Sustainable Information Technology Ecosystem
supply and demand side management

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Drivers of Next Generation of IT Services
Up and coming Small and Medium Enterprises

IT Advantage in the Emerging Economies
- Enabling Business Transformation

Retail Example:
Subhiksha Trading Services

"IT will be the key enabler and the key differentiator between operations that are or aren’t well run. Whether it is managing the front end or logistics support or in stock and inventory management".

- R. Subramaniam, MD and Founder of Subhiksha Trading Services
- The Economic Times, March 13, 2007

Subhiksha Store
Vadodara, Gujarat, India
Drivers of Next Generation of IT Services

Micro businesses in emerging economies

IT services as a means for micro-businesses to improve quality of life if provided at a given price point

Sustainable IT Ecosystem

Deconstruct conventional supply chain and replace with Sustainable IT ecosystem
The Road Ahead

Next Generation IT Services

- IT and telecommunications is a means to overcome physical infrastructure issues such as transportation, increase productivity and improve the standard of living.
- Necessitates a total cost of ownership (TCO) that enables growth in new areas e.g. 800 million in India who want to use IT as a means to improve quality of life and business competitiveness.
  - Achieving the TCO necessitates management of available energy in the IT ecosystem as a key resource.

Devising a Sustainable IT Ecosystem

- Evolve an "end to end" metric and process to address sustainability in IT
- Design, manufacture, operate and manage end of life of products that minimize consumption of available energy – a "cradle to cradle" perspective
Exergy or Available Energy

- “Exergy” is a measure of the quality of energy
  - Or, alternatively, the amount of work available from a given amount of energy (‘available energy’)

- From the 2nd Law of Thermodynamics:
  - Irreversibilities in real processes continuously degrade the quality of energy, simultaneously destroying exergy
  - For example, the conversion of coal to electricity
    - Or electricity to heat
    - Or rejection of heat to ambient

Approach

- Can a measure of the total exergy destroyed across a product’s lifetime (‘lifetime exergy’) be a measure of the environmental sustainability?
Operation
Powering the electronics and thermal Management

Exergy consumed:
- Electronics and electro-mechanical systems
- Work required to remove heat
  - Flow Work
    - volume flow, $m^3/s$
    - pressure drop, $Pa$
  - Thermodynamic Work
    - Temperature, °C

Technology Trends
chip packaging, integrated photonics, semiconductor technology

Source: Chandrakant Patel projections, non industry data
Thermal Management Challenge
stacked devices: chip and package scale

Heat Sink
Passive e.g. body of the handheld

High power density microprocessor with stacked devices

Chip, Package and System Scale
Work required to remove the heat

Demise of Passive Only Cooling Solution

- Work Required at the chip interface level due to high power density and advent of new packaging

Air (25°-40 °C)
Data Center Cooling

Conventional approach in controlling temperature in the data center

- Single point temperature measurement at the return of the CRAC (Computer Room Air Conditioning Unit), typically set at 20 °C

$$T_{\text{in}} \sim 14 \, ^\circ \text{C}$$

$$T_{\text{return at 20}} \, ^\circ \text{C}$$
IT Ecosystem
Billions of Users and 1000s of Data Centers

Coefficient of Performance of the Ensemble

Total Heat Dissipation
(Flow Work + Thermodynamic Work) of Cooling system

Impact

Flow Work + Thermodynamic Work

Heat Generated Energy to Remove Heat

Services

- 10 to 100 W
- 2-40 W

2 MW

48 GW Assume: 4 billion handhelds at 12 W

200 Million Metric Tons of coal

Annualized Destruction of Available Resources – Coal

Assume: 5000 data centers

20 GW

48 GW

20 GW

Assume: 85 Million Metric Tons

Total

175 Million Metric Tons CO₂ emission

Data Center Total Cost of Ownership

Cost\(_{\text{total}}\) = \left( \frac{S}{f^2} \right) \left( A_{\text{critical}} \cdot f^2 \right) + (1 + K_1 + L_1 + K_2 L_1) U_{\text{grid}} P_{\text{consumed}} + R \left( M_{\text{cool}} S_{\text{eng}} + IT_{\text{adj}} + \sigma \right)

Real Estate

Burdened power consumption

Personnel, equipment, SW per rack

J₁: capacity utilization factor, i.e. ratio of maximum design (rated) power consumption to the actual data center power consumption

K₁ = F(J₁): burdened power delivery factor, i.e. ratio of amortization and maintenance costs of the power delivery systems to the cost of grid power

K₂ = F(J₁): burdened cooling cost factor, i.e. ratio of amortization and maintenance costs of the cooling equipment to the cost of grid power

L₁: cooling load factor, i.e. ratio of power consumed by cooling equipment to the power consumed by compute, storage and networking hardware (inverse of COP\(_{\text{ensemble}}\))

Factors that impact the "Burdened Power Cost"

- Lack of vital information from single-input single-output environmental control
- Increased sensitivity
- Energy Consumption

Patel and Shah, Cost Model for Planning, Development and Operation of a Data Center

Depreciation factors

↓ J₁

↓ L₁
Balance of **Power and Cooling**

Dynamic Provisioning of Power and Cooling

Dynamic allocation of *compute and cooling resources* to minimize energy consumption while meeting user needs.

![Diagram](image)

**Global Workload Placement**

- Phoenix, AZ, 45 °C
- New Delhi, 20 °C
- Data Center

![Diagram](image)

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**Smart IT**

IT-Facility End to End Management

- *compute, power, cooling resources provisioned based on the need*
- *commodity flexible building blocks that enable dynamic change in configuration*

**Policy based Control Engines, Tools**

**Sensing Infrastructure**

**Flexible & Configurable Elements**

**T** in at 25 °C, 27 °C ?

What is the operational limit?

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Data Center Scale
“Smart” Data Center

20 ºC Ext Ambient

45 ºC Ext Ambient

Workload Placement

Power measurement and monitoring

• CRAC temperature control sensors moved from return to supply side;
• Variable Frequency Drives added to AC units;
• Temperature sensors added to rack inlets;
• Advanced algorithms control operation of AC units.

Dynamic Smart Cooling Architecture
HP Labs Smart Data Center
Palo Alto, California

HD Area:
140 KW from 14 fully loaded racks in 400 square feet

CRAC 1
94 KW

CRAC 2
92 KW

CRAC 3
80kW

CRAC 4
39 KW

CRAC 5
37 KW

CRAC 6
28 KW

CRAC 2

CRAC 1

CRAC 3

CRAC 4

CRAC 5

CRAC 6

HD Area

RIT
RIT
RIT
RIT
RIT

High Performance Cluster – low load in this state

Conventional Mode

Dynamic Smart Cooling Mode

• 35% Energy Savings
• Improved reliability
Local Disturbances – Vent Tile Blockage

Scenario: IT department performed maintenance on a rack and covered nearby vent tiles for 4 hours with bag. DSC responds and keeps impacted racks below maximum.

Global Disturbance – Chiller Failure

Scenario: Groundskeeper blows leaves into primary cooling tower during routine cleanup. Leaves block filter in cooling tower retarding condenser water flow that ultimately results in chiller failure. DSC delayed the impact of the failure allowing for repair.
**HP R&D Lab-Data Center**
Dynamic Smart Cooling Implementation in Bangalore

### Facility Building Blocks
- **Chillers**
  - 3 air-cooled
  - 2 water-cooled
- **Pumps**
  - 7 Primary
  - 5 Secondary
- **CRAC units**
  - 55 units
- **Diesel Generators**

### IT Building Blocks
- **Servers**
  - Non-Stop servers
  - Proliant servers
  - Blade servers
  - Custom Enclosures
- **Storage** (XP/EVA)
- **Multiple Network topologies**
- **Sensor Network**
  - 7500 sensors

### Supply Side and Demand Side Management

#### Supply Side (Availability of Resources)
- Devise a 2nd law based tool that enables a “cradle to cradle” approach in quantifying and designing the IT ecosystem
- Can it be used to:
  - Dematerialize the ecosystem i.e. least materials design
  - Seek out appropriate materials
  - Seek out appropriate distributed energy sources
  - Seek out analytical techniques to address operations and “end of life”
  - Leverage the rich instrumentation used for demand side management to detect and understand anomalies

#### Demand Side (Consumption of Resources):
- Library of **flexible** and **scalable** building blocks overlaid with **pervasive sensing** and **control** to provision resources based on the need
Dematerializing the Ecosystem
Data Center Management: modeling, measurement and inference

Reduce redundancy, manage "end of life":
- Minimize redundancy in the data center facility infrastructure
  - Example: empirical data and inference techniques to eliminate excessive redundancy e.g. standby air conditioners
- Hardware "Damage Boundary" [1] and minimizing hardware redundancy
  - IT-Facility measurement and inference techniques in place, can we push the limits of operation
  - Example: Understanding the impact inlet temperature \( T_{\text{in}} \) to life of components by having thermo-mechanical models in place
  - Understanding thermo-mechanical behavior to determine root cause of failure and manage "end of life"
- Drive reliability studies have been presented before at USENIX using large samples, SMASH data – opportunity to extend the work [2][3]

*Used for fragility assessment – can this be extended to other areas to determine operational limits


Rigid Drive Mechanism (Thermal)

\[
T_{\text{drive core}}, ^\circ C = T_{\text{in}}, ^\circ C - \frac{Q_{\text{drive spindle}}}{T_{\text{in}}} - \frac{T_{\text{drive core}}}{10K}
\]
Thermo-Volume Resistance

Expedient Thermo-Fluids Modeling of Systems

Can we represent sub-systems as “thermo-volumes” with thermo-mechanical attributes?

“Thermo-Volume” [Ref] Resistance

System Blower (s)

Extract the temperature at a given location e.g. chip, hard drive temperature

- Patel and Belady, ECTC1997
- Bash and Patel, ISPS1999
- Patel and Bash, Thermal Management Course Notes, 2007

\[
\frac{\partial P}{\partial x} = \frac{1}{2} \frac{f_1}{d_{duct}} \rho v^2_{duct} + \frac{1}{2} \frac{f_1}{d_{duct}} \rho v^2_{duct}
\]

Epoxy Glass Printed Circuit Board

\[T_{chip}\]

Rigid Drive Mechanism (Mechanical)

Susceptibility to vibration:

- over the years, stiffness to mass ratio has gone up due to miniaturization
- however, in-situ disturbances in data centers can coincide with natural frequency of the arm
Dematerializing the Ecosystem
Lifetime Exergy Advisor - Case Study of Sample PC

Extraction Data

Ref: HP Labs – UC Berkeley data

Joules: Currency of the Flat World

ecosystem: billions of handhelds and printers, thousands of data centers and print factories

Cradle to Cradle Design: Least Material, Appropriate materials based on the 2nd Law of Thermodynamics

Least Energy through need based provisioning of resources

Sustainable IT Ecosystem

Opportunity for collaboration CS-ME-EE
Thank You

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