2} = 8.74 \times 10^{-6} \cdot P \cdot X \text{[TonsCO}_2 \text{/ year]}
\]

Where \( P \) is the average power needed in Watts and \( X \) in grCO₂/kWh.

CO2 and Costs related to Metrics (simplified computations)

- The annual electricity costs (OPEX) a data center requires is computed as

\[
M_{\text{Euros}} = 8.74 \cdot P \cdot Y \text{[Euros / year]}
\]

where \( Y \) represents the relationship between cost of energy. For the purpose of our investigation it was assumed as \( 1\text{kWh} \sim \$Y \) (usually \( 0.05 < Y < 0.12 \)).
A Simple Problem

A datacenter reports a PUE=2.3. The datacenter requires power to the IT equipment equal to 200kWatt. The operator of the datacenter wants to reduce PUE value to 1.7 by replacing old equipment with new and reorganising the infrastructure to support free cooling. The total expenses required for this action are estimated to 200.000 Euros.

a. Compute the consumed power before and after the transformation
b. Compute the number of years that the operator will have the return by his investment assuming that 1kWh~0.07€
c. Compute the expected reduction of CO2 emissions per year assuming that 1kWh~600 gr/CO2

Answer

a. PUE=P_{in}/P_{IT}\Rightarrow P_{in}=2.3*200=460kW
PUE_{new}=P_{IT}/P_{IN_{new}}\Rightarrow P_{IN_{new}}=1.7*200=340kW.
120kW are saved!
b. In one year the reduced electricity costs are 365*24*120*0.07=73.416€. It is expected that in less than 200.000€/73.416€=2.7 ~ 3 years the operator will start gaining money from his investment.
c. In one year the saved carbon emissions are 365*24*120*600/10^6(Tons/year)=630TonsCO2/year less!

Energy Efficiency Metrics - DCeP

The overall energy efficiency of the datacenter is measured taking into account the useful work. PUE and DCiE describes energy efficiency of NCPI equipment, neglecting useful work.

Data Center Productivity (DCeP) metric considers the useful productivity of the datacenter

\[
DCeP = \frac{Useful\ Work}{Total\ Required\ Energy\ to\ produce\ the\ work}
\]

Term "useful work" describes the number of tasks executed by the data center

When the useful work is described as a rate (transaction per second) then the denominator is a Power value (P_{in}). On the other hand when useful work is an absolute number of tasks then the denominator is an Energy value (E_{DC}) describing the required energy during the assessment window that produced the number of tasks.
Energy Efficiency Metrics - DCeP

General Formulation →

\[ DCEP = \frac{\text{Useful Work}}{P_{IN}} = \frac{\sum_{i=1}^{m} [V_i \cdot U_i(t,T) \cdot T_i]}{E_{DC}} \]

- \( P_{IN} \) or \( E_{DC} \) represents the consumed power or energy respectively for the completion of the tasks.
- \( m \) is the number of tasks initiated during the assessment window,
- \( V_i \) is a normalization factor that allows the tasks to be summed,
- \( U_i \) is a time based utility function for each task,
- \( t \) is the elapsed time from initiation to completion of the task,
- \( T \) is the absolute time of completion of the task (assessment window),
- \( T_i \neq 1 \) when task is completed during the assessment window or 0 otherwise.

The assessment window must be defined in such a way to allow the capture of data center’s variation over time (not too big not too small). The DCeP factor gives an estimate of the performance of the data center and is not as accurate as DCIE or PUE due to its relativity!!

Energy Efficiency Metrics – Generic Formulation

General Formulation →

\[ \text{Efficiency} = \frac{\text{Computation}}{\text{Total Energy}(P_{IN})} = \left( \frac{1}{\text{PUE}} \right) \times \left( \frac{1}{\text{SPUE}} \right) \times \left( \frac{\text{Computation}}{P_{IT}} \right) \]

- PUE captures inefficiencies due to power delivery and cooling of the datacenter
- SPUE captures inefficiencies due to power delivery and cooling of the server. These can be server’s power supply, voltage regulator modules and cooling fans. SPUE is defined as the ratio of the total server input power over the useful server power, i.e. the power consumed by motherboards, CPU, DRAM, I/O cards, etc. The combination of PUE and SPUE measures the total losses associated to non critical components that exist in the data center’s NCPI and IT equipments.
- Computation is the useful work
- \( P_{IT} \) is the power delivered to IT equipments
Energy Efficiency Metrics - Proxies

The described metrics constitute a generic basis to quantify the performance of a datacenter. A more detailed description is given by The Green Grid Association where different proxies have been established to quantify the different relative types of performance is a datacenter.

The main criteria to establish a proxy are

- **Ease of use**: the proxy should be easy to compute
- **Accuracy**: the proxy should provide results that describes accurately the measured performance
- **Responsiveness**: The proxy should react immediately to changes
- **Cost**: low cost measurement platforms to evaluate. Take advantage of already existing measurements considered in a typical datacenter
- **Time**: the proxy should be implemented in a time period less than a week
- **Completeness**: the proxy should account for every device in the datacenter
- **Objectivity**: the proxy should require minimum personal judgement. It should be objective
- **Utility**: the proxy should provide enough information to make better decisions on a datacenter
- **Operational Ability**: the proxy should not interrupt the daily operation of a datacenter

Proxy #1#2: Useful work and Productivity Link

Proxy #1 is similar to the DCEP factor described above but the utility function U(t,T) is set to 1 and normalisation factor Vi should be defined by the engineer for each task.

\[
Pr_{proxy}(DCEP) = \frac{\sum_{i=1}^{n} [N_i W_i]}{E_{DC}}, Pr_{proxy}(ProdLink) = \frac{\left( \frac{N_{DC}}{N_{subset}} \right) \sum_{i=1}^{n} W_i}{E_{DC}}, \text{units} - \text{tasks} / \text{kWh}
\]

- \(n\) is the number of instrumented applications running during an assessment window (\(T_a\))
- \(N_n\) is a normalisation factor for each software application
- \(N_{DC}\) is the number of servers in datacenter
- \(N_{subset}\) is the number of servers in subset
- \(W_i\) is the number of units of usefull work during \(T_a\). It can be a number reported by an API regarding the number of emails from a email server, the number of ‘http gets’, etc
- \(E_{DC}\) is the total energy consumed by the datacenter during \(T_a\), \(E_{DC}=P_n * \Delta T_a\)
Energy Efficiency Metrics - Proxies

Use of Proxy→ This proxy is used as a baseline to measure the performance of a datacenter. Any changes on the operation of the datacenter will change proxy’s value and will enable a clear observation on the positive effects (or negative) of that change.

Proxy#3 → DCeP Subset
is used to provide a higher resolution analysis of the performance on a subset of servers in datacenter

\[
Pr_{\text{Proxy#3(DCePSubset)}} = \frac{\left( \frac{N_{DC}}{N_{\text{subset}}} \right) W_{\text{subset}}}{E_{DC}} \text{, units – tasks / kWh}
\]

\(W_{\text{subset}}\) is the number of useful work reported by an instrumented software running on a server subset

Use of Proxy→ Rapid and clear view on actions such as virtualization or processor scaling on a subset of the datacenter.
Energy Efficiency Metrics - Proxies

**Proxy#4** → Bits per kWh

is used to describe efficiency of telecommunication equipments. It is targeted to outbound routers of the datacenter

\[
\text{Proxy}_{4(kWh)} = \frac{\sum_{i=1}^{k} b_i}{E_{DC}}, \quad \text{Mbits / kWh}
\]

\(k\) is the number of outbound routers of the datacenter
\(b_i\) is the total number of bits coming out of the \(i^{th}\) router during the assessment window

**Use of Proxy** can measure the underutilization of routers or redundant components in the system. Consider a stream of bits forwarded by a small router which would require less energy than the same stream of bits forwarded by a pair of large redundant routers. The small router would have a higher “bits per kilowatt-hour” metric, implying a more energy efficient system for forwarding the bit stream. Proxy(bkWh) can identify and remove idle servers without affecting outbound bit stream, provide server consolidation and identify methods to increase bit rates without increasing the power consumption.

---

Energy Efficiency Metrics - Proxies

**Proxy#5#6** → Weighted CPU Utilization SPECint_rate and SPECpower

These proxies are a more generic approach to describe useful work at server level. They are related to CPU utilization of servers in the datacenter or a subset. They do not distinguish between the type of work or application.

\[
\text{Proxy}_{5(int\_rate),6(power)} = \frac{T \cdot \sum_{i=1}^{N} \left[ U_i < \frac{B_i}{S_i} \right] \left( \frac{CC_i - CB_i}{CB_i} \right) }{E_{DC}}, \quad \text{units} = < \frac{\text{jobs / kWh}}{\text{ssj ops / kWh}} >
\]

\(N\) is the number of servers
\(U_i\) is the average CPU utilization over \(T\) of server \(i\)
\(B_i\) is the rate benchmark Specint_rate 2000 or Specinrate 2006.
\(S_i\) is the SPECpower ssj_ops/sec at 100% server utilization of server \(i\)
\(CC_i\) is the nominal clock speed of the CPU of server \(i\)
\(CB_i\) is the clock speed of the CPU, used to establish \(B_i\) (the rate benchmark result of server \(i\))
\(T\) is the assessment window
Use of Proxy

These metrics model data centers productivity and the correlation of the actual useful work to the maximum possible work if all servers were running at 100% utilization.

**SPECint_rate** benchmarks (SPECint) is a computer benchmark specification for CPU's integer processing power

**SPECpower_ssj2008** is the first industry-standard SPEC benchmark that evaluates the power and performance characteristics of volume server class and multi-node class computers. The drive to create the power and performance benchmark comes from the recognition that the IT industry, computer manufacturers, and governments are increasingly concerned with the energy use of servers.

Use of Proxy

Keep a running inventory of all IT assets that are used in the datacenter. Any upgrade can be compared to the curves (CUPS/kWh) and make a clear observation on the impact on the performance of the datacenter.

Proxy#7 → Compute Units per Second Trend Curve

Is used to weight server performance based on the year the server was purchased. As a baseline the performance of a server purchased in 2002 has been set equal to 1 MCUPS (Million Compute Units per Second).

\[
Pr_{proxy_{CUPS}} = \frac{T \cdot \sum_{i=1}^{n} \left(\frac{i - 2002}{5}\right) \cdot N_i \cdot U_i}{E_{DC}}, \quad \text{units} = \text{MComputeUnits/kWh}
\]

- \(i\) is the year of purchased of the server
- \(U_i\) is the average server utilization over \(T\) of servers in the datacenter purchased at year \(i\)
- \(N_i\) is the number of servers in datacenter that were purchased in year \(i\)
- \(m\) is the year of purchased of the oldest server in the datacenter
- \(n\) is the of purchased of the newest server in the datacenter
- \(T\) is the assessment window

Use of Proxy

Keep a running inventory of all IT assets that are used in the datacenter. Any upgrade can be compared to the curves (CUPS/kWh) and make a clear observation on the impact on the performance of the datacenter.
**Energy Efficiency Metrics - Proxies**

**Proxy#8 → Operating System Workload Efficiency**

Is used to provide a measure of the efficiency that a datacenter provides a IT resource, namely the OS. It does not distinguish between useful work (number of web pages visited, # of emails, transactions performed, # http gets, etc...). It is a point in time measurement.

\[
Pr_{\text{OSW}} = \frac{\text{Count}_{\text{OS}}}{P_{\text{DC}}} \quad \text{units} = \frac{\text{OS instance}}{kW}
\]

\(\text{Count}_{\text{OS}}\) is the number of OS instance count at specific time of measurement

\(P_{\text{DC}}\) is the required power at the time of measurement

**Use of Proxy** → For capacity planning of the datacenter. E.g. If the measured value is 0.5 OS/kW and the facility is adding 400 OS instances per year, the increasingly power requirement is 200kW per year. If the facility can only support 100kW then there must be resizing of the datacenter

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**Energy Efficiency Metrics**

**CUE Carbon Usage Effectiveness**

With the penetration of renewable energy sources in the datacenters, a big or small portion of the consumed energy is produced by ‘clean’ sources (zero carbon). For that reason, the CUE metric is used to model the effect of power needs and carbon emissions of the datacenter

\[
\text{CUE} = \frac{\text{Total CO}_2 \text{ emissions}}{\text{ITEnergy}} = \frac{\text{CEF} \cdot \text{PUE} \cdot \text{E}_{\text{in}}} {\text{unitEnergy} \cdot \text{E}_{\text{IT}}}
\]

CEF_ is the carbon emission factor and depends on the source of electricity production (for Greece is around 0.750Kg/kWh)

\(\text{E}_{\text{in}}\) is the total ‘dirty’ energy consumed by the datacenter

\(\text{E}_{\text{IT}}\) is the energy delivered to the IT equipments
**Energy Efficiency Metrics**

**DPPE (Data Center Performance per Energy)**

The metric follows the general rules presented above and introduces one more factor for the green energy supply by the renewable sources.

\[
DPPE = \frac{\text{Datacenter Work}}{\text{Carbon Energy}} = ITEU \times ITEE \times \frac{1}{PUE} \times \frac{1}{1 - GEC}
\]

where

\[
ITEU = \frac{\text{Total Measured Energy of IT}[KWh]}{\text{Total Specification Energy IT (bymanufacturer)[KWh]}}
\]

\[
ITEE = \frac{a \cdot \sum \text{server capacity} + b \cdot \sum \text{storage capacity} + c \cdot \sum \text{NW capacity}}{\text{Total Specification Energy IT (bymanufacturer)[KWh]}}
\]

\[
GEC = \frac{\text{GreenEnergy}}{\text{DC total Power Consumption}}
\]

**ITEU** represents the IT equipment utilization, **ITEE** represents the IT equipment energy efficiency, **PUE** represents the efficiency of the physical infrastructure and **GEC** represents the penetration of renewable (green) energy into the system.
### Energy Efficiency Metrics

**DPPE (Data Center Performance per Energy)**

ITEU is the average utilization factor of all IT equipment included in the data center and can be considered as the degree of energy saving by virtual techniques and operational techniques that utilize the available IT equipment capacity without waste.

ITEE is based on DCeP and it aims to promote energy saving by encouraging the installation of equipment with high processing capacity per unit electric power. Parameters a, b, c are weighted coefficients.

PUE is the efficiency of the physical infrastructure of the data center.

GEC is the available ‘green’ energy that the data center is supplied additionally to the grid electricity.

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### Monitoring Energy Efficiency

- The measurement architecture of the energy efficiency metrics incorporates sensors and application that can be already built in the main datacenter equipment or it might be required to develop new sensor network architectures.

- The main elements of a measuring system for the energy efficiency metrics in a datacenter are:
  - **Device Layer**: the type of devices that must be monitored. This layer is responsible for measuring the critical parameters, important for the computation of the energy efficiency metrics.
  - **Communication layer**: the type of communication needed to deliver the measured data from the device layer.
  - **Application Layer**: the required software and middleware for the data aggregation and manipulation to compute the metrics.
Monitoring Energy Efficiency

The measurement architecture incorporates sensors for measuring critical parameters.
Monitoring Energy Efficiency

- **Total Datacenter Energy Consumption (Large Scale Measurement)**

  RF 434MHz clamp sensors that monitor energy consumption from 1 phase or 3 phase electricity installations and deliver data to a central agent pc through a 434MHz communication link

- **Energy Consumption in small scale (servers, routers, etc...)**

  2.4GHz mesh network of plug sensors that measure energy consumption from plugged devices and deliver data to a central agent pc

Monitoring Energy Efficiency

- **Power Measurements from intelligent PDUs**

  Monitor energy consumption through intelligent PDUs over a web interface or command line interface (CLI)

- **Environmental parameters in Datacenters (temperature, humidity)**

  2.4GHz mesh network of environmental sensors that measure temperature and humidity and deliver data to a central agent pc
Monitoring Energy Efficiency

- Other parameters from IP enabled devices

Modern air-conditioning units and UPS systems, servers and routers can be monitored through an IP connection. This enable SNMP requests from the central agent in order to collect all important parameters for the computation of energy efficiency metrics.
Case Study - Datacenter of I.H.U

- The datacenter consists of devices such as the UPS, switches, router, servers and environmental monitoring devices.

- Normally in a datacenter there are one or two data gathering monitor devices. These devices could vary from a specialized device to a simple PC which are running a program that requests data from various devices and acts accordingly. The data could be stored in the file system of the device or in a database for future reference.

- In order to gather data from all these devices typically the SNMP protocol is used.
Simple Network Management Protocol (SNMP) is an "Internet-standard protocol for managing devices on IP networks.

Devices that typically support SNMP include routers, switches, servers, workstations, printers, modem racks, and more.

It is used mostly in network management systems to monitor network-attached devices for conditions that warrant administrative attention. SNMP is a component of the Internet Protocol Suite as defined by the Internet Engineering Task Force (IETF).

It consists of a set of standards for network management, including an application layer protocol, a database schema, and a set of data objects.
Case Study - Datacenter of I.H.U

An SNMP command consists of 10 fields as follow:

<table>
<thead>
<tr>
<th>IP header</th>
<th>UDP header</th>
<th>Version</th>
<th>Community</th>
<th>PDU-type</th>
<th>Request-ID</th>
<th>Error-Status</th>
<th>Error-Index</th>
<th>Variable bindings</th>
</tr>
</thead>
</table>

The community is either “private” or “public” i.e., properties visible to the guests or not, custom communities are also available in some devices for better granularity and security reasons.

The PDU-Types are as follow:

GetRequest
A manager-to-agent request to retrieve the value of a variable or list of variables. Desired variables are specified in variable bindings (values are not used). Retrieval of the specified variable values is to be done as an atomic operation by the agent. A Response with current values is returned.

SetRequest
A manager-to-agent request to change the value of a variable or list of variables. Variable bindings are specified in the body of the request. Changes to all specified variables are to be made as an atomic operation by the agent. A Response with (current) new values for the variables is returned.

GetNextRequest
A manager-to-agent request to discover available variables and their values. Returns a Response with variable binding for the lexicographically next variable in the MIB. The entire MIB of an agent can be walked by iterative application of GetNextRequest starting at OID 0. Rows of a table can be read by specifying column OIDs in the variable bindings of the request.

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GetBulkRequest
Optimized version of GetNextRequest. A manager-to-agent request for multiple iterations of GetNextRequest. Returns a Response with multiple variable bindings walked from the variable binding or bindings in the request. PDU specific non-repeaters and max-repetitions fields are used to control response behavior. GetBulkRequest was introduced in SNMPv2.

Response
Returns variable bindings and acknowledgement from agent to manager for GetRequest, SetRequest, GetNextRequest, GetBulkRequest and InformRequest. Error reporting is provided by error-status and error-index fields. Although it was used as a response to both gets and sets, this PDU was called GetResponse in SNMPv1.

Trap
Asynchronous notification from agent to manager. Includes current sysUpTime value, an OID identifying the type of trap and optional variable bindings. Destination addressing for traps is determined in an application specific manner typically through trap configuration variables in the MIB. The format of the trap message was changed in SNMPv2 and the PDU was renamed SNMPv2-Trap.

InformRequest
Acknowledged asynchronous notification from manager to manager. This PDU uses the same format as the SNMPv2 version of Trap. Manager-to-manager notifications were already possible in SNMPv1 (using a Trap), but as SNMP commonly runs over UDP where delivery is not assured and dropped packets are not reported, delivery of a Trap was not guaranteed. InformRequest fixes this by sending back an acknowledgement on receipt. Receiver replies with Response parroting all information in the InformRequest. This PDU was introduced in SNMPv2.

The variable bindings are the data exchanged between the monitor and the target machine.

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How to specify an object

- The object are specified using a tree form based on the Management information base (MIB)

- MIBs describe the structure of the management data of a device subsystem; they use a hierarchical namespace containing object identifiers (OID). Each OID identifies a variable that can be read or set via SNMP. MIBs use the notation defined by ASN.1.

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Coding SNMP command

```
$res = snmpget($snmp_host, $snmp_community, $snmp_object);
```

- Target host ($snmp_host)
- Using community ($snmp_community)
- Target object from the MIB ($snmp_object)
- Returns the response for that object ($res)
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Getting System Description via SNMP

function updateSysDescr(&$output,$hostID,$snmp_host)
{
    $snmp_community = "public";  // community
    $snmp_object = ".1.3.6.1.2.1.1.1.0";  // variable binding
    $snmp_set_valueretrieve(SNMP_VALUE_PLAIN); // type of return values
    // Do the request
    $res = snmpGet($snmp_host, $snmp_community, $snmp_object);
    // Check for results
    if ($res!="")
    {
        // Gather the output
        $output .=  "System Description = ".$res."<br />
        return $res;
    }
    else
    return "";
}

Typical call for the above function is as follow:
$res=updateSysDescr($output,"11".,"192.168.1.1");

Getting System Data via SNMP

function getData($hostID,$snmp_host,$label,$oid)
{
    $snmp_community = "public";  // Community
    $snmp_object = $oid;  // Variable OID
    $snmp_set_valueretrieve(SNMP_VALUE_PLAIN); // Format of the return value
    // Do the request
    $res = snmpGet($snmp_host, $snmp_community, $snmp_object);
    // Gather the data
    $output .=  $label.".$hostID.".$oid." = ".$res."<br />
    return $output;
}

Typical call for the above function is as follow:
$res=getData($hostID,$snmp_host," 1min",".1.3.6.1.4.1.2021.10.1.3.1");
$res=getData($hostID,$snmp_host," 5min",".1.3.6.1.4.1.2021.10.1.3.2");
$res=getData($hostID,$snmp_host,"15min",".1.3.6.1.4.1.2021.10.1.3.3");

Showing also the hierarchy of the MIBs as all the commands refer to the same object but different
variables of it the 1 minute measurement, the 5 minutes measurement average and the 15 minutes
average.
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Getting System Data in a loop

Another typical use of the OIDs is being build in a loop as they are based on same root object and referring to similar data.

```java
// set the index i
for($i=1;$i<25;$i++)
{
    // Check if leading zero is necessary
    if($i<10)
    {
        $name="0".$i;
    }
    else
    {
        $name=$i;
    }
    // Execute the SNMP request of the input bytes
    $resIn=getData($hostID,$snmp_host,"in oct GigabitEthernet0/".$i,
        ",1.3.6.1.2.1.2.2.1.10.101".$name);
    // Execute the SNMP request of the output bytes
    $resOut=getData($hostID,$snmp_host,"out oct GigabitEthernet0/".$i,
        ",1.3.6.1.2.1.2.1.16.101".$name);
}
```

In this case the input and output packets of 25 interfaces of a switch.

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Grouping SNMPs together

Common SNMPs for the same target systems means that we can generate some basic functions in the form of

```latex
function switchCisco(&$output,$ip) // Network Switch
function routerCisco(&$output,$ip) // Network router
function UPSMachine(&$output,$ip) // UPS
function windowsMachine(&$output,$ip) // Windows OS
function linuxMachine(&$output,$ip) // Linux OS
```

which are then in turn calls the getData with the SNMPs corresponding to the specific type of the target system. The gathered data are stored using basic INSERT SQL statement to a database in a unique fashion.
Running everything together

- The data gathering device runs in parallel in a threaded fashion instances that requester targeting each of monitored devices and file the responses accordingly.

- For security reasons normally the data gathering device is well specified to the monitored device so other devices or people cannot get data that might be used to illegally access or modify the operation of the monitored device.

References