Can Integrated Photonics Technology Transform Data-Centers?

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Workshop on Optical Interconnects in Data Centers
July 27-28, 2015
ICT is the fastest growing sector in energy consumption

- Data centers are 2-3% of U.S. electricity demand
- Growing at 2x/7 years
- “Mega” data centers represent a small fraction of total energy consumed.
- Data centers are 10% of Federal Government electricity usage.
- Some metrics:
  - 1 Google query ≈ 1kJ
  - $E_{refrigerator} \approx E_{TV} \approx 1\text{kWh/day} \approx E_{iPhone}?!$

Smart phone energy usage dominated by data center and access network energy consumption.
Data Centers are Stunningly Inefficient

- So what are the challenges/opportunities to improving energy efficiency?

- What is the magnitude of remaining “low-hanging fruit?” (Note: these are not of interest to ARPA-E.)

- Can we identify the high-hanging fruit and what would be the impact of reaching it?
Opportunities for Enhanced Energy efficiency in Data Centers
Opportunities for Enhanced Energy efficiency in Data Centers

1. Grid Connection
2. Power Delivery/Cloud Demand
3. Response

Cooling

Electrical Inversion/Conversion

Data

Bat

DC to DC

Bat

Bat

Data
Opportunities for Enhanced Energy Efficiency in Data Centers

2. Electrical Power Conversion and Delivery to Servers

- Grid
- AC
- DC
- Electrical Inversion/Conversion
- Bat
- DC to DC
- Cooling

Data Center

- Data
- heat
- CHANGING WHAT’S POSSIBLE
3. Cooling

Opportunities for Enhanced Energy Efficiency in Data Centers
4. Over-provisioning and Redundancy

Opportunities for Enhanced Energy Efficiency in Data Centers
Opportunities for Enhanced Energy Efficiency in Data Centers

5. Servers, Chips, Memory

Grid

Cooling

Electrical Inversion/Conversion

AC

DC

DC to DC

Bat

Data
Opportunities for Enhanced Energy Efficiency in Data Centers

6. **Communications:**
   - Chip Level;
   - Memory Interconnect;
   - Board/Rack Level Interconnect;
   - Network

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Grid

AC to DC

Electrical Inversion/Conversion

Data

Cooling

Bat

DC to DC

Data
Integrated Photonic Data-Com for Data Centers

- Potential Opportunities/Challenges:
  - Reduce data-com energy by 10x?
  - Enable more efficient architectures and better thermal management?
  - Coordinate with Integrated Photonics Manufacturing Initiative.

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Potential Opportunities/Challenges:

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Coming Soon: Optical Interconnects

This approach to signal transfer is moving from longer-distance applications, such as linking separate computers, to joining chips within a computer.

Today
Optical connections between individual computers are commercially available.

2-5 Years
Optical communications will enter the computer, connecting one circuit board to another.

5-10 Years
Chip-to-chip communications will enter the market.

15+ Years
Experts disagree on whether optical interconnects will ever connect the subsystems within a chip.
Integrated Photonic Interconnects:

• Why haven’t OI become mainstream yet?
  ➢ Lack of application pull?
  ➢ Lack of maturity in the technology?
  ➢ Lack of standards?
  ➢ Lack of proper fabrication facilities?
  ➢ Cost?
  ➢ Need HPC and DCs to converge?
  ➢ All of the above?

• Need to transition from “finger-fab.” to “foundry fab.”

Coordinating with the Integrated Photonics Institute for Manufacturing Innovation (IP-IMI) can address these concerns.
Some more questions:

- Are there common performance metrics for all data centers?
- At what scale do OI have impact?
- Do we need HPC and DCs to “converge” – and what does this mean?
- How important is it to minimize E-O-E conversions?
- How will the trends in “cloud computing” drive the challenges and technical solutions?
- Are there other photonic things to consider besides interconnects? (e.g., mixed format data, optical memory, even, …. optical computing?)
- What other questions should be asked?
What are the appropriate metrics?

Hint: One of them is NOT Power Utilization Efficiency

Possible Metrics:
- \( E/b \)?
- Latency? Number of hops?
- Transactions/s/J?

What are the appropriate targets?
What’s the appropriate “White-Space” chart for Data Center performance?

NOTIONAL

- **Present**
- **Future**

- Line of constant load
- Limit due to metal trace technology

**Transactions/kJ**

**M-Transactions/sec**
The Heilmeier Questions

For this workshop:

1. What are the critical challenges?
2. How is it solved today?
3. What is the new technical idea; why can we succeed now?
4. What will be the impact if successful?  (Who cares?)
5. How will the program be organized?
6. How will intermediate results be generated?
7. How will you measure progress?
8. What will it cost and how long will it take?
Workshop Goals

- Outline key energy efficiency challenges in data centers;
- Outline key energy efficiency challenges in data communications in data centers;
- Outline possible technology pathways to transform data-comm in data centers;
- Outline possible program metrics/targets;
- Coordinate program plan with IP-IMI.
Agenda: Monday, July 27

9:30 –11:30am Sidebars
11:00 am–12:00 pm Registration
12:00 –1:30pm Lunch and opening remarks – Eric Rohlfing and Mike Haney

Data center energy challenges

1:00 – 1:45pm Yuval Bachar, Facebook, “Facebook's next generation Mega (and Micro) data centers optical technology”
1:45 - 2:30 pm Vladimir Stojanovic, UC Berkeley, "Si-Photonic interconnects in data-centers of the future: Energy-efficiency, bandwidth density, latency"
2:30– 3:00 pm Greg Fish, Aurrion, “WDM in Data Center Interconnects"
3:00 - 3:15 pm Break
3:15 – 3:25 pm Introduction to Breakout Session # 1 – Mike Haney
3:25 - 5:00 pm Breakout Session 1: Define and prioritize challenges
5:00 – 5:30 pm Present results of breakout sessions
5:30 – 7:30 pm Networking Reception
**Agenda: Tuesday, July 28**

**Enabling approaches and technologies from optics and photonics**

8:15 – 8:45 am  *Dev Shenoy*, Dept. of Energy, “Integrated Photonics Institute for Manufacturing Innovation (IP-IMI)”

8:45 – 9:30 am  *John Shalf*, Lawrence Berkeley National Laboratory, “Exascale Computing Architecture: Adjusting to the new normal for technology scaling”

9:30 – 10:00 am  *Keren Bergman*, Columbia University, "Energy consumption and performance design space trade-offs for optical data center networks"

10:00 – 10:30 am  *Peter de Dobbelnaere*, Luxtera, "Optimizing opto-electronic integration for reduced interconnect power dissipation"

10:30 – 10:45 am  Break

10:45 – 11:00 am  Introduction to Breakout Session #2 - *Mike Haney*

11:00 – 12:30 pm  Breakout session 2a: Define challenges for DATACOM in data centers

12:30 – 1:30 pm  Working Lunch (Read out from session 2a)

1:30 – 3:30 pm  Breakout session 2b: Define paths and metrics

4:00 – 5:30 pm  Breakout session reports and open discussion

5:30 – 6:30 pm  Sidebars
Breakout discussion 1:
List and define opportunities to data center energy efficiency

- What are the technological challenges to providing a transformative improvement in data center energy efficiency?
- How will the trends in “cloud computing” drive the challenges and technical solutions?
- What are the key metrics and are there common performance metrics for all data centers?
- Do we need HPC and DCs to “converge” – and what does this mean?
- What other questions should be asked?
Breakout discussion 2a and 2b:

Opportunities for integrated photonic networks in data centers

- At what scale do integrated OI have impact?
- Will OI open up new architectural opportunities?
- How important is it to minimize E-O-E conversions?
- What photonic technologies/integration platforms should be considered?
- Are there other photonic things to consider besides interconnects? (e.g., mixed format data, optical memory, even, .... optical computing?)
- What are the appropriate metrics and targets?
- Can you define the white space(s) we should target?
- What other questions should be asked?