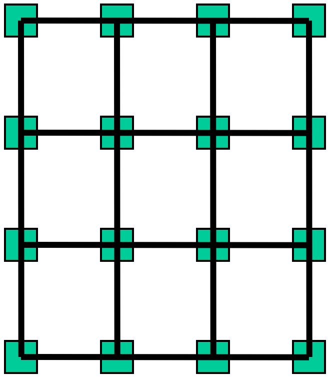
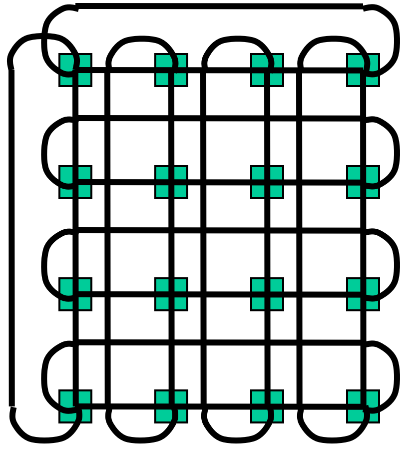
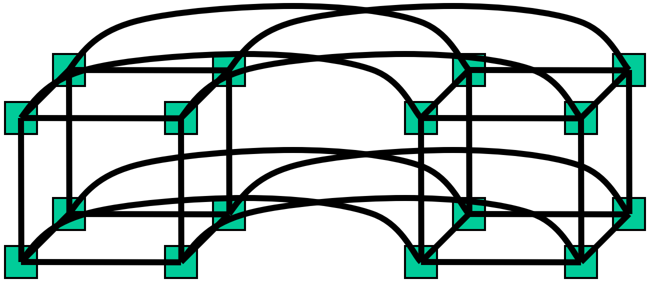
Lecture 24: WSC, Datacenters

- Topics: network-on-chip wrap-up, warehouse-scale computing and datacenters (Sections 6.1-6.7)

Topology Examples


Grid


Torus


Hypercube

Criteria 64 nodes	Bus	Ring	2Dtorus	6-cube	Fully connected
Performance Bisection bandwidth	1	2	16	32	1024
Cost Ports/switch Total links	 1	 3 128	 5 192	 7 256	 64 2080

k-ary d-Cube

- Consider a k-ary d-cube: a d-dimension array with k elements in each dimension, there are links between elements that differ in one dimension by 1 (mod k)

- Number of nodes $N = k^d$

(with no wraparound)

Number of switches :	N	Avg. routing distance:	$d(k-1)/2$
Switch degree :	$2d + 1$	Diameter :	$d(k-1)$
Number of links :	Nd	Bisection bandwidth :	$2wk^{d-1}$
Pins per node :	2wd	Switch complexity :	$(2d + 1)^2$

Should we minimize or maximize dimension?

Warehouse-Scale Computer (WSC)

- 100K+ servers in one WSC
- ~$150M overall cost
- Requests from millions of users (Google, Facebook, etc.)
- Cloud Computing: a model where users can rent compute and storage within a WSC, there's an associated service-level agreement (SLA)
- Datacenter: a collection of WSCs in a single building, possibly belonging to different clients and using different hardware/architecture

Workloads

- Typically, software developed in-house – MapReduce, BigTable, etc.
- MapReduce: embarrassingly parallel operations performed on very large datasets, e.g., organize data into clusters, aggregate a count over several documents
- Hadoop is an open-source implementation of the MapReduce framework; makes it easy for users to write MapReduce programs without worrying about low-level task/data management

MapReduce

- Application-writer provides Map and Reduce functions that operate on key-value pairs
- Each map function operates on a collection of records; a record is (say) a webpage or a facebook user profile
- The records are in the file system and scattered across several servers; thousands of map functions are spawned to work on all records in parallel
- The Reduce function aggregates and sorts the results produced by the Mappers, also performed in parallel

Word Count Histogram Example

MR Framework Duties

- Replicate data for fault tolerance
- Detect failed threads and re-start threads
- Handle variability in thread response times
- Use of MR within Google has been growing every year:
  Aug'04 → Sep'09
  - Number of MR jobs has increased 100x+
  - Data being processed has increased 100x+
  - Number of servers per job has increased 3x

WSC Hierarchy

- A rack can hold 48 1U servers (1U is 1.75 inches high and is the maximum height for a server unit)
- A rack switch is used for communication within and out of a rack; an array switch connects an array of racks
- Latency grows if data is fetched from remote DRAM or disk (300us vs. 0.1us for DRAM and 12ms vs. 10ms for disk)
- Bandwidth within a rack is much higher than between arrays; hence, software must be aware of data placement and locality

Power Delivery and Efficiency

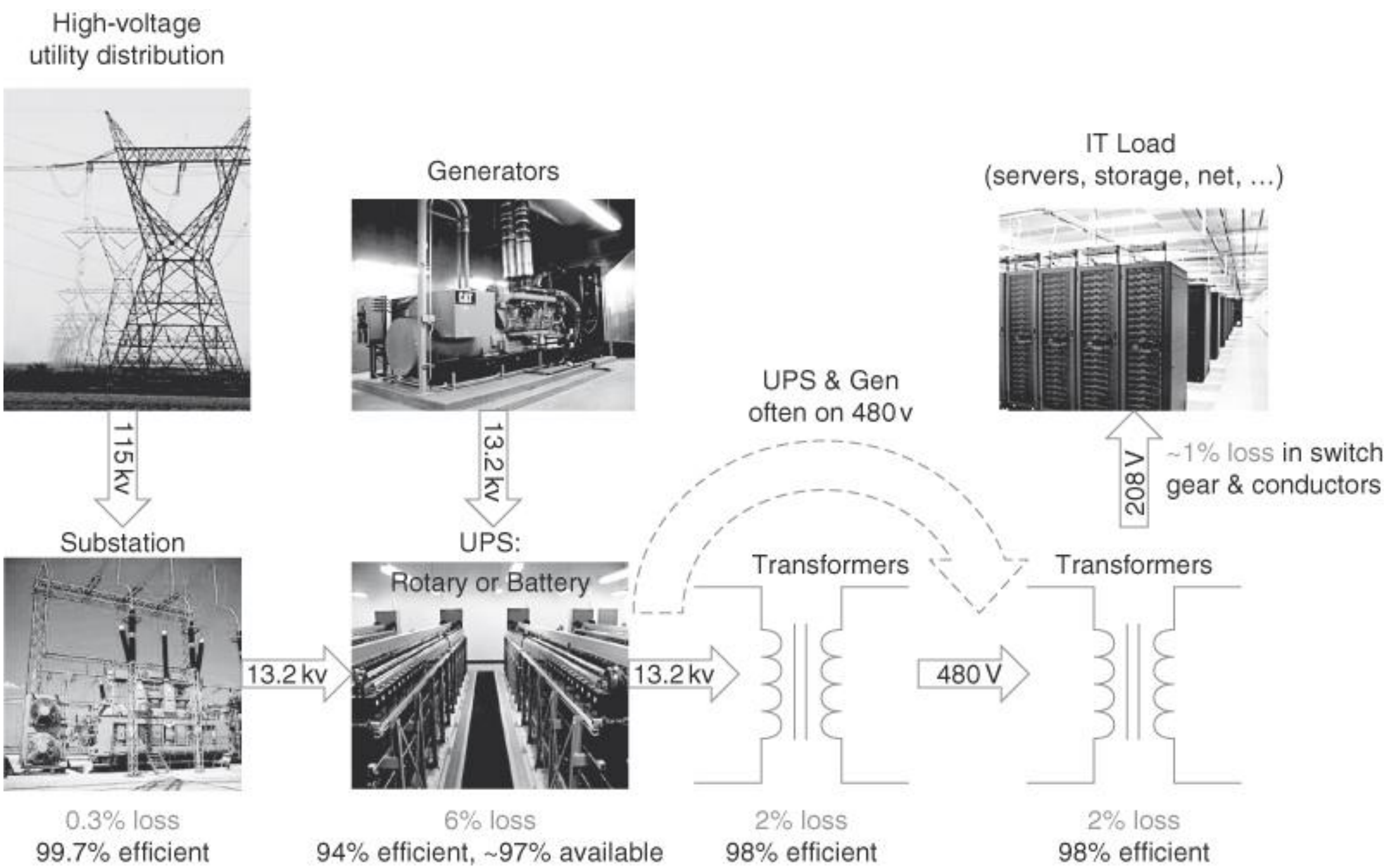


Figure 6.9 Power distribution and where losses occur. Note that the best improvement is 11%. (From Hamilton [2010].)

Source: H&P Textbook

PUE Metric and Power Breakdown

- PUE = Total facility power / IT equipment power (power utilization effectiveness)
- It is greater than 1; ranges from 1.33 to 3.03, median of 1.69
- The cooling power is roughly half the power used by servers
- Within a server (circa 2007), the power distribution is as follows: Processors (33%), DRAM memory (30%), Disks (10%), Networking (5%), Miscellaneous (22%)

CapEx and OpEx

- Capital expenditure: infrastructure costs for the building, power delivery, cooling, and servers

- Operational expenditure: the monthly bill for energy, failures, personnel, etc.

- CapEx can be amortized into a monthly estimate by assuming that the facilities will last 10 years, server parts will last 3 years, and networking parts will last 4

CapEx/OpEx Case Study

- 8 MW facility : facility cost: $88M, server/networking cost: $79M

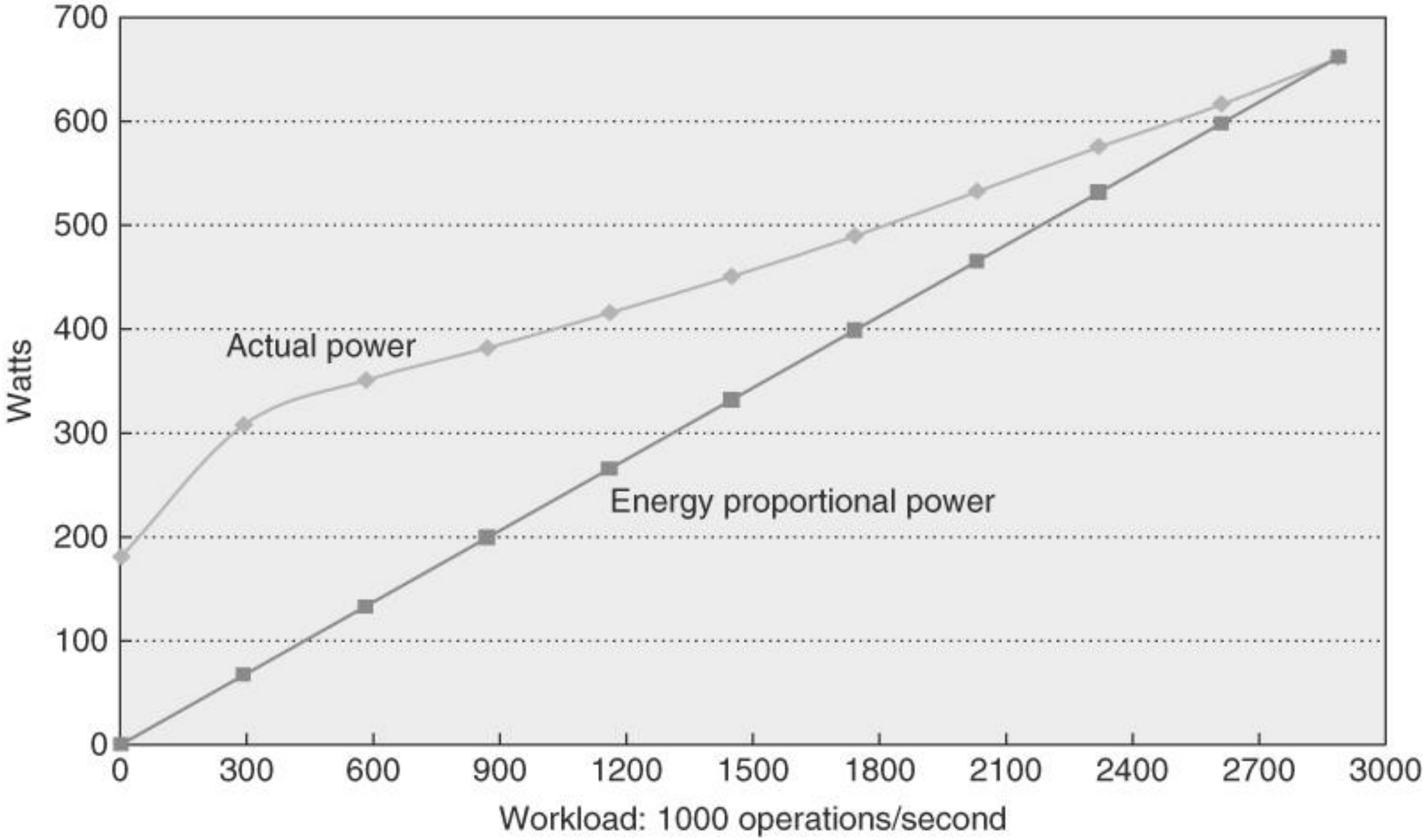
- Monthly expense: $3.8M. Breakdown:
  - Servers 53% (amortized CapEx)
  - Networking 8% (amortized CapEx)
  - Power/cooling infrastructure 20% (amortized CapEx)
  - Other infrastructure 4% (amortized CapEx)

  - Monthly power bill 13% (true OpEx)
  - Monthly personnel salaries 2% (true OpEx)

Improving Energy Efficiency

- An unloaded server dissipates a large amount of power
- Ideally, we want energy-proportional computing, but in reality, servers are not energy-proportional
- Can approach energy-proportionality by turning on a few servers that are heavily utilized
- See figures on next two slides for power/utilization profile of a server and a utilization profile of servers in a WSC

Power/Utilization Profile



Source: H&P textbook.

Server Utilization Profile

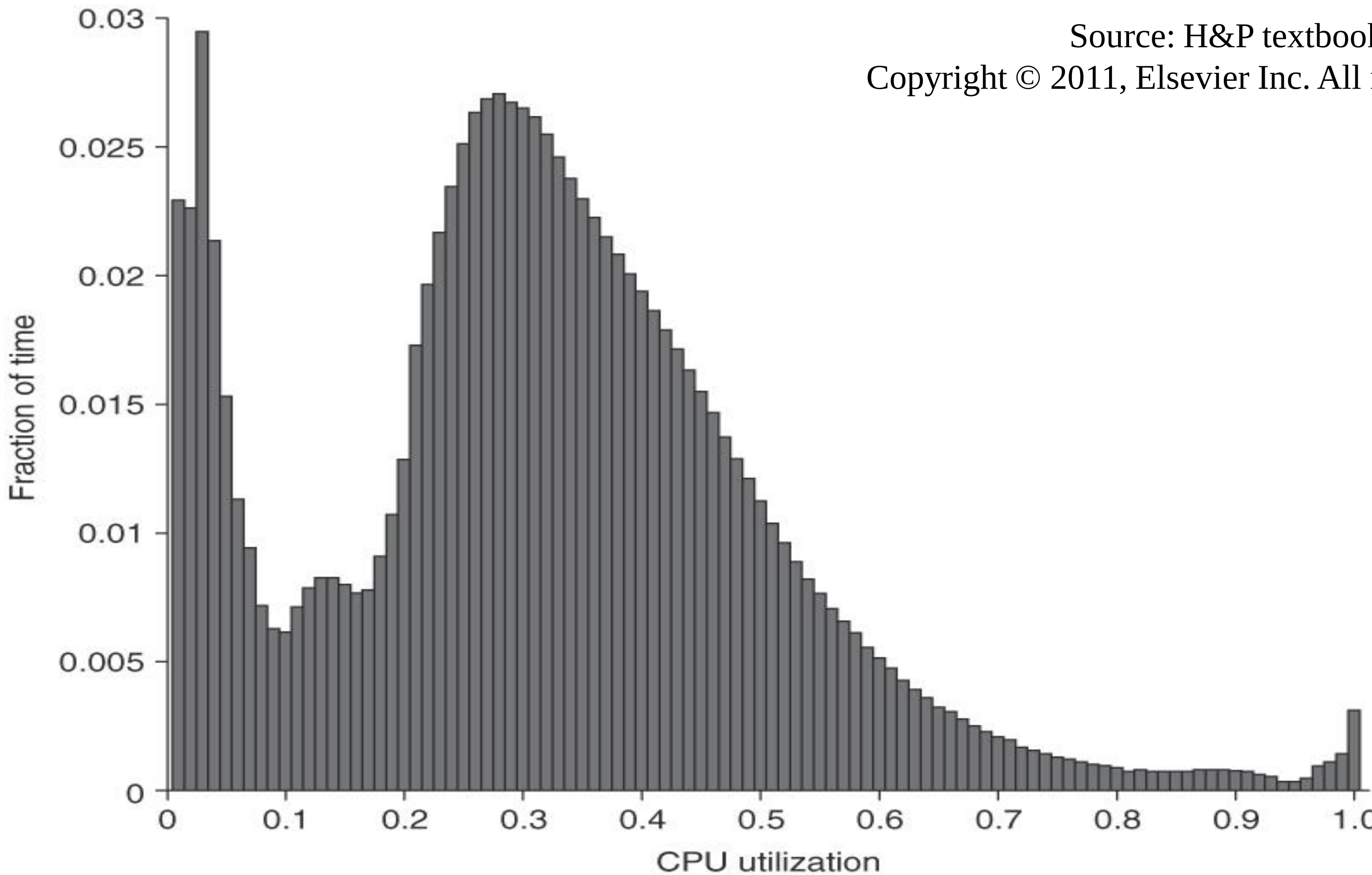


Figure 6.3 Average CPU utilization of more than 5000 servers during a 6-month period at Google. Servers are rarely completely idle or fully utilized, in-stead operating most of the time at between 10% and 50% of their maximum utilization. (From Figure 1 in Barroso and Hölzle [2007].) The column the third from the right in Figure 6.4 calculates percentages plus or minus 5% to come up with the weightings; thus, 1.2% for the 90% row means that 1.2% of servers were between 85% and 95% utilized.

Other Metrics

- Performance does matter, especially latency

- An analysis of the Bing search engine shows that if a 200ms delay is introduced in the response, the next click by the user is delayed by 500ms; so a poor response time amplifies the user's non-productivity

- Reliability (MTTF) and Availability (MTTF/MTTF+MTTR) are very important, given the large scale

- A server with MTTF of 25 years (amazing!) : 50K servers would lead to 5 server failures a day; Similarly, annual disk failure rate is 2-10% ➔ 1 disk failure every hour

Important Problems

- Reducing power in power-down states
- Maximizing utilization
- Reducing cost with virtualization
- Reducing data movement
- Building a low-power low-cost processor
- Building a low-power low-cost hi-bw memory
- Low-power low-cost on-demand reliability

Title

- Bullet