Foreword:

Special Section on Data Center Cooling

Data centers account for a significant and growing fraction of the worldwide electricity demand, rising by an average of 11% per year from 2000 to a consumption of 27.1 GW in 2010, representing 1.3% of the total worldwide electricity demand[1]. In locations with concentrated data center infrastructure, this can represent an even greater fraction of total energy consumption. For example, in Ireland in 2016, data centers consumed 250 MW or 7.8% of the all-island total; the Irish national grid operator expects this to increase to double-digit percentages by 2018[2]. Meanwhile, the amount of digital data generated globally has multiplied on average by approximately 1.5 times per year, from 0.1 zettabytes (ZB) in 2005 to 8.5 ZB in 2015, projected to hit 40 ZB by 2020[3].

Despite this rapid growth in total energy consumption, the energy efficiency of data centers has not improved at a similar pace. Uptime Institute noted just a small improvement in the average power utilization effectiveness (PUE) from 1.89 in 2011 to 1.70 in 2014[4]. The significance of this evolution has not gone unnoticed. Lowering the overall energy footprint by improving data center cooling strategies is now at the forefront of the agenda for information and communication technology (ICT) companies and policy makers.

This Special Topics section on Data Center Cooling focuses on thermal management and energy efficiency in data centers and telecommunication equipment, as well as other systems-level issues related to the proliferation of interconnected embedded computing devices.

Our main goal with this Special Section was to provide an industry perspective on the current challenges and future trajectories, based on anticipated technical advances, market trends, or factors related to policy and regulation. This idea emerged from conversations at the *3rd Workshop on Thermal Management in Telecommunication Systems and Data Centers* held in Redwood City, California, on November 4-5, 2015. The five papers in this Special Section represent views of both academic and industry researchers from the thermal management community.

Garimella *et al.* reviews the key challenges encountered in electronics cooling applications at different scales, from data centers down to small-scale devices found in portable and wearable electronics and the automotive sector. This paper is based on the proceedings at the aforementioned workshop, and identifies both common themes and diverging views in the electronics cooling community.

Bar-Cohen appeals for the continued ‘inward migration’ of thermal management within integrated circuit (IC) packages utilizing local on-chip microfluidic and thermoelectric heat dissipation, as an enabler for next generation high efficiency data centers.

Salamon focuses on the challenges for telecommunications equipment, identifying the key drivers for network traffic growth, which reflects the exponential growth in digital data generation. The paper covers a wide gamut of applications in the field, from small-scale photonics IC and transistor cooling, wireless networking to telecom central offices.

Chainer *et al.* explores the use of advanced liquid cooling schemes in data centers to enable continued gains in efficiency and performance. Their demonstrations show that ‘warm’ liquid cooling can enable year-round heat rejection to the ambient without the use of chillers; this is not viable with air cooling due to dramatic increases in fan power. Liquid cooling at the die level may offer a path for continued scaling of system performance as transistor scaling approaches atomic dimensions, via enabling 3D chip stacking.

In Patterson’s ‘Case for Containment,’ he looks back at the historical development of air flow management systems in data centers, from early tribal knowledge carried by operators through the development of government policies and societal recommendations in response to high scrutiny on energy use. The fact remains that there is a large reliance on air cooling in data centers, and there are efficiency gains still available following the basic containment strategies described herein; it is not just a good idea, but often the law.

We gratefully acknowledge the contributions of the authors and reviewers who contributed to these papers, Ravi Mahajan for inviting this Special Section as the IEEE CPMT Co-Editor

[1] S. V. Garimella, T. Persoons, J. Weibel, and L.-T.Yeh, “Technological drivers in data centers and telecom systems: Multiscale thermal, electrical, and energy management,” Appl. Energy, vol. 107, pp. 66-80, 2013.

[2] EirGrid Group & SONI, All-Island Generation Capacity Statement 2017-2026, Dublin, 2017.

[3] J. Gantz, and D. Reinsel, The Digital Universe in 2020: Big Data, Bigger Digital Shadows, and Biggest Growth in the Far East, International Data Corporation (IDC), sponsored by EMC, 2012.

[4] Uptime Institute, 2014 Data Center Industry Survey.

(Special Topics), and the academic[5] and industry[6] participants at the *3rd Workshop on Thermal Management in Telecommunication Systems and Data Centers*. We hope that this Special Section can provide a stimulus for continued engagement between academic and industrial researchers within the data center and broader thermal management community.

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[5] Purdue University, Trinity College Dublin, Kyushu University, University of Houston, and Stanford University.

[6] Amazon Lab126, CoolIT Systems Inc, EXA Corporation, Fujitsu Limited (Japan), Hewlett Packard Labs, Huawei Technologies (US, Sweden and China), Intel Corporation, Qualcomm, Samsung Electronics, and Toyota Research Institute of North America.