Project Title: Advanced Refrigerant-based Cooling Technologies for the Information and Communications infrastructure (ARCTIC)

Lead organization: Alcatel-Lucent

- Services Business Division (BD), NSIT IPTV Test Lab, Bell Labs CTO, Bell Labs

PI: Todd Salamon, PhD

Partners:

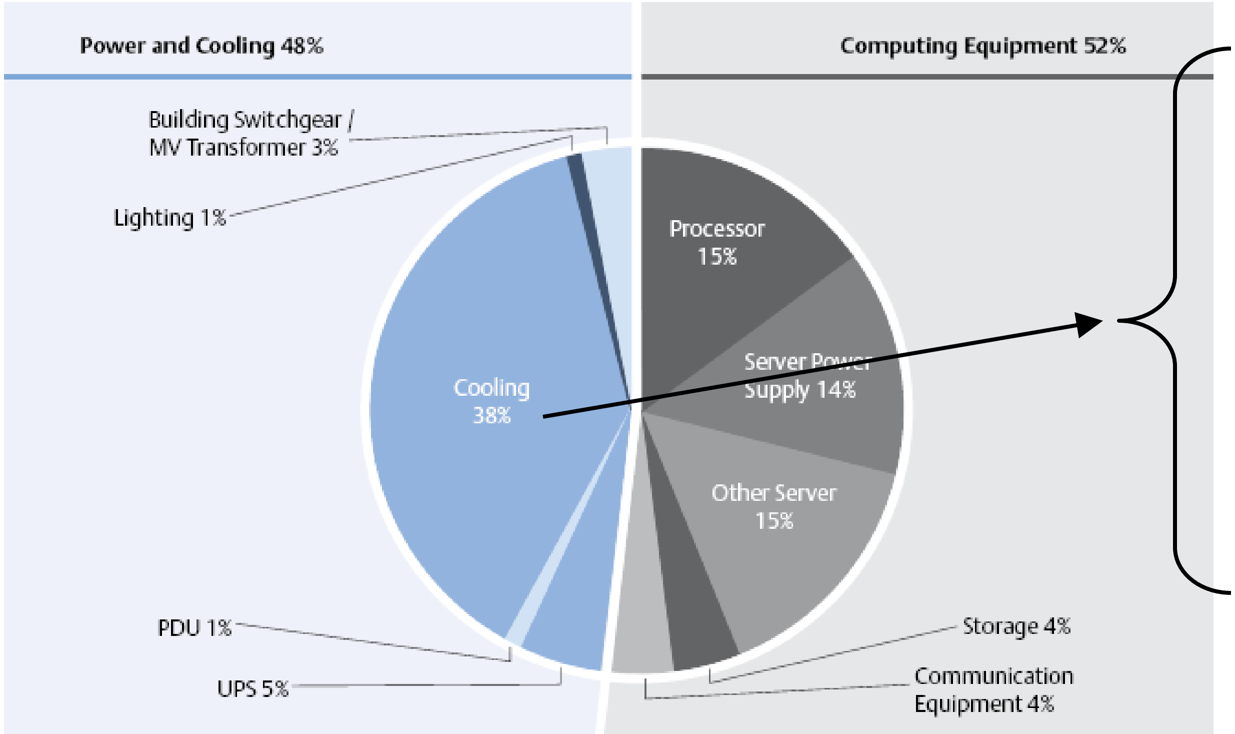
- Modine – subcontractor and cost share provider
- USHose – subcontractor and cost share provider

Start date: April 1, 2010

Completion date: March 31, 2012

Project type: R&D

The Problem ARCTIC is addressing: Power for cooling is a substantial fraction of total power usage in a data center or central office



[1] Cooling load assuming chilled water based cooling system. Based on a 5,000 ft^2 model data center. Source: Emerson Network Power, November 2007.

- Cooling is 30% to 50% of total power budget[2]
- Cooling power budget
  - CRAC units: 25% to 50%
  - Server fans: 10% to 15%
  - Physical plant: 40% to 60%

[2] Schmidt and Iyengar, "Thermo-dynamics of information technology data centers", *IBM J. Res. & Dev.* (2009)

Project Goal: develop and dramatically accelerate the commercialization of a game-changing, refrigerant-based, liquid-cooling technology and achieve a revolutionary increase in energy efficiency and carbon footprint reduction for our nation's Information and Communications Technology (ICT) infrastructure.

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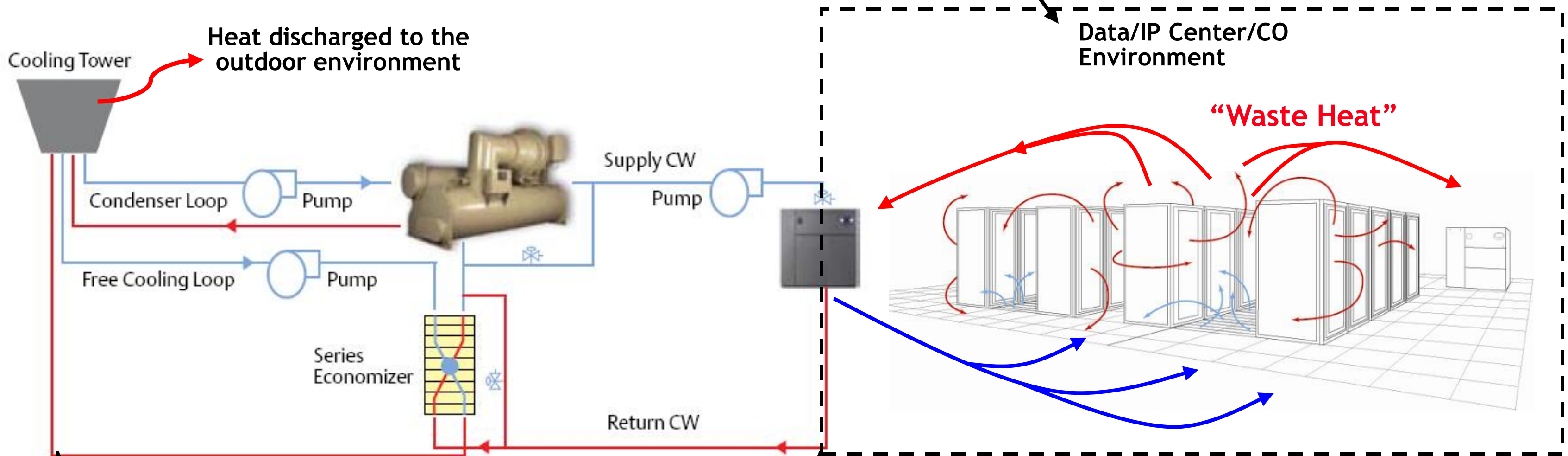
Project Background

focus of ARCTIC project – improve cooling in the primary heat transfer path



Transport of "waste heat" in a secondary cooling loop to the external environment
(4 distinct cooling loops shown optimize system for varying outdoor ambient conditions)

Transport of "waste heat" in the primary heat transfer path.

ARCTIC is addressing cooling needs within the Data Center/Central Office

- Air-based cooling technologies are energy inefficient and limited in ability to cool high equipment heat densities
- We believe Alcatel-Lucent's refrigerant-based cooling technology can meet this market need, both for retrofits and green field installations

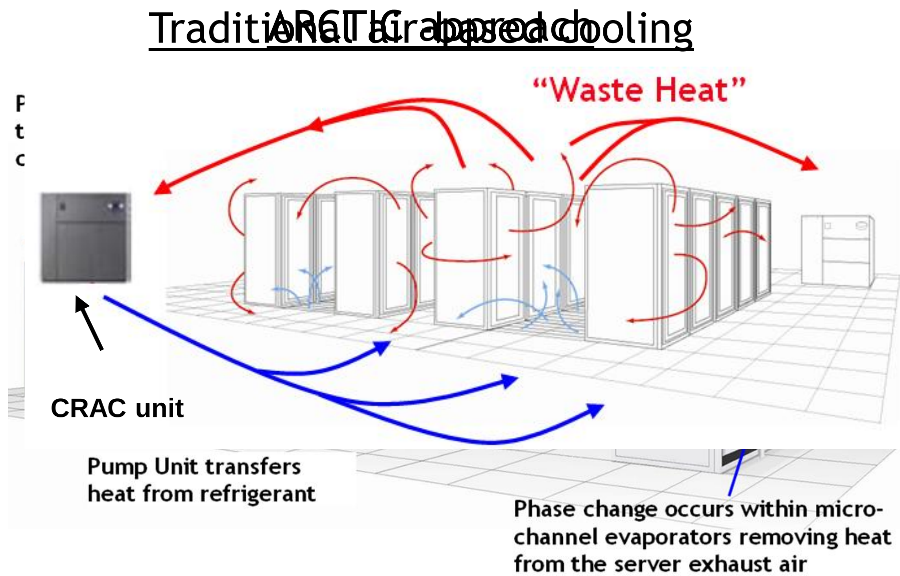
Approach, Results, Deliverables

ARCTIC's approach

- Use of a pumped refrigerant to provide local cooling at the heat source

Anticipated results

- Up to 90% energy savings compared to conventional CRAC-based cooling
- Ability to cool significantly higher rack-level heat densities



Task focus / Deliverables

- Manufacturing optimization of key components
- Ensuring market acceptance by reducing cost, understanding system-level performance and developing viable next-gen commercialization strategies
- Advanced research innovations that dramatically enhance the ability to deal with ever-increasing heat densities and footprint reduction by bringing the liquid cooling much closer to the actual heat sources

The following are transformational / game changing attributes of the approach:

Ability to retrofit live equipment without service interruption

- Addresses large installed base of existing ICT equipment

Up to 90% more energy efficient than conventional CRAC-based approaches

Current shelf-level cooling technology increases rack power densities 3x over existing CRAC-based cooling, allowing for better real estate utilization

- Component-level cooling enhancements will enable much higher device densities

Eliminates problems associated with hot- and cold-aisle air streams mixing and localized hot spots present in conventional CRAC-based approaches

- Synergistic energy savings in building chilled water system as need for over-cooling is reduced or eliminated

Refrigerant is a widely-used, non-toxic dielectric liquid which, unlike water, is non-conducting, non-corrosive and will not damage electronics in case of a leak

Increased reliability: servers operate at lower temperatures, while server fans run at lower speed, reducing power and the associated acoustic noise

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Energy savings for a representative data center

Comparison of cooling power requirements for a 1.5 MW data center cooled by chilled water CRAC units (left) and ALU's rack-level liquid cooling (right)

Chilled water CRAC units

- 500 server cabinets at 3 kW per cabinet
- 22,000 square foot service area
- CRAC units cool 47 kW; consume 13 kW
- 32.1 chilled water CRAC units required to cool total equipment load (Supported by actual conditions: 32 of 40 units are running in practice)

- **Energy required: 32 x 13 kW x 8760 hours = 3,640,000 kWh**

Rack-level liquid cooling

- 150 server cabinets at 10 kW per cabinet
  - **Space freed up for 350 cabinets**
- 3 heat exchangers + 6 fans total per cabinet (2 fans per heat exchanger)
- Pump unit uses 800 W
- Each fan uses 25 W (150 W per cabinet)
- Cooling power: 30.5 kW = (10 pumps x 0.8 kW/pump + 150 cabinets x 0.150 kW / cabinet)

- **Energy required: 30.5 kW x 8760 hours = 267,000 kWh**

Annual energy savings of 93% or 3,373,000 kWh x $0.10/kWh = $0.34M

Real estate savings: 350 cabinets * 12 sq ft/cabinet x $200/sq ft* = $0.84M

* *construction cost estimated at $200/sq ft.*

Estimates of national energy savings annually[1,2]

Energy savings relative to CRAC units[1]

US ICT annual energy expenditure of 120 billion kWh, with 25% for cooling

- Cooling energy expenditure = 0.25 x 120 billion kWh = 30 billion kWh
- CRAC unit energy expenditure = 0.25 x 30 billion kWh = 7.5 billion kWh

In prototype lab observe an 11.8 efficiency improvement relative to CRAC units

- Overall energy savings = (1 – 1/11.8) x 7.5 billion kWh = 6.9 billion kWh

Energy savings due to improved real estate utilization (CAGR of 6%)[2]

- 0.06 x 0.137 x 10^9 sq ft x 332 kWh/ sq ft = 2.7 billion kWh

Potential energy savings: 6.9 billion kWh + 2.7 billion kWh = 9.6 billion kWh

Potential financial savings: 9.6 billion kWh * $0.10/kWh + 0.06 * 0.137 x 10^9 sq ft x $200/sq ft = $2.6B

[1] based on the DOE presentation entitled "Routing Telecom and Data Centers Toward Energy Efficient Use" dated May 13, 2009 http://sites.energetics.com/ICT_roadmap09/pdfs/ICT_Vision_and_Roadmap_051309_draft.pdf

[2] http://architecture2030.org/current_situation/building_sector.html

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Jobs/ Employment

The direct impact of ARCTIC on jobs/ employment is the following:

- Alcatel-Lucent:
  - The R&D component of the effort created 2 **Post-Doctoral Member of Technical Staff** positions for the 2-year duration of the program.
  - **Skilled contractors** have been hired for lab work in Naperville, IL and Murray Hill, NJ.
- Modine:
  - The following positions have been created: i) Retain a **Manufacturing Engineer** (Complete); ii) Contract a **Sample Technician** for an 8-12 week period (has not been needed yet, work has retained current sample technician job); and iii) Hire a full-time **Product Development Engineer** (Complete).
- U.S. Hose:
  - One new **Engineering Technician** position will be created for the two-year duration of the project.

Potential Impact on Long-Term National Jobs/ Employment if the Technology is Successful Commercially

Alcatel-Lucent: Full-time positions include: i) **R&D**; ii) **Sales and Marketing**; iii) **Managers and Support Personnel** for installation, operation and maintenance; and iv) **Design Engineers** supporting retro-fits and integration of the technology directly into Alcatel-Lucent products.

Modine: The long-term commercial aspects of this concept will allow Modine's OEM Coil Group to support manufacturing jobs in North America and fund other development work that allow this group to be a viable supplier in the HVAC&R market. This will support the following jobs: i) **Development/Application Engineer** (1) and **Manufacturing Engineer** (1); ii) **Drafter/Designer** (0.25); and iii) **Heat exchanger manufacturing** (4 to 6 personnel for ½ shift).

U.S. Hose: This new product will continuously support the following positions: i) **Engineering Technician** overseeing product manufacturing; and ii) 4 **Manufacturing Employees** responsible for assembly, welding, testing, and manufacturing of hoses.

Other direct economic impact: The following positions will also be required to support the liquid-cooling technology: i) **Trained installers** and **contractors** for retro-fit installations; ii) **Designers, engineers** and **manufacturing personnel** for supplying component-level cooling technologies; and iii) **Facilities personnel** at end-user locations trained in the installation, operation and maintenance of the technology.

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Project Status - Manufacturing optimization of key components & cost reduction

Heat exchanger (HX) optimization for enhanced shelf-level cooling (Modine)

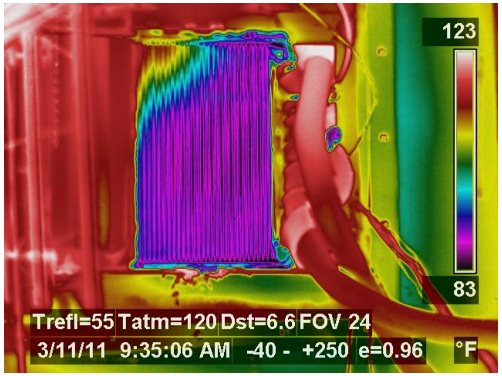
- Goal: Enhance system performance by optimizing the shelf-level HXs for a 15% increase in COP = (cooling capacity)/(input power), possibly eliminating fans.

  Status: i) Modeling studies of several HX designs complete.

  ii) Prototype samples of 5 different HXs designs made and being tested to meet near-term production needs.

  iii) High-capacity, next-generation coil design identified and resources are being allocated for prototyping.

Thermal image of heat exchanger under test



Develop and research new connector technologies (USHose)

- Goal: Reduce hose assembly cost while maintaining performance and improving availability and lead time.

  Status: i) Developing lower cost hose components and materials and associated manufacturing processes.

  ii) Identified fire retardant polyester (PET) monofilament braid material and supplier to create a non-conductive hose assembly with a PTFE core.

  iii) Identified alternative fitting supplier with better price, performance, functionality, availability, and technical support.

New fitting design

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Project Status – Understanding system-level performance and developing viable next-gen commercialization strategies

System-level testing (Alcatel-Lucent)

- Goal: Perform system level evaluation of: i) new designs for heat exchangers and hose assemblies; and ii) new refrigerant distribution system layout.

  Status: i) Lab modifications in 100 kW Prototype Data Center complete and ready for testing of new refrigerant distribution system layout and new component designs.

  ii) Evaluating new prototype heat exchanger designs prior to large-scale system-level testing.

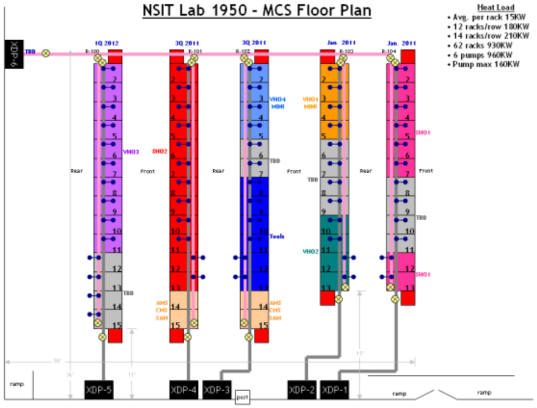
ALU Prototype Data Center

Business Development (Alcatel-Lucent)

- Goal: i) Develop a successful product offering that substantially reduces the energy required to cool data centers and allows higher heat densities; and ii) incorporate technology innovations into commercialization roadmap and accelerate introduction into next-gen product offerings.

  Status: i) Resources allocated for incorporating technology innovations into commercialization roadmap, including: compliance and agency testing, vendor sourcing, training, product literature (installation, operation & maintenance manuals).

NSIT IPTV Test Lab for large-scale system testing



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Project Status - Research innovations for high heat densities

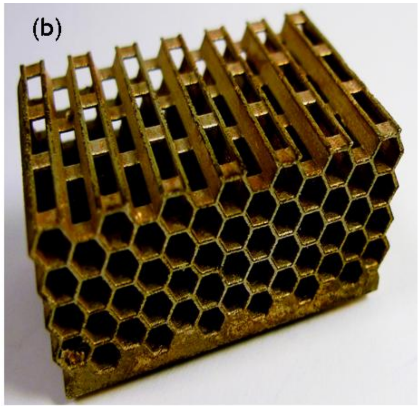
<u>Component-level air-cooled heat sink development (Alcatel-Lucent)</u>

- Goal: Improve heat sink performance with novel three-dimensional features to continue use of air cooling at the component level.

  Status: i) Several prototype heat sinks made using a novel manufacturing process; wind tunnel tests in progress.

  ii) Numerical models constructed to evaluate effect of features on fluid flow and heat transfer.

<u>Monolithic honeycomb 3DHS cast from copper</u>



<u>Component-level liquid cooling (Alcatel-Lucent)</u>

- Goal: Enable ever-increasing device heat densities by bringing the liquid much closer to the actual heat sources

  Status: i) Prototypes are being constructed to evaluate several approaches to liquid cooling of components

<u>Lab for evaluation of component-level cooling technologies</u>

<u>Rack-level test apparatus (Alcatel-Lucent)</u>

- Goal: Outfit a lab with a refrigerant pumping system and an instrumented model test rack for evaluating component-level air- and liquid-based cooling solutions

  Status: i) complete

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What's left?

Heat exchangers: i) Complete prototype testing, decide on preferred design and execute build for system testing; and ii) Build and test prototype high-capacity coil.

Hose assemblies: i) Create and test prototype hoses incorporating new materials, connectors and manufacturing processes; and ii) Execute build for system testing.

System-level testing: i) Collect base-line performance data of current technology; ii) Evaluate performance with new refrigerant distribution layout and mitigate any performance issues; iii) Evaluate heat exchangers; and iv) Evaluate hose assemblies.

Component-level cooling technologies: i) Perform additional parametric studies of three-dimensional air-cooled heat sinks; ii) Evaluate liquid-cooling prototypes in terms of their ability to cool high-heat-density components, cost, ease of use and any effects on overall system-level performance.

Business Development: i) Perform compliance and agency certification of preferred new component designs; ii) Create orderable items and associated vendor documentation; iii) Update Installation, Operation and Maintenance manuals; and iv) Incorporate into product pricing, configuration and forecasting tools.

After ITP-Sponsorship

Commercial product offering for the shelf-level technology:

- ALU Services Business Division believes that the refrigerant-based cooling technology offers tremendous potential for improving the energy efficiency of the ICT sector, and has allocated resources supporting a service product offering, the ALU Modular Cooling Solution, focused on retrofitting existing data centers and central offices. Several commercial sales have been made to date.
- Developments completed within DOE ARCTIC will require additional efforts to incorporate into the commercial product after grant completion:
  - Modine believes that a heat exchanger meeting the desired performance metrics of DOE ARCTIC can be commercialized within 12 months of project completion. The high-capacity coil will also be evaluated, but may take longer for commercialization.
  - R&D efforts into enhanced component-level cooling will require incorporation into the commercialization roadmap to enable a next-generation product offering.

Other application areas for the refrigerant-based cooling technology:

- Alcatel-Lucent believes that there are opportunities for the cooling technology more broadly within ICT as well as within ALU products, which could have synergistic effects with the ALU Modular Cooling Solution in impacting the energy efficiency of data centers and central offices.

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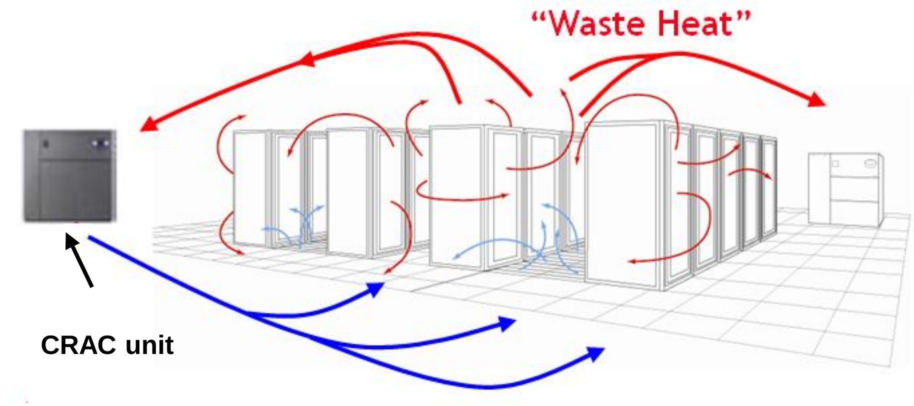
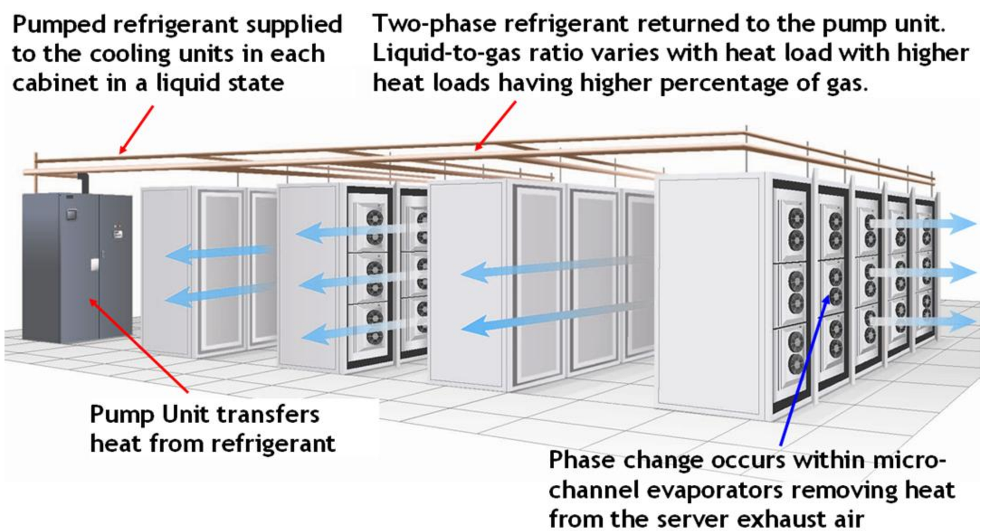
Value Proposition for End User

Traditional air-based cooling



Alcatel-Lucent's Modular Cooling Solution



- Uses as little as 10% of the electrical power of current technology
- Lowers ambient noise
- Lowers server operating temperatures
- Improves site reliability
- Improves Real Estate usage
  - Allows higher rack densities
- Minimizes operating expense
- Easily expandable
- Highly reliable
- Retrofits with no down time

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Summary

The Problem: Data center and central office cooling

- High energy costs
- Air cooling is reaching its limits

Our approach: pumped refrigerant-based cooling

- No longer rely on air as primary cooling medium
- Provide a more scalable path to increased device densities and functionality
  - 10's-100's kW/rack
- Scalable path to saving 25% of cooling costs (i.e., 10% of OPEX)

Paths to commercialization:

- ALU Modular Cooling Solution (ALU Services BD)
  - Data centers/ Central Offices (retro-fits & green field)
- Other ICT and ALU BD-specific applications

ALU NSIT IPTV Lab

ALU Prototype Data Center

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