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CONTENTS

SPECIAL ISSUE ON "MULTIMEDIA SENSOR NETWORKS IN SUSTAINABLE SYSTEMS"

Multimedia Sensor Networks in Sustainable Systems

Andres Kwasinski,
Rochester Institute of Technology, USA,
axkeec@rit.edu

On a broad scale, contemporary engineering research and development is faced with the need to address a number of important challenges. Due to its influence not only on technology advancement but also on society's development, one of the most important challenges is the evolution of our technology and society towards environmentally sustainable practices. One key component in this evolution, and in the research and development of the needed technologies, is the sensing of environmental variables that enable adaptable systems with sustainable-sensible operation. This application domain, which in many ways could be considered as emergent, is bound to see a notable growth in the near future. In this special issue of the E-letter, we present a selection of papers covering some of the main applications and research problem areas involved with the use of multimedia sensor networks in sustainable systems.

We start with the paper "Opportunities for Multimedia Environmental Sensor Networks", by Wark, O'Rourke, Kottege, Hu and Moore. This paper discusses large-scale sensing of the natural environment. This article describes a multimedia wireless sensing platform and its application to sense the environment. Some of the applications described in the letter include the use of audio sensing to track the extension of a particular species and the use of fused weather and video sensed data to correlate meteorological information with the coloring of foliage.

The use of multimedia wireless sensor networks to achieve low-cost remote monitoring and control in smart grid applications is discussed in Vehbi Gungor's paper "Multimedia Wireless Sensor Networks for Smart Grid Applications". The paper presents some of the many applications where multimedia wireless sensors could be used to enhance electric grids and realize the vision of a smart grid. Some of these applications include automatic detection and reporting of outages, power cable monitoring using audio and video sensors for both safety and theft prevention applications, demand response at the end-user side to efficiently use resources, and monitoring of renewable energy generation. The paper also includes a discussion of important research challenge in this area.

The discussion of the use of multimedia sensing to the smart grid is continued in Usman Khan's paper "A sensing-based adaptive model for the smart grid". The paper addresses the development of a model of the electric power grid, called the cyber-physical model, made from the hybrid combination of data-driven models and physics-based dynamical models.

To effectively implement these applications, it is important for the multimedia sensors to operate following tight constraints for energy efficiency. This issue is discussed in the paper "Energy Efficiency in Wireless Multimedia Sensor Networks" by Almalkawi, Alaei, Guerrero-Zapata, Barcelo-Ordinas, and Morillo-Pozo. This paper discusses the energy efficiency considerations for numerous techniques and components for multimedia wireless sensor networks, including energy efficiency in multimedia coding, in in-node processing, in the sensing subsystem, in QoS-based multipath routing protocols and in privacy and security.

We believe that this special issue, although succeeding in presenting an introduction to some important research areas in the application of multimedia sensor networks in sustainable systems, only amounts to the tip of an iceberg that presents a wide range of challenging and interesting technological problems. Finally, we would like to thank all the authors for their contribution and hope these articles can stimulate further research works in this area of great importance from both the technological and societal impact standpoint.

Andres Kwasinski received the diploma degree in electrical engineering from the Buenos Aires Institute of Technology, Argentina, in 1992, and the M.S. and Ph.D. degrees in electrical and computer engineering from the University of Maryland, College Park, in 2000 and 2004, respectively. He is currently an assistant professor in the Department of Computer Engineering, Rochester Institute of Technology, New York. Prior to this, he was with Texas Instruments, Inc., the Department of Electrical and Computer Engineering at the University of Maryland, and Lucent Technologies.

Opportunities for Multimedia Environmental Sensor Networks

Tim Wark, Damien O'Rourke, Navinda Kottege, Wen Hu, Darren Moore
Autonomous Systems Laboratory, CSIRO ICT Centre
Tim.Wark@csiro.au

Abstract
Advances in low-cost, low-power multimedia platforms are enabling a wide range of new opportunities in large-scale sensing of the natural environment. We briefly describe a number of projects we currently have underway in this area and outline the key research challenges and opportunities we see. In particular we focus on the topics of energy management, sensor fusion and visualization of multimedia information.

1. Introduction

Wireless sensor networks are gradually evolving from their early implementations as networks designed to deliver simple scalar measurements, into those dealing with local processing of much more complex signals such as audio and video [1]. Given the usual energy resource and bandwidth constraints in sensor networks, new research challenges and application opportunities are now emerging for distributed processing and delivery of this multimedia information.

One of the key research challenges for environmental multimedia platforms is that of energy management. Whereas traditional sensor networks research has largely focused on energy reduction of radio, in multimedia class platforms, energy consumption is typically dominated by components such as CMOS cameras, DSP-class platforms and audio codecs [2]. As such, new classes of protocols are required in order to manage energy for tasks such as triggering and sampling. Likewise storage, analysis and transmission of multimedia data introduces new challenges arising from constraints in storage space, computational resources and bandwidth for transmission.

In this letter we briefly describe the current platforms we have developed for use as environmental multimedia monitoring platforms. We also outline some of the current applications using these platforms as well as discuss some future opportunities we see for multimedia sensing in the context of long-term environmental deployments.

2. Platforms

In order to explore the challenges around long-term environmental sensing, we have developed a custom wireless multimedia sensor node platform for our long-term remote outdoor deployments [2, 3]. Each node consists of PIR, Low-Power Audio (LPA), High-Power Audio (HPA) and image sensors, a powerful Blackfin processor (comprising a Digital Signal Processor (DSP)) and a low power wireless mote. The low power PIR and LPA sensors consume relatively small amounts of energy and can remain on continuously to opportunistically trigger the higher power audio and image sensors that require the use of the DSP. A servo mechanism is also included for panning capability, thereby providing higher versatility with little extra cost.

The mote platform runs TinyOS and uses the IPv6 protocol for inter-node communication. The DSP uses Analog Devices' proprietary VDK operating system. On each device we have developed a significant number of Remote Procedure Calls (RPCs) that allow us to carry out operations such as, battery check, start/stop the DSP, obtain SD card information, check the temperature, adjust the image quality/resolution, ping the nodes, add/remove audio or image compression, set/read individual DSP registers, and many more such commands.

3. Acoustic Sensing

The use of distributed acoustic sensing for deriving information about the environment has been an area of growing interest for the research community [4, 5, 6]. One of our recent projects has had a goal of capturing frog vocalizations in a reservoir catchment area using multiple remote wireless acoustic nodes each equipped with modems to return data. Nodes also had temperature, humidity and leaf wetness sensors to capture environmental parameters to correlate with acoustic observations.

The mote, being the lower-powered device, acts as the master device to duty cycle the DSP and modem according to a predefined schedule based on its real time clock (RTC) as well as sample the environmental sensors. The whole system was powered by 12V sealed lead acid batteries and a solar panel. One of the main design considerations was to minimize power consumption while acquiring the required data. This was achieved by optimizing the time where power hungry components such as the DSP and 3G modem were switched on as a function of the amount of stored energy.

One of the key goals of this work has been to generate spatio-temporal maps of acoustic activity spread over a large geographical area as a means to provide a valuable resource for ecological monitoring and management. An example application would be tracking the evolution of phenomena such as species migration over time and space. Unlike environmental attributes captured via other modalities (e.g. visual features, temperature, humidity), the location of acoustic activity is de-coupled from the location of the actual sensor (microphone). Current work is exploring ways to derive these maps from highly sparse spatial and temporal observations to estimate likelihoods of events occurring.

4. Visual Sensing

The growth in availability of cheap, low-power CMOS sensors has meant that long-term, distributed visual sensing in the environment is increasing plausible. There are numerous opportunities for visual-sensing networks ranging from capturing overlapping images about the environment, through to detecting and/or classifying specific events in the visual domain.

One of our recent projects has been to monitor a rainforest in Australia [7]. This has involved the deployment of a large-number of micro-climate nodes[1]. Ongoing work is looking at how to supplement the micro-climate information from this network with visual event detection – this can include images of certain animal species, along with extraction of visual features about the environment such as ‘greenness’ measures of foliage. Current research is focusing on ways to balance the energy consumption and overall utility of nodes using a combination of low-power (e.g. passive infrared) sensors and high-power (CMOS camera and DSP-class platform) sensors for performing tasking tasks such as triggering, detection and classification.

[1] Network is now extended to 180 nodes since the initial deployment described in paper.

6. Future Opportunities

As the price-point for key components in multi-media class nodes continues to drop, we expect to see growing opportunities for utilizing these classes of networks. While privacy issues will somewhat limit the use of multimedia information in urban/built environments, the opportunity to build distributed ‘eyes and ears’ for the natural world is highly compelling given the growth of global issues such as climate change, water management and sustainable agriculture [8].

We foresee a move away from multimedia information being something that is recorded, transmitted and stored in a remote server, to a model where important information is stored locally (in devices) and can be queried to return information that is relevant to a specific request – e.g. in what regions was species A observed in the last 12 months. Likewise, as the fidelity of information that can be derived from satellite remote sensing increases, along with the increased availability of Unmanned Aerial Vehicle (UAV) class platforms, we expect to see growing opportunities to fuse these two classes of information streams, where the focus can move to deriving the most complementary information sources for a particular application.

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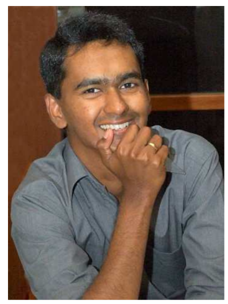
Tim Wark is a Principal Research Scientist in the Autonomous Systems Laboratory where he currently leads the Pervasive Computing Research group covering areas of distributed information, embedded systems and sensor networks. Tim holds a PhD from the Queensland University of Technology and is a Senior Member of the IEEE.

Damien O'Rourke graduated with a BEng degree from Dublin City University (DCU) in 2000. Following a short period as a network design engineer he went on to pursue a research masters degree in side-channel signal analysis of embedded cryptosystems. Upon graduating in 2003 he took on a full-time lecturing position which later led him to pursue his PhD in Wireless Sensor Networks which he obtained in 2009. He has been working as a postdoctoral research fellow for CSIRO since October 2008 and his current research interests include the development of efficient event detection and signal processing algorithms for wireless multimedia sensor networks, as well as diversity techniques for wireless sensor networks in general.



Navinda Kottege is a Postdoctoral Fellow at the Autonomous Systems Lab conducting research in wireless sensor networks with a focus on acoustic localisation and bioacoustic diversity. Previously he conducted robotics research at The Australian National University and was a team member of the Serafina project which developed swarming technology for autonomous underwater vehicles. His fields of interest include Spatio-temporal event mapping, Localisation, Navigation, Experimental robotics, Cooperative robotics and Mechatronics. Navinda completed his PhD in Robotics at The Australian National University in 2009.

Wen Hu is a senior research scientist and research team leader at the Autonomous Systems Laboratory in the CSIRO ICT Centre. He received his PhD in sensor networks from the University of New South Wales. His current research interests are low power communications, compressive sensing and security issues in sensor networks.

Darren Moore is a senior research engineer at the Autonomous Systems Laboratory in the CSIRO ICT Centre. His engineering expertise and interests lie in embedded software development, wireless sensor networks, acoustic signal processing, and environmental monitoring. He received his MEng in microphone array processing from the Queensland University of Technology.

Multimedia Wireless Sensor Networks for Smart Grid Applications

Vehbi Cagri Gungor
Bahcesehir University, Besiktas, TURKEY
cagri.gungor@bahcesehir.edu.tr

1. Introduction

The recent advances in low cost wireless technologies and embedded systems have enabled the realization of multimedia wireless sensor networks (MWSNs) [1]. In general, MWSNs ubiquitously retrieve and transmit multimedia content, such as still images, audio, video, and scalar data from the physical environment and enable distributed decision-making and acting based on the application requirements.

Recently, multimedia wireless sensor networks (MWSN) have been considered as a promising technology to achieve low-cost remote monitoring and control in smart grid applications, from power generation to consumer sites [2-7]. The potential applications of MWSNs in smart grid span a wide range, including distribution automation, remote power grid monitoring and control, power fraud detection, fault diagnostics, smart PHEV charging, real-time pricing, demand response, energy management, etc. [3-6]. However, the realization of these MWSN-based smart grid applications directly depends on effective wireless multimedia communication capabilities between electric power system elements and electric utility decision-support systems.

Overall, this position paper presents potential applications of MWSNs in smart grid along with the related research challenges. Specifically, the use of MWSNs for smart grid applications, such as electric fault diagnostics, power outage detection, surveillance of power substations and transmission and distribution systems (T&D) systems, demand response and automation, and renewable energy generation monitoring, have been briefly described. Hopefully, we expect that this position paper will provide a recent perspective to the state of the art in MWSN-based smart grid applications and motivate the universities and industry to explore this promising research and application field.

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2. MWSN-Based Smart Grid Applications

Electric power grid infrastructure contains three main subsystems, i.e., power generation, power transmission and distribution, and consumer sites.

With its collaborative and low-cost nature, MWSNs can improve the performance of all these three subsystems, making MWSNs a critical component of the next-generation power grids, i.e., *the smart grid* [4]. In the following, the main MWSN-based smart grid applications are described briefly:

- ***Electric Fault Diagnostics and Power Outage Detection:*** Smart grid can be considered as the integration of power grid with renewable energy resources, automated control and communications to improve energy efficiency, reliability, and safety of the power grid. However, in most of the countries, existing power delivery systems suffer from the lack of online power outage detection and fault diagnostics systems. For example, in several states of the United States, the only way an electric utility detects that there is a power outage is when a customer calls to report it [4-6]. With the two-way communications enabled by the MWSNs in power grid, online outage detection and fault diagnostics systems can be efficiently implemented. Moreover, MWSNs can be deployed in many parts of the power delivery systems. For example, image and video sensors can monitor the power T&D systems to detect vegetation or animal contacts causing safety problems in the grid. In case of any danger, these sensors can activate circuit breakers and reroute the current [6]. In addition, low-cost multimedia sensors can be used for accurate sag measurements in overhead power lines. To this end, multiple video sensors in MWSNs can provide larger field of view and more field of regard than a single Pan-Tilt-Zoom camera used in existing systems [6].

- ***Surveillance of Power Substations and***

T&D Systems: Copper cables and steel structures of the transmission and distribution (T&D) systems are being stolen in many countries for their valuable metal content [4-8]. Preventing cable theft is a serious problem since T&D lines cross several miles of rural areas with no effective means of physical security or protection. To address these problems in large-scale smart grid, MWSN-based power cable monitoring and warning systems can be implemented with audio and video sensors. In addition, image and video sensors can be utilized in the surveillance of power substations and control centers. In these critical power infrastructures, image and video sensors can be triggered with the detection of an anomaly by the scalar data sensors and proper actions can be taken timely [6].

- ***Demand Response and Automation:*** Energy efficiency, safety, and monitoring of the buildings can be realized with MWSN-based smart grid systems. Specifically, energy efficient lighting, heating, ventilation, air conditioning (HVAC), smart charging of electric vehicles demand response and real-time pricing programs, can all be achieved through the deployment of reliable MWSN communications in smart grid [7]. In these systems, different kinds of communications technologies, such as IEEE 802.15.4, Bluetooth, Low-Power Wi-Fi, Ultra Wideband, can be used to connect different physical links in smart grid environments. Information about the availability of the processing and energy resources in the multimedia sensor nodes can be collected by the smart grid gateway [3-7]. To use network resources efficiently, smart grid gateway can optimize network operations based on this collected information.

- ***Renewable Energy Generation Monitoring***: Nuclear fusion, hydro, or fossil fuels are used by the traditional power grid [7]. However, in the next generation power grid integrated with MWSN technologies, renewable and alternative power generation, such as wind and solar power generation, have started to be utilized. In these systems, power supply and demand matching is critical. To achieve this objective, monitoring weather conditions and forecasting the amount of the power generation in solar and wind farms are required for determining how much energy will be generated and need to be stored by the power grid. In these systems, fault diagnostics and monitoring operations can be done efficiently and reliably with MWSNs.

3. Research Challenges

The major communication challenges for the realization of potential MWSN-based smart grid applications can be outlined as follows:

- ***Application-Specific QoS requirements:*** Multimedia applications in smart grid may have different requirements with respect to delay, reliability, and energy efficiency [4]. This necessitates efficient communication solutions addressing diverse quality of service (QoS) requirements.

- ***Variable link capacity and packet errors:*** In harsh smart grid environments, wireless links exhibit widely varying characteristics over time and space and high bit error rates are observed in communication [2, 4]. Therefore, capacity and delay attainable at each link are location dependent and vary continuously making QoS provisioning a challenging task.

- ***Dynamic network connectivity and topologies:*** In smart grid environments, the topology and connectivity of the network may vary due to link and sensor node failures [4]. Hence, to balance the trade-offs among resources, reliability, and latency requirements, adaptive communication protocols are required.

- ***Energy Consumption:*** Since multimedia applications may produce high volumes of data [2], energy consumption is more critical compared to traditional wireless sensor networks.

- ***Resource Limitations:*** The design and implementation of WMSNs are limited by three types of resources: i) energy, ii) memory, and iii) processing. Thus, communication solutions for WMSNs need to satisfy application-specific QoS requirements using these limited resources.

4. Conclusions

The potential applications of MWSNs in smart grid span a wide range, including distribution automation, remote power grid monitoring and control, power fraud detection, fault diagnostics, smart PHEV charging, real-time pricing, demand response, energy management. However, MWSN-based smart grid applications have unique challenges due to their severe energy limitations and QoS requirements coupled with location and time varying nature of wireless communications in harsh smart grid environments. Future work includes developing cognitive and cross-layer communication solutions, which integrate the communication protocol layers with the consideration of available resources in terms of bandwidth, energy, processing, and memory.

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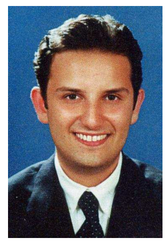

Vehbi C. Gungor (M'08) received the B.S. and M.S. degrees in electrical and electronics engineering from Middle East Technical University, Ankara, Turkey, in 2001 and 2003, respectively. He received the Ph.D. degree in electrical and computer engineering from the Georgia Institute of Technology, Atlanta, GA, USA, in 2007 after working at the Broadband and Wireless Networking Laboratory.

Currently, he is the Co-Director of the Computer Networks and Mobile Communications Lab and the Graduate Programs (Ph.D. and M.S.) Coordinator of the Computer Engineering Dept. at Bahcesehir University, Istanbul, Turkey. Before joining to Bahcesehir University, he was working at Eaton Corporation, Innovation Center, WI, USA as a Project Leader of the Smart Grid and PHEV Advanced Connectivity Project. His current research interests are in smart grid communications, next-generation wireless networks, wireless ad hoc and sensor networks, cognitive radio networks, IP networks, and plug-in hybrid electric vehicles. Dr. Gungor has authored several papers in refereed journals and international conference proceedings, and has been serving as a reviewer and program committee member to numerous journals and conferences in these areas. He is also the recipient of the IEEE ISCN 2006 Best Paper Award, the European Union FP7 Marie Curie IRG Award in 2009, and the San-Tez Project Awards issued by Alcatel-Lucent and the

Turkish Ministry of Industry and Trade in 2010. He is also the Principal Investigator of the Smart Grid Communications R&D project funded by Türk Telekom.

A Sensing-based Adaptive Model For The Smart Grid

Usman A. Khan, Tufts University, khan@ece.tufts.edu

1. Abstract

A key consideration in the design and analysis of the future smart grid is an appropriate modeling paradigm that retains certain structural properties. The underlying structure of the grid model is specially helpful when we implement distributed sensing and control algorithms for a computationally-efficient, reliable, and scalable operation of the grid.

In this paper, we present a structure-preserving model of the electric power grid that we term as the *cyber-physical model*. The cyber-physical model is a hybrid of data-driven models and physics-based dynamical models. The data-driven models capture the dynamics of the system modules that cannot be modeled from basic principles, e.g., aggregate system load; whereas the physics-based models describe the dynamics of system modules that are modeled from the underlying physics, e.g., generator modeling by Partial Differential Equations (PDEs).

2. Introduction

The evolution of smart-grid involves a sensing infrastructure that is spatially distributed over the entire grid. The sensing infrastructure, along with its advantages in estimation, control, and dispatch problems, can be specially helpful in describing the grid dynamics. In this paper, we present a new modeling paradigm for the future smart grid that is based on the sensing and communication infrastructure.

This new paradigm is motivated by our recognition of the needs for gradual evolution of today's electric power systems into the future energy systems capable of exhibiting adaptive performance such as flexibility, efficiency, sustainability, reliability and security. While the recognition of the desired end state of future energy systems is emerging [1], [2], it also is essential to revisit the modeling framework underlying use of sensors and controllers in today's electric power systems. The availability of computing power has led to the development of algorithms for forecasting system load and dispatching generation resources ahead of time plus stand-by-reserve to balance the anticipated demand under possible failure of the system components.

One hidden challenge is that models of the interconnected power system currently used for dynamic analysis are not capable of capturing the effects of end-users' feedback nor they model very small scale DGs located close to them. In order to begin to overcome this problem, this paper proposes a new framework for modeling actions of end-users explicitly. This paper starts with the recognition that incorporating relevant load models for large-scale realistic power systems will require careful sensitivity analysis of dynamic interdependencies of both transmission and distribution (T&D) systems, and further systematic load aggregation.

Our modeling approach is qualitatively different from the currently used models that do not explicitly account for the effects of sensing and communication. The proposed approach is based, instead, on representing all physical components as modules interconnected by means of an electric network. However, not all physical components can be modeled from first principles because of the extreme non-uniformity and the complexity of various classes of components. Instead, many components and/or groups of components have to be monitored and their models have to be identified using extensive signal processing, sensing, and model identification.

We illustrate such combined cyber-physical models of key components, and use these to introduce a structure preserving model of a cyber-physical infrastructure of the interconnected system. Such a model becomes a basis for deciding what to sense and at which rate, what level of data mining is needed for which (groups of) physical modules to achieve predictable performance for cyber-physical future energy systems. This model rests on the premise that the performance of future energy systems can be shaped in major ways by means of broadly available cyber technologies. In order to make the most out of the available cyber technologies, the first step is to establish models which capture these interdependencies.

A direct consequence of this modeling approach is that resulting model preserves the underlying structure of the smart model. This is because the load dynamics are retained in the model description by modeling them using cyber principles, for example, AR models; as opposed to the traditional constant impedance/power load models where the load dynamics are removed from the system. The structure-preserving cyber-physical model lends itself naturally to the implementation of distributed sensing and control algorithms where communication and sensing follow the system structure. Applications of this model can be motivated by [3], [4], [5], [6], [7]. Parts of this work have been presented in [8], [5], [6]. In the following, we develop cyber-physical model of the electric power system.

3. Cyber-Physical Model of the Power System

Consider an electric power network with K steam turbine generators[2] and M loads where the loads are considered to be aggregated loads at the sub-station level. We model the generators using their Partial Differential Equation (PDE) descriptors. On the other hand, modeling the electric load from the underlying physics is a practically impossible task. This is because modeling the electric load in a typical energy system, with millions of diverse components ranging from appliances in residential households through medium to large-size industrial and commercial consumers, is highly nontrivial. To avoid this modeling difficulty, we postulate a cyber model for the electrical load based on sensor-based identification. We then combine the cyber and physical models of all of the system modules as they are interconnected via the electric transmission network. Below, we explain the procedure.

A. Physics based description of the generator module

We model the dynamics of the generators as a governor-turbine-generator (G-T-G) set [9]. The generator dynamics in discrete-time are given by (using a standard approximation of first order derivatives)

$$\begin{aligned} x_{g,k+1} &= \left(I + \Delta_T \begin{bmatrix} -\frac{D}{J} & \frac{1}{J} & \frac{e_T}{J} \\ 0 & -\frac{1}{T_u} & \frac{K_T}{T_u} \\ -\frac{1}{T_g} & 0 & -\frac{r}{T_g} \end{bmatrix} \right) x_{g,k} + \begin{bmatrix} -\frac{\Delta_T}{J} \\ 0 \\ 0 \end{bmatrix} P_{g,k} + \begin{bmatrix} 0 \\ 0 \\ \Delta_T \omega_s^{ref} \end{bmatrix} + u_{g,k}, \\ &= F_g x_{g,k} + c_g P_{g,k} + u_g + u_{g,k}, \end{aligned} \tag{1}$$

where Δ_T denotes the sampling rate,

$$x_{g,k} = [\omega_{g,k} \;\; P_{T,k} \;\; a_k]^T, \tag{2}$$

collects of the generator's frequency, mechanical power, and valve opening. The vector, $x_{g,k}$, is the state vector of the steam-turbine generator at time k. The generator's parameters, D, J, K_T, T_u, T_g, are the damping coefficient, moment of inertia, and the time constants of the turbine and the generator, respectively, $P_{g,k}$ is the power supplied by the generator, and $u_{g,k} \sim \mathcal{N}(0,Q)$ is a white noise input vector.

B. Sensor based identification of the load module

We characterize the electric load modules much as the same way as the G-T-G set is characterized. We postulate a cyber model for the electric load based on a Newton-like representation of load dynamics governed by the instantaneous mismatch between the power delivered to the load, $P_{L,k}$ at time k, and the power consumed at the load, L_k at time *k*. We have (after discretization using a standard approximation of the first order derivatives)

$$\omega_{L,k+1} = \left(1 - \Delta_T \frac{\mathbf{D}_L}{\mathbf{J}_L}\right)\omega_{L,k} - \frac{\Delta_T}{\mathbf{J}_L} P_{L,k} - \frac{1}{\mathbf{J}_L} L_k + u_{L,k},$$

where $\mathbf{J}_L$ and $\mathbf{D}_L$ refer to the effective moment of inertia and the damping coefficient of the aggregate load[3]. We model the load consumed, L_k, by an auto-regressive (AR) process of order p driven by zero-mean white noise, v_k. The AR model is given by [8]

$$L_{k+1} = \sum_{j=1}^{p} \phi_j L_{k-j} + v_k, \tag{4}$$

where the ϕ_j s are the coefficients of the AR model identified using standard statistical techniques[4]. Let $\hat{L}_k$ denote the estimate of the power consumed, then

$$\hat{L}_k = \sum_{j=1}^{p} \phi_j L_{k-j}, \tag{5}$$

is the optimal estimate of the AR model in (4). We assume that the past samples, $\mathbf{L}_{k-j}$, are available by using sensing methodologies [8].

C. Combined cyber and physical model

[2] Here we use steam-turbine generators, but the results are generalizable to any other kind.

[3] The values of J_L and D_L can be obtained using systematic model identification methods at each sub-station [8].

[4] Clearly, more advanced adaptive models to learn the load dynamics can be formulated, see [10], [11] for details. However, AR models sufficiently capture the basic idea of our approach.

The power supplied by the generator, $P_{g,k}$, and the power delivered to the load, $P_{L,k}$ are related by the interconnection network of the generators and loads. Let

$$\mathbf{P}_{g,k} = \left[P_{g,k}^{1} \dots P_{g,k}^{K}\right]^{T}, \qquad (6)$$

be the vector of power supplied by the K generators, and let

$$\mathbf{P}_{L,k} = \left[P_{L,k}^{1} \dots P_{L,k}^{K}\right]^{T}, \qquad (7)$$

be the vector of power delivered to the M loads. Define

$$\mathbf{\Omega}_{g,k} \triangleq \left[\omega_{g,k}^{1} \dots \omega_{g,k}^{K}\right]^{T}, \qquad (8)$$

$$\mathbf{\Omega}_{L,k} \triangleq \left[\omega_{L,k}^{1} \dots \omega_{L,k}^{K}\right]^{T}, \qquad (9)$$

Then $\mathbf{P_{g,k}}$ and $\mathbf{P_{L,k}}$ are related by

$$\begin{bmatrix} \mathbf{P}_{g,k+1} \\ \mathbf{P}_{L,k+1} \end{bmatrix} = \begin{bmatrix} \mathbf{P}_{g,k} \\ \mathbf{P}_{L,k} \end{bmatrix} + \Delta_T \mathcal{H} \begin{bmatrix} \mathbf{\Omega}_{g,k+1} \\ \mathbf{\Omega}_{L,k+1} \end{bmatrix}, \qquad (10)$$

where $\mathcal{H}$ is a $I \times J$ interconnection matrix. Equation (1), (3) and (10) complete the cyber-physical description of the dynamics generated by a power system with K steam-turbine generators and M arbitrary loads and can be written concisely as an n -dimensional vector

$$\boldsymbol{x}_{k+1} = \boldsymbol{F}\boldsymbol{x}_k + \boldsymbol{b} - \frac{1}{J_L}\boldsymbol{G}_L\widehat{\boldsymbol{L}}_k + \boldsymbol{u}_k, \qquad (11)$$

where

$$\boldsymbol{x}_k = \left[x_{g,k}^{1T} \dots x_{g,k}^{KK}\ \mathbf{\Omega}_{L,k}^{T}\mathbf{P}_{g,k}^{T}\mathbf{P}_{L,k}^{T}\right]^{T}, \qquad (12)$$

is the global state vector of the entire system and $\boldsymbol{F}$; $\boldsymbol{b}$; $\boldsymbol{G}_L$ are the appropriate quantities derived from (1),(3), (4), and (10). For more details, see [8].

Here we note that the description in (11) involves all of the system state-variables as dynamical components. In other words, the integration of the cyber-based load model captures the dynamics of each system variable resulting into a more precise system model as opposed to the models where load dynamics are not incorporated. Clearly, the resulting model accuracy depends on the sophistication of the load-prediction and its associated noise (error) statistics. However, as we mentioned before, this accuracy can be easily improved by considering a more detailed information-theoretic load description.

4. Applications and Conclusions

In this paper, we present our recent work on modeling experience of cyber-based physical energy systems. We describe a novel cyber-based dynamic model in which the resulting description greatly depends on the cybertechnologies supporting the physical system. Notably, the newly introduced models have network structure–preserving properties–as opposed to the traditional constant impedance/power models where the load dynamics in the system are ignored–that are key to the effective distributed decision making. Particular emphasis is on the aggregate load modeling enabled by novel sensing and data mining in order to address the critical challenges posed by the future energy systems.

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Usman A. Khan (S’99) Khan is an Assistant Professor in the Electrical and Computer Engineering department at Tufts University where he is leading an active research group in networked signal processing and control. Prof. Khan is also involved in undergraduate curriculum development in the systems area. His research interests include statistical signal processing for large-scale dynamical systems, networked control and estimation, and distributed linear/nonlinear iterative algorithms.

Dr. Khan received his B.S. degree (with honors) in Electrical Engineering from University of Engineering and Technology, Lahore-Pakistan, in 2002, M.S. degree in Electrical and Computer Engineering from University of Wisconsin-Madison in 2004, and Ph.D. degree in Electrical and Computer Engineering from Carnegie Mellon University in 2009. He was a post-doctoral researcher in the Electrical and Systems Engineering department at the University of Pennsylvania’s School of Engineering and Applied Sciences where he was an active member of General Robotics, Automation, Sensing and Perception (GRASP) Lab. He worked as a researcher in National Magnetic Resonance Facility at Madison (NMRFAM) from 2003 to 2005, and as a research assistant in the Computer Science Dept. at UW-Madison from 2004 to 2005. Dr. Khan is an associate member of IEEE Sensor Array and Multichannel (SAM) Technical Committee (TC).

Energy Efficiency in Wireless Multimedia Sensor Networks

Islam T. Almalkawi, Mohammad Alaei, Manel Guerrero-Zapata, Jose M. Barcelo-Ordinas, and Julian Morillo-Pozo
Universitat Politècnica de Catalunya, UPC, Barcelona, Spain
{islam, malaei, guerrero, joseb, jmorillo}@ac.upc.edu

1. Introduction

Wireless Multimedia Sensor Networks (WMSN) [1] are wireless networks of multimedia sensor nodes, such as cameras and microphones, and capable to retrieve video and audio streams, still images, as well as scalar sensor data. WMSNs promise a wide range of potential applications in both civilian and military areas. In these applications multimedia support has the potential of enhancing the level of information collected, enlarging the range of coverage, and enabling multi-resolution views.

However, in-node multimedia signal processing and in-network multimedia communications in WMSNs lead to significant amount of energy consumptions in addition to other network resources such as bandwidth, data rate, memory, and processing capability. In this letter, we discuss those techniques aimed to improve the energy efficiency of multimedia transmission over wireless sensors networks.

2. Energy Efficiency in Multimedia Coding and In-node Processing

The first step towards achieving energy efficiency in WMSNs is to reduce the amount of transmitted multimedia data by the source nodes by using power efficient multimedia source coding and compression techniques. The existing video coding techniques that have been used for WMSNs vary in their high compression efficiency, error resiliency, and low encoding-decoding complexity and can be classified into four groups:

1) Layered Coding (LC) [2] is a type of video source coding technique by which the original data is encoded to one important base layer (coarse version) and one or more less important successive enhancement layers (to get the fine version). At the destination side, the base layer can be combined again with all or a subset of the higher-quality layers to achieve the desired level of video resolution. However, the loss of the base layer makes the information received from the enhancement layers useless.

2) Predictive Video Coding (PVC) [3], used in MPEG-x and H.26x standards, is based on the idea of reducing the bit rate generated by the source encoder by exploiting data statistics. PVC coding employs two modes for encoding the video: 1) Intra-frame coding mode (I-frame) that is used to reduce the redundancy within one frame by exploiting the spatial correlation in the frame, and 2) Inter-frame coding mode (P-frame) or motion compensated predictive that is used to reduce data redundancy in subsequent frames by exploiting both spatial and temporal correlation, being here where resides the complexity of this technique since it requires high computation capabilities and buffering.

3) Multiple Description Coding (MDC) [4] is used to enhance the error resiliency of video delivery by splitting the multimedia content into two or more independent and equal important streams (multiple descriptions). Each description alone provides acceptable low quality version of the original and combining all descriptions together gives higher resolution.

4) Distributed Video Coding (DVC) [5], used for low complexity encoding by shifting the complexity to the sink side, incorporates concepts from source coding with decoder side information for creating an Intra-coded frame along with a side information frame. This approach is one of the most promising in WMSN.

3. Energy Efficiency in the Sensing Subsystem.

In WMSNs, the use of densely deployed sensor nodes leads to having redundant information for the same events occurred in the network, e.g. overlapping of field of views (FoVs) of camera sensors located in the same geographical area. Therefore, the second step to save energy in WMSNs is to reduce the amount of exchanged redundant data by developing efficient and distributed filtering and in-network cooperative processing mechanisms such as storage management, data fusion and collaborative sensing. For example, the energy consumption in the WMSN Sensing Subsystem (in the order of tens of mW) is much higher than the energy consumption reported in scalar sensors (in the order of few μW). The reason is mainly due to power hungry transducers, the longer acquisition time, the power hungry A/D converters and the amount of operations to manipulate multimedia data. Sensor management policies can reduce this energy by selecting and scheduling the camera nodes activity at the same time that the application requirements are satisfied. Examples of such management policies can be found in [6][7]. In these works, nodes collaborate in sensing the area by clustering nodes with overlapping FoV. If nodes only belong to one cluster, the scheduling is based in round robin basis. However, FoV clustering allows for multi-cluster membership with more complex scheduler sensing mechanisms that can achieve higher energy savings.

4. Energy efficiency in QoS-based multipath routing protocols

The multimedia nature of the collected information adds more constraints on the design of the routing protocols in order to meet the application-specific QoS requirements and network conditions, and in consequence, makes the proposed routing protocols for typical WSNs not directly applicable for WMSNs. Proposed routing protocols for WMSNs needs to be more efficient to handle the high amount of multimedia data and transfer it to the intended destinations in a way that sustains the energy level of the network as long as possible while maintaining the quality of the received content at the same time. We notice that most of the existing proposed protocols for WMSNs follow the classical layered structure of the communication protocol stack without taking into consideration the especial requirements of handling real-time multimedia content over WMSNs. Some of these proposals may achieve a good performance in terms of some metrics related to each of their intended individual layers, but these performance metrics are not jointly optimized to maximize the overall network performance with minimum energy consumption. We believe that the correlation characteristics and interdependencies among the layers of the communication stack in WMSNs cannot be neglected and should be exploited for better performance and efficient communication. So, cross-layer optimization can be the solution to meet the especial requirements of WMSN and its design challenges in order to provide enough support for multimedia applications and maximize network performance.

In [8] a routing protocol is proposed for efficient multimedia communication over WMSNs by presenting a cross-layer based energy-aware clustered multi-path routing with QoS-aware multimedia packet scheduling scheme. The proposed routing protocol aims to support different traffic classes of different QoS requirements by choosing the suitable path for each data type, while maintaining minimum end-to-end delay, high throughput and packet delivery ratio by selecting the paths with better link quality and avoiding collisions and interferences. Also it aims to save energy at nodes by moving the multimedia processing complexity as well as the aggregation process to the cluster heads side. The proposed packet scheduling mechanism is based on an adaptive QoS-aware TDMA approach that is used at two levels in the network: within clusters and among cluster heads. The use of contention-free TDMA-based approach is because contention-based approaches like CSMA/CA, at heavier traffic loads as the case of WMSNs, increase wasted energy and delays due to idle listening and collisions. Thus, it remains a challenge to achieve acceptable QoS performance using contention-based approaches.

5. Energy efficiency in Security and Key Management Schemes

Many applications of WMSNs have their additional requirements in terms of privacy and security, such as military applications, medical care applications, and other video surveillance systems. In addition to the fact that WMSNs are vulnerable to attacks more easily than the wired networks because of their nature as a broadcast medium. Proposed security mechanisms for WMSNs should have minimal impact on overall performance through balancing their security features against the communication and computational overhead required to implement them.

Several proposals in the literature targeted the security implementations in WMSNs and some of them are surveyed in [9]. Also in [8], a light-weight distributed security scheme of key management is proposed to secure the communication in clustered WMSNs and satisfy the authentication and confidentiality requirements against most types of attacks. The proposed security scheme is a light-weight scheme in terms of energy efficiency, processing and memory complexity, and communication overhead. It is designed to be scalable for large networks because every node needs only to generate a small number of shared security keys regardless the total number of deployed nodes. In addition, the proposed security scheme allows for message broadcasting within the clusters using unique-cluster security keys and for aggregation processing.

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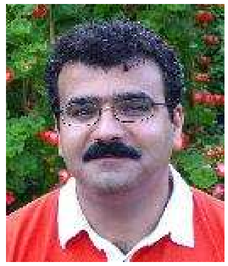
Islam T. Almalkawi is a PhD student at Universitat Politècnica de Catalunya in Spain. He received his B.S. (2004) in Electrical&Computer Eng. from Hashemite Univ. in Jordan, M.S. (2008) in Information Networking jointly from Carnegie Melon Univ. and Athens Information Technology in Greece.



Mohammad Alaei is a PhD student at Universitat Politècnica de Catalunya in Spain. He received his B.S. in Computer Engeniering (1998) at Shahid Beheshti Univ. (Iran) and M.S in Computer Engeniering (2002) at Univ. of Isfahan (Iran).

Manel Guerrero-Zapata is a Tenured Assistant Professor at Universitat Politècnica de Catalunya (UPC) in Spain. He received his PhD, M.S. and B.S. in Computer Science from the UPC in 2006, 1999 and 1997 respectively.

Jose M. Barcelo-Ordinas is an Associate Professor at Universitat Politècnica de Catalunya (UPC) in Spain. He received his PhD and M.S. in Telecommunications Engineering at UPC in 1998 and 1991 respectively.

Julian D. Morillo-Pozo is an Adjunt Professor at Universitat Politècnica de Catalunya (UPC) in

Spain. He received his PhD and M.S in Computer Science at UPC in 2009 and 2002 respectively.

TECHNOLOGY ADVANCE COLUMN

Real-time Applications over New Network Architectures

Guohui Wang
IBM T. J. Watson Research Center
wangg@us.ibm.com

Internet is evolving quickly today. To handle the rapid growth of bandwidth requirement and increasing complexity of large scale network management, many new network architectures have been proposed in recent years, such as service oriented network, software defined network, content centric network and hybrid packet/circuit switched network. Most of the proposed architectures make radical changes on the protocols, management software and switching hardware in the Internet.

Some of these network architectures are explicitly designed to address the bandwidth requirements from multimedia applications on the Internet. Others are proposed from different perspectives, such as ease of management, where the implications of proposed network on multimedia applications remain to be seen. The purpose of this special issue is to discuss some of the new network architectures and their implications to the multimedia and streaming applications.

The first article "Considerations on the Transmission of Multimedia Sessions for Future Internet" summarizes recently proposed P4P and information centric network for future Internet. It also discusses the advantages and weaknesses of these new architectures on the transmission of multimedia sessions, the new design challenges and research directions in this space.

The second article "Streaming High-bandwidth Real-time Video Traffic in Residential Wireless Networks: A Measurement Study" presents an analytical study that characterize the performance of interactive video traffic over residential connections. The authors measure the properties of wireless and end-to-end links in residential networks in terms of the bandwidth available for streaming, loss and latency that packets experience and the effect on streaming quality. They find that HD video streams suffer from the insufficient uplink bandwidth and high latency in broadband networks.

The third article "The IRMOS/ISONI Real-time Cloud Infrastructure: A Virtualized e-Learning Case Study" presents ISONI, an intelligent service oriented networking infrastructure developed by IRMOS EU project, which essentially acts as an IaaS cloud computing infrastructure that can provide guaranteed resource allocation to deployed applications. This article discusses the design of ISONI framework and the performance of real-time e-learning content delivery applications.

The explosion of data transfer in the Internet has also motivated the design of new switching architectures. The fourth article "On Hybrid Optical/Electrical Network for Datacenters and Stream Computing" discusses a hybrid optical/electrical network which combines the conventional electrical packet-switched network with optical circuit switched devices to provide extremely high bandwidth for applications. The authors demonstrate the feasibility of such a network by the use of software controlled optical switches for stream processing applications. They also discuss the remaining challenges to realize such a hybrid network in Internet data centers and HPC environments.

Guohui Wang is a research staff member in IBM T. J. Watson research center. Before joining IBM, he received a Ph.D. From Rice University and a MS from Chinese Academy of Sciences and a BS from University of Science and Technology of China. His research interests lie in networked system design and performance analysis. His most recent research has been focused on new network architecture, network control and virtualization in cloud data centers. Guohui is a member of IEEE communication society and ACM SIGCOMM.

Considerations on the Transmission of Multimedia Sessions for Future Internet

Yi Sun, Hanwen Zhang, Haibin Zhai, Yang Guo, Gaogang Xie ICT, China
{sunyi, hwzhang, zhaihaibin, guoyang,xie}@ict.ac.cn

1. Introduction

According to the investigation [1] of Morgan Stanley, more than 50% of the traffic on Internet is used to transmit multimedia sessions such as voice, video, image etc. With the increase of the network bandwidth and the development of new transmission technologies, multimedia applications will become more and more popular on the future Internet. It is considered as one of the main reasons of traffic explosion and traffic scalability problems for the Internet. Meanwhile, different from the common data sessions (e.g. Email, file downloading), the transmission of multimedia sessions not only requires high bandwidth but also has strict QoS requirements on delay, jitter and packet loss. The “best effort” mode of current TCP/IP network does not fulfill the demand of the multimedia session transmissions for future Internet. Therefore, supporting efficient transmission of multimedia sessions is one of the most important goals when designing new architectures and protocols for the next generation of Internet. In this paper, we briefly overview the basic ideas of different proposals for future Internet and analyze their advantages and weaknesses to support the transmission of multimedia sessions. We further discuss a few of our ongoing research projects in this space.

2. Supporting Multimedia Sessions for Future Internet

In the middle of 1990s, the Internet Engineering Task Force (IETF) designed IPv6 protocol in order to better meet the needs of rapidly growing address space in the Internet. The main features include larger address space, strictly inherited addressing mechanisms, simple data header, better quality of service, IPSec, address auto-configuration, flexible multicast support etc. IPv6 takes into account the efficient support of multimedia transmission. Firstly, compared with IPv4, IPv6 considers the QoS requirements of the sessions with a flow tag in the header of protocol to control the priority of the sessions based on the urgency and QoS requirements of different multimedia information. Secondly, IPv6 enhances the functionality of multicast. Multicast can effectively save the network bandwidth and improve data transmission efficiency, which is particularly important for the transmission of multimedia sessions.

We have implemented an IPv6-based multimedia streaming distribution platform to realize live VoD services to a large number of users. According to our experiment results, although IPv6 has a positive effect on the QoS and multicast support of the multimedia sessions, it is incapable of solving the traffic explosion and scalability problems. This is because IPv6 still relies on the location based (IP address) transmission model and cannot realize traffic optimization based on the content of sessions. In the future internet, we believe network should be content-aware. Therefore users can retrieve their required data from the optimal provider.

P2P technology has greatly improved the spread of multimedia services in the network. Using P2P technology, P2P streaming systems effectively alleviate the enormous pressure of servers’ computing resources and bandwidth, and improve the quality of streaming services. Currently, most of the popular P2P streaming applications do not consider the efficiency of network resource utilization and simply think that all the nodes are completely equal to exchange data. Thus the traffic transmission routes among P2P nodes are completely disordered. With the widely spread of P2P multimedia systems, the resulting traffic explosion, on the one hand, has brought huge pressure to the Internet backbone network, which limits the scalability of network traffic; on the other hand it makes P2P multimedia system itself face issues such as poor performance and decreased quality of service.

Researchers at Yale University proposed P4P architecture [3] (Proactive Provider Participation for P2P) in 2008. P4P architecture aims to establish cooperation between P2P applications and network providers, so as to solve issues of network traffic scalability and quality of service caused by P2P applications, especially multimedia applications. Different from P2P, which randomly selects nodes to exchange data, P4P architecture can fully utilize network topology, pricing strategy and other control information mastered by network providers to exchange data with nodes in the same router or regional network. It therefore significantly reduces the load of the network. Moreover, intelligently selecting nodes to exchange data can also improve the data transmission capacity and ensure the quality of multimedia services.

Cooperated with Yale University, we have designed a P4P DHT mechanism and implemented it on a major P2P multimedia application system (PPLive). We concluded that P4P architecture can eliminate topology mismatch between P2P overlay network and the actual transmission network. Its core principle is adding new entities (iTracker) in the existing network architecture to achieve the optimization of network traffic. However, the new entities become a performance bottleneck. In addition, we find the core mechanism of P4P is not effective in reducing the traffic of non-P2P multimedia systems. Due to these reasons, we expect to solve the explosion of multimedia traffic from the architecture itself.

ICN (Information Centric Network) is another new architecture for future Internet. The most prominent examples of ICN are content centric network (CCN) [4] and named data network (NDN) [5]. The basic idea of ICN is to propose a paradigm shifting from the traditional host (location) centric mode of the current Internet to a content centric mode for the future Internet. In ICN, data names instead of IP addresses are used for routing and data delivery, making data rather than its containers a first-class citizen of the Internet.

These named data based approaches can satisfy application demands directly and better accommodate Internet users' usage patterns. Particularly it is efficient for the transmission of the multimedia sessions which have a large amount of data reused many times by different users. ICN caches named data along the transmission path and serves duplicate requests by the cached data at the locations close to requesting clients. Therefore, it reduces the data transmission delay, avoids network congestion and optimizes network traffic, resulting in significant improvement in the network scalability and the throughput of the multimedia content delivery. Moreover, ICN inherently support seamless mobility. This feature is important for the QoS guarantee of multimedia sessions that have long communication time and larger handover events. Finally, the information centric characteristics of ICN can be easily extended to support multicast and traffic aggregation. This is helpful to alleviate the network traffic burden caused by the transmission of multimedia applications.

Despite of the advantages illustrated above, the ICN architecture has its own weaknesses on the transmission of multimedia sessions. In order to maintain dynamic connections, ICN requires sending data requests (interest) and replies on a single packet basis. This one request per packet mode incurs serious overhead for the multimedia content transmission, because multimedia sessions usually consist of a large number of short packets. In addition, the single packet request/reply mode may have difficulties in satisfying the real time requirements of multimedia applications. Latest research work [6] has proposed to solve this problem by traffic classification and request aggregation. And in our opinion, the content-based architecture of ICN is not enough for the efficient transmission of the different sessions for future Internet. We should extend this idea to the service based or service oriented Internet architectures [7]. Different from the content, service is dynamic and has more properties requiring more complicated mechanisms for naming and routing.

Other new Internet architectures proposed in recent years also take into consideration of the transmission of multimedia transactions. For example, Openflow [8] and Nebula [9] provide a separate control plane and use it to make corresponding strategies to guarantee the QoS of the multimedia sessions.

3. Conclusions

In future Internet, various multimedia applications will generate dominant amount of traffic. This brings new challenges for the network performance, especially on the scalability and the QoS support. The current Internet architecture based on TCP/IP has its inherent weaknesses. In recent years, different proposals on future Internet architectures and protocols have been raised. All of these approaches consider enhancing the multimedia transmission efficiency as an important policy, and this will further promote the development and popularity of multimedia applications.

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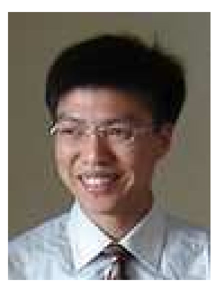
Yi Sun currently acts as an associate professor at Institute of Computing Technology, Chinese Academy of Sciences (ICT/CAS) and an adjunct associate professor at Maquarie University, Sydney. His research interests include future Internet architecture and mobile computing.

Hanwen Zhang is an Assistant Professor at ICT/CAS. Her current research interests include mobile network, network protocol and architecture.

Haibin Zhai is a Ph.D. candidate of ICT/CAS, Beijing, China. His research interests include peer-to-peer systems, and future Internet architecture.

Yang Guo is a postgraduate at ICT/CAS. His research interests include Internet architecture and mobile Internet.



Gaogang Xie is a professor at ICT/CAS. His research interests include future Internet architecture and programmable virtual router.

Streaming High-bandwidth Real-time Video Traffic in Residential Wireless Networks: A Measurement Study

Ramya Raghavendra, IBM Research, USA
Elizabeth M Belding, University of California Santa Barbara, USA
{rraghav}@us.ibm.com, {ebelding}@cs.ucsb.edu

1. Multimedia traffic

The popularity of social networking and chat applications have resulted in an increase in data that users are generating and uploading to the web, compared to web traffic that was predominantly in the downlink direction. The delivery of multimedia content is growing at a tremendous rate, increasing 76% every year on average, with video communication and real-time traffic growth predicted to increase tenfold by the year 2013 [1]. This surge of media rich applications is leading to a “broadband access” gap, created by broadband access links, or the edges, that are not growing at the same rate as core routing, switching and transmission capacity. Upgrading access links is expensive and new technologies often take several years to deploy. As a result, access technology can vary dramatically from neighborhood to neighborhood, and even home to home in the same neighborhood.

There have been numerous measurement studies of Wi-Fi networks; broadband networks and the Internet in the past, but an overwhelming majority of them are based on TCP traffic. Real-time video streaming applications typically use a streaming protocol such as RTP and RTCP, with UDP at the transport layer. Hence, the conclusions from prior work do not apply directly when studying video streaming performance. Video traffic analysis has been studied over wireless LANs [2] as well as over the Internet [3]. These studies focus on the performance of video streaming applications that can tolerate a high amount of initial delay due to buffering.

However, there are no comprehensive studies that characterize the performance of interactive video traffic over residential connections. Video streaming in such networks suffers from losses and delays at the wireless link, the access link, as well as the ISP network. The common consensus among users is that high bitrate video quality suffers in residential networks. Various factors contribute to the degradation in video quality: wireless losses, congestion, poor uplink quality, queuing, large delays and jitters. It is important to understand what factors affect the video quality, and to what extent, in order to build robust video streaming techniques.

We analyze the results of 24 hour long monitoring and real-time streaming experiments from eight residences that have broadband Internet connections in order to characterize the interactive video streaming quality. A detailed report of our measurement study is presented in [17]. Using videos encoded with MPEG-4, and using RTP and UDP protocols for streaming, we study the properties of wireless and the end-to-end links in terms of the bandwidth available for streaming, loss and latency that packets experience, and the effect on streaming quality.

2. Measurement Study

We study factors that affect the video quality: available bandwidth, packet latency, delay variation and packet loss, and discuss the implication of these measurements on real-time video streaming.

Bandwidth: We measure the capacity available on the wireless link as well as the total end-to-end capacity. The capacity can be bottlenecked either at the wireless link, due to contention or poor quality links, or at the broadband uplink. We observe that the bottleneck in a broadband network is at the access hop, i.e., the last hop from the residence to the ISP network. Measuring the bandwidth available for a user helps predict the maximum bitrate for video streaming that can be sustained. In a cable network, this refers to the portion of the shared link allocated to a user, while in a DSL network it refers to the ISP’s cap on the user’s traffic rate. We did not observe any difference in the available broadband bandwidth between houses and apartments, but did observe a difference between the speeds of cable and DSL networks. While the DSL downstream bandwidths are typically higher than cable bandwidths, the gap between the upload and download bandwidths is much wider in cable networks than DSL networks. This implies that an interactive video application such as video chat is more constrained by the low uplink speed in a cable network.

Understanding the link stability is important in the design of a video streaming solution since loss or late delivery of a single frame can cause disruption for a perceivable length of time, depending on the type of frame lost. We see that a high degree of variation is seen in broadband networks, especially in cable networks where residences share the connection to the headend. Wireless networks show variation due to the changing environment and changes in interference and contention from other users and networks or non-802.11 devices that share the spectrum.

The conclusions from our bandwidth study can be summarized as follows:

- Wireless networks see high utilization for short periods of time, but for the most part, are not heavily utilized.
- Broadband uploads witness slow speeds that are much lower than the bit rates needed by high-definition videos.
- Broadband links have a high degree of variation in the available bandwidth.

Packet Latency: In contrast to data transmission, which is usually not subject to strict delay constraints, real-time video requires bounded end-to-end delay. In real-time video streaming, video frames are played as they are received and packet delay variation, or jitter, degrades the perceptual quality of the video. If a frame arrives late, the players freeze the most recently seen image. When the next frame arrives, it is displayed briefly to preserve the timing for the subsequent frame. A video packet that arrives beyond its playback deadline is useless and can be considered lost.

The conclusions of our latency analysis are:

- Packets experience considerable, but varying, delays on the access link. Some broadband links can have large queues that make real-time traffic infeasible.
- The video receiver should have a playout buffer that accounts for the large broadband jitter values. Since the maximum end-to-end delay is known, a real-time streaming system should choose APs that are likely to deliver a packet in time, taking into account the link delays and jitter.

Packet Loss: The extent of packet loss and loss burstiness are both important link characteristics that can affect the video quality significantly. Loss burst lengths are important to video applications since players can typically mask losses of a few bytes. However, losses that last for a long duration can result in perceivable video quality degradation such as a frozen frame [11]. The wireless network shows a more bursty loss length, with loss lengths in the order of tens of packets on average. This variation in loss length behavior affects the choice of error recovery techniques for streaming video in residential networks over both the wireless and broadband links. While wireless networks have high loss rates, the delays on broadband networks increase as the load increases.

Discussion: As the popularity of multimedia applications and the amount of video traffic generated continues to increase, the measurement study shown here points out critical constraints that exists in the present day networks, i.e. the capacity and latency of the broadband links. The upload bandwidths available are in the order of 1 Mbps, which is much below what is required for a HD video of 720p or 1080p resolutions.

The bandwidth available can also vary, specifically in cable networks where the medium is shared and this will pose a problem for video encoders that scale the encoding rate based on available bandwidth [12], [13]. The latency and jitter measurements imply that players need to include a large playout buffer, which affects the real-time traffic. The queuing delays that are seen during high load conditions can introduce delays in the order of several hundreds of milliseconds up to a second, which can severely degrade an interactive video quality.

4. Conclusions

We study the properties of wireless and end-to-end links in residential networks in terms of the bandwidth available for streaming, loss and latency that packets experience and the effect on streaming quality. We find the uplink bandwidth in broadband networks is typically insufficient to stream HD video streams. Further, the high latency that can be experienced on these networks can make real-time communication nearly infeasible. The measurements presented in this work can serve as a guide on what video resolutions will be supported, and the buffer sizes needed for residential real-time video applications.

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Ramya Raghavendra is a Researcher at IBM TJ Watson Research Labs. Prior to that, she received her PhD from University of California Santa Barbara. Her research interests lie in the areas of network measurement and mangement, and wireless networking. She is the recipient of Google Anita Borg scholarship, UCSB Oustanding Graduate Student award and ACM SRC award.

Elizabeth M. Belding is a Professor in the Department of Computer Science at the University of California, Santa Barbara, and is currently the department’s Vice Chair. Elizabeth’s research focuses on mobile networking, specifically multimedia, monitoring, advanced service support, and solutions for developing and underdeveloped regions. Elizabeth is the recipient of an NSF CAREER Award, and a 2002 MIT Technology Review 100 award, awarded to the world’s top young investigators.

The IRMOS/ISONI Real-Time Cloud Infrastructure: a Virtualised e-Learning Case-Study

T. Cucinotta, F. Checconi, Scuola Superiore Sant'Anna, Italy, {t.cucinotta} @sssup.it
G. Kousiouris, D. Kyriazis, T. Varvarigou, National Technical University of Athens, Greece
A. Mazzetti, GIUNTI Labs, Italy
Z. Zlatev, J. Papay, M. Boniface ,University of Southampton IT Innovation Centre, UK
S. Berger, D. Lamp University of Stuttgart, Germany
T. Voith, M. Stein, Alcatel Lucent, Germany

1. Introduction

Nowadays, applications are increasingly developed and made available in distributed infrastructures, where users access their services from remote. In the Cloud Computing model, applications are developed by Software-as-a-Service (SaaS) providers, by means of tools made available by Platform-as-a-Service (PaaS) providers, for being deployed over the resources made available by Infrastructure-as-a-Service (IaaS) providers. The viability of IaaS is dependent on the use of virtualisation technologies, which allow for deploying multiple virtual machines (VMs), hosting multiple Operating Systems and services, over the same physical hosts, achieving an increased server consolidation level.

In this evolving scenario, more and more distributed applications with *tight interactivity and timing requirements* are being deployed over virtualised IaaS infrastructures. Unfortunately, when multiple VMs are deployed over the same physical resources (e.g., links and CPUs), the level of performance experienced by each VM is not stable any more, but it depends heavily on the overall workload imposed by the other VMs competing for the shared resources. However, using proper scheduling technologies and performance modelling techniques, it is possible to deploy virtualised distributed applications with a stable performance level, as being experimented with the virtualised Cloud Computing infrastructure developed in the IRMOS EU Project (http://www.irmosproject.eu/)

In this paper, we show how these concepts have been practically applied to a real e-Learning application. A more extended discussion can be found in the original article [8] appeared at the IEEE SOCA 2010 Conference.

2. Performance Isolation in IRMOS/ISONI

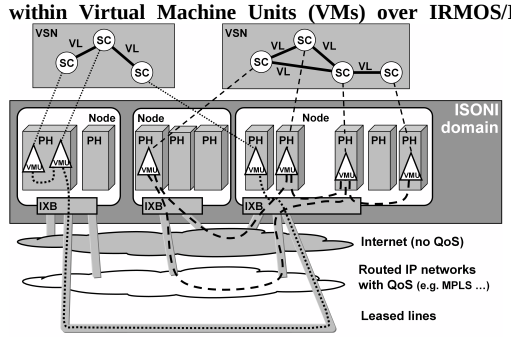
One of the core components developed in IRMOS is the Intelligent Service-Oriented Networking Infrastructure (ISONI) [1] . It acts as a Cloud Computing (http://www.cloudcomputing.org/) IaaS provider for the IRMOS framework and manages a set of physical computing, networking and storage resources available within a provider domain (see Figure 1).

ISONI provides the visualised resources over which IRMOS applications are deployed. One of the key innovations introduced by ISONI is its capability to ensure guaranteed levels of resource allocation for each individual application instance hosted within the ISONI domain.

This is realised by allowing applications to be deployed in form of a Virtual Service Network (VSN). This is a graph whose vertices represent Application Service Components (ASCs) which may be deployed in form of VMs, and whose edges represent communications among them.

In order for the system represented by a VSN to comply with real-time constraints as a whole, QoS needs to be supported for all the involved resources, particularly for network links, CPUs and storage resources. To this purpose, VSN elements are associated with precise resource requirements, e.g., in terms of the required

Figure 1: Deployment of Service Components (SCs) within Virtual Machine Units (VMs) over IRMOS/ISONI.



computing power for each node and the required networking performance (i.e., bandwidth, latency, jitter, etc.) for each link. These requirements are fulfilled thanks to the allocation and admission control logic pursued by ISONI for instantiating VMs within the managed set of available physical resources, and to the low-level mechanisms shortly described in what follows (a comprehensive ISONI overview is out of the scope of this paper and can be found in [1]).

Isolation of Computing. In order to provide scheduling guarantees to individual VMs scheduled on the same system, processor and core, IRMOS incorporates a deadline-based real-time scheduler [2] for the Linux kernel. It provides temporal isolation among multiple possibly complex software components, such as entire VMs (with the KVM hypervisor, a VM is seen as a process). It uses a variation of the Constant Bandwidth Server (CBS) algorithm [3] , based on Earliest Deadline First (EDF), for ensuring that each group of processes/threads is scheduled for Q time units (the budget) every P time units (the period) on the available CPUs.

Isolation of Networking. Isolation of the traffic of independent VMs within ISONI is achieved by a VSN-individual virtual address space and by policing the network traffic of each deployed VSN. The two-layer address approach avoids unwanted crosstalk between services sharing physical network links. The traffic policing avoids that the network traffic going through the same network elements causes any overload leading to an unduly uncontrolled growth of loss rate, delay and jitter for the network connections of other VSNs. Therefore, bandwidth policing is an essential building block to ensure QoS for the individual virtual links. It is important to highlight that ISONI allows for the specification of the networking requirements in terms of common and technology-neutral traffic characterisation parameters, such as the needed guaranteed average and peak bandwidth, latency and jitter. An ISONI transport network adaptation layer abstracts from technology-specific QoS mechanisms of the networks, like Diffserv [4], Intserv [5][6] and MPLS [7] . The specified VSN networking requirements are met by choosing the most appropriate transport network, among the available ones: either networks without any QoS like the Internet, or networks with QoS mechanisms or leased lines (see Figure 1).

3. Performance Prediction

One of the key steps in deploying applications with precise QoS guarantees within IRMOS is the one of building a performance model of the application behaviour. This allows for correlating the inter-dependencies between application-specific parameters, the achievable QoS levels and the corresponding needed allocation on the available physical resources.

This is a key information for the SaaS provider to correctly dimension the resource allocation for applications, and establish an accurate pricing policy for the customer(s).

Application performance in the cloud depends on many complex factors such as the application workload, the conditions of the network paths between the user(s) and the server(s) and the computing workload of the physical host(s). However, the ISONI support for temporal isolation of VMs with guaranteed QoS highly reduces the interference due to shared resources. This allows for benchmarking the performance of an individual application in isolation and model it as a pure function of application-specific parameters and the amount of allocated resources.

Performance Estimation through ANN. When building a performance model, many times the application internal software structure may be too complex to be modelled. Or, it may be unknown because developers are reluctant to share detailed information about their application internals, for confidentiality purposes. In other cases, the use of external libraries or components whose internals are unknown makes it impossible to build an exact model. So, from a modelling point of view, it is critical to be able to identify the expected QoS output using a *black-box* approach.

Therefore, we use a combination of a stochastic model for predicting statistics over the expected run-time networking performance, and an Artificial Neural Network (ANN) for identifying the dependency of a component QoS from factors like application-level parameters (e.g., number of clients) or scheduling parameters (e.g., allocated budget and period). These two models, put together, allow for a precise estimate of the overall end-to-end QoS experienced by end-users.

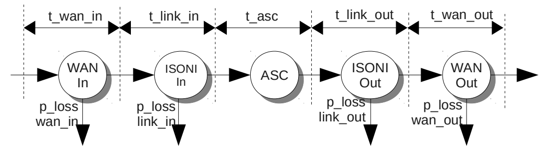


Figure 2: Stochastic performance model: t_wan_in and t_wan_out are modeled as exponential distributions, the other delays as Erlang ones.

Stochastic Performance Model. Sometimes one has to inevitably deal with non-predictable factors, such as the actual number of users actually making use of a certain application, or the amount of other networking traffic that interferes with the application we are designing on general-purpose networks, such as the Internet. To this purpose, in IRMOS we used a Monte-Carlo type discrete event simulation, modelling a generic system by composing a few building blocks: a users request generator, a Public Wide Area Network, a Private Network internal to an ISONI domain and the VM hosting the actual ASC. The model uses a mix of exponential and Erlang probability distributions (see Figure 2) for modelling the latencies of application requests while traversing the involved networks, and it may also simulate packet loss due to buffer saturation.

The individual parameters of the model need to be tuned by resorting to proper benchmarking techniques. The behaviour of the latencies inside the ISONI internal network may be accurately estimated thanks to the ISONI networking isolation, and they depend merely on the requested network-level QoS parameters specified in the VSN, and the requests pattern. On the other hand, parameters relative to the QoS-unaware WAN must be estimated based on available statistics on the overall network workload foreseen at the time of usage of the application.

The behaviour of the ASC is also estimated in stochastic terms, by using an Erlang distribution, or by resorting to the black-box approach based on ANN sketched out above.

The simulator is capable of providing the full probability distribution of the end-to-end response-times, as well as simpler statistics that may be easily leveraged at design-time, such as the average or a given percentile of the distribution. For example, this allows for finding the configuration parameters granting a given end-to-end response-time with a given probability.

The e-Learning Application

In order to validate the proposed methodology, we focused on an e-Learning mobile instant content delivery application, in which real-time requirements play an important role. In this scenario a user can receive on his/her mobile phone some e-Learning contents relevant to his/her position (e.g., near historical monuments). The application is able to receive queries with GPS data from multiple clients, search the

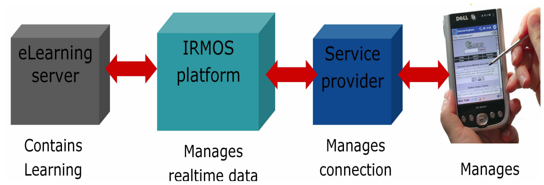


Figure 3. Components of the e-Learning application.

database and respond with e-Learning contents corresponding to the provided GPS coordinates (see Figure 3). The application server is installed as a VM image within the IRMOS infrastructure. Using ISONI, each instance of the application can be assigned precise computing and networking resources. The allocation is tuned through the ANN-based and stochastic-based models just described. The timing requirements of the application are mainly related to the response times of the individual requests submitted by the multitude of users. Thanks to the deployment within IRMOS, these response times depend mostly on application-specific parameters, i.e., the number of concurrent users querying the same e-Learning instance and the size of the downloaded contents. This ensures that the high-level requirements defined within a Service-Level Agreement can be met with an agreed level of reliability. More details are available in .

4. Conclusions

In this work, we discussed how a real e-Learning distributed application has been deployed with stable QoS levels within the IRMOS platform, by flanking the temporal isolation mechanisms available within IRMOS with proper performance analysis, modelling and benchmarking. Further details are available in [8].

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Tommaso Cucinotta is Assistant Professor at the Real-Time Systems Laboratory of Scuola Superiore Sant'Anna. His main research interests are: QoS control for soft real-time applications; real-time support for General-purpose OSes and virtualisation; security in real-time and embedded systems.

The other co-authors of this paper are researchers from prominent academic and industrial applications that participated to the IRMOS consortium. More information is available at: http://www.irmosproject.eu/.

On Hybrid Optical/Electrical Networks for Datacenters and Stream Computing

L. Schares [1], P. Pepeljugoski[1], M. Sanduleanu[1],
K. Katrinis[2], D. Lugones[3], M. Collier[3], E. Schenfeld[1].
[1] IBM – TJ Watson Research Center, Yorktown Heights, NY USA.
[2]IBM Research, Dublin Research Lab, Ireland. [3] Dublin City University, Ireland.
schares@us.ibm.com

1. Why Hybrid Networks?

Many modern "big-data" workloads, such as software redistributions, all-to-all data shuffles, real-time streaming, or cluster-type applications, need to move huge amounts of data between servers. As a result, network bandwidth and latency start to become performance bottlenecks. In traditional tree-like data center networks – that include, e.g., top-of-rack, aggregation and core switches/routers – the end-to-end latency between two nodes can be tens of microseconds if data has to travel through several stages of Ethernet switches/routers. In such networks, the capacity between different branches of the tree is often significantly oversubscribed due to the high power dissipation and cost of core routers. As a result, congestion can lead to further impairments for latency-sensitive applications.

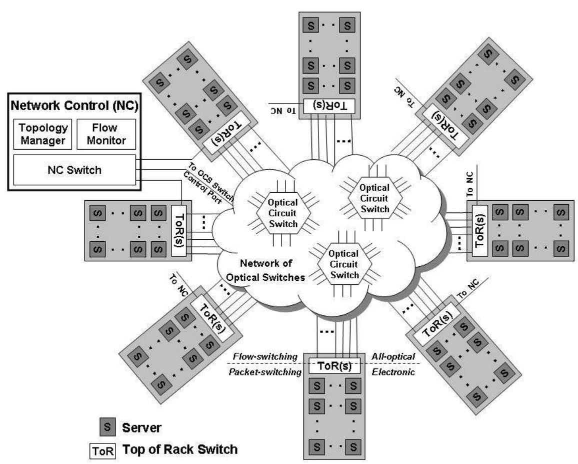

Figure 1 – Sample system architecture using hybrid OCS/electrical fabric in datacenter network

Hybrid optical/electrical networks, formed by adding an optical circuit switched (OCS) network in parallel to a conventional electrical (packet-switched) network, are an attractive alternative for high-bandwidth and latency-sensitive data traffic. Various OCS network implementations have been proposed in recent years for High-Performance Computing (HPC) [1-3], datacenters/cloud [4-7] and stream processing clusters [8-10]. A sample architecture is shown in Figure 1. Those demonstrations have often used 3D-Micro-Electro-Mechanical-Systems (MEMS) mirror-based optical switches to implement networks for the purpose of switching data traffic among server racks or other higher levels of server aggregation in HPC systems and datacenters.

Most optical connectivity in today's datacenters is provided by active optical cables or by pluggable optical transceivers connected to fiber cables. In fact, as data rates and the number of lanes per I/O port increase (for example, 100-Gb/s Ethernet links may use 10+10 lanes at 10 Gb/s each or 4 lanes at 25 Gb/s each), power dissipation, size and weight make it increasingly unlikely that copper cables will be used for interconnection exceeding a few meters. Hybrid networks promise various advantages compared to conventional, optically interconnected networks using only electrical switches and routers: cost savings due to reduced numbers of optical transceivers, lower sensitivity to bandwidth and protocol upgrades at the edge of the network, and reduced switching latency once optical circuits are set up. In this article we review current research on optically switched and hybrid optical/networks, and we outline challenges and future work required to make such networks a reality.

2. Hybrid OCS Network for Stream Computing

The hybrid optical/electrical network approach is particularly suited for streaming applications, which often have long-lived circuit-like communication patterns that are typically on the order of minutes or longer. In past work [8-10], we demonstrated the use of a software-controlled optical circuit switch in a stream computing system with layer-2 routing, and we showed that current 3D-MEMS mirror array technology that switches at a rate of tens of milliseconds satisfies the need of most streaming applications.

In our demonstrator, a software optimizing scheduler adapted the physical interconnect topology in response to system needs, matching logical flow graphs by reconfiguring the optical switch. The dynamic reallocation of network resources allowed us to balance the networking load over time for varying data and data processing graphs. Our OCS demonstrator comprised three IBM BladeCenter® chassis interconnected over two networks: an optical network using a 3D MEMS-mirror based optical circuit switch for data traffic, and a parallel electrical 1-Gb/s Ethernet network for both control and data traffic. Each chassis hosted four blade servers and a 10-Gb/s Ethernet switch module with optical transceivers. The 10GbE switches were optically connected to the OCS. Our stream computing middleware included a dynamic routing mechanism that reconfigured data streams to use either the optical or the electrical network. We demonstrated full functionality of our hybrid optical/electrical network demonstrator and ran streaming applications with multiple jobs. Our middleware was able to control the optical switch and set up the proper layer-2 routing, and the optimizing scheduler reconfigured both the optical and electrical network appropriately in response to changing requirements of streaming applications.

3. Future Research Directions

It is now well understood that an electrical network needs to be working in tandem with an OCS fabric for handling communication patterns. The use of the latter is inherently not effective/efficient for collectives and short-lived flows, as well as for OCS topology management and flow control.

MEMS-mirror based optical circuit switches are commercially available with hundreds of ports and low insertion loss. Economies of scale have recently started to significantly reduce the per-port cost, as these switches are increasingly being used in telecommunication networks (namely in reconfigurable optical add-drop multiplexers, or ROADMs). However, many challenges are still in the way of deploying commodity MEMS-based interconnects in production datacenters or HPC systems. These mainly stem from the fact that such devices switch at (point-to-point) circuit granularity and exhibit a reconfiguration delay that exceeds by multiple orders of magnitude the time that a packet/message of typical size takes to traverse a circuit.

At the physical layer, there are technologies that provide significantly faster optical circuit switching than the millisecond-times of MEMS-mirror based switches. For example, switching times in the nanosecond range have been shown by silicon photonics based switches [11] and by tunable lasers combined with a passive wavelength selective switch [12]. However, optical insertion loss has limited both schemes to a few tens of ports. While such short time constants allow far more efficient switching for short packets, the small switch radices may limit the applicability of these optical switch technologies to small or mid-sized networks.

Given all the above, significant research on routing, flow control and resource allocation is required towards an out-of-the-box hybrid network solution. Novel incremental routing algorithms need to be devised that hide or otherwise minimize the penalty of long switch reconfiguration, potentially using the electrical network as an interim bypass medium. Promising routing schemes include layer-2 multipath implementations based on the IETF TRILL standard, or software-defined network topologies based on the OpenFlow protocol. The problem becomes more challenging at larger scales, where alternative optical switching technologies need to be evaluated and supported with efficient reconfiguration algorithms.

Methods for efficient real-time traffic partitioning between the optical/electronic network need to be devised, including real-time traffic aggregation and monitoring techniques. Particularly when applied within the HPC domain, it is critical to take into consideration the communication footprint of workloads of interest. Eventually, this should increase our understanding of the classes of applications that can immediately benefit from hybrid optical/electrical interconnects and ultimately unveil whether this constitutes a workload-optimized or blanket solution, constrained by projected optical switch technology evolution.

In hand with the “science” required to mature the area, several engineering issues need to be resolved, both to enable production deployment, as well as for creating prototypes for the purpose of experimentation. The key issue here is the integration of hybrid inter-rack interconnects with the edge networking infrastructure (e.g. Top of Rack switches in datacenters or Network Interface Cards in HPC), at protocol and technology level.

Lastly, the role of sub-systems affecting the performance of a fabric should not be underestimated. In view of this, inter-disciplinary approaches may further improve a hybrid interconnect solution, such as compiler-assisted techniques for allocation of communication resources and joint-optimization of task scheduling/partitioning and logical communication embedding.

4. Conclusions

The use of optical circuit switching in hybrid computer networks has significant potential to improve bandwidth, latency and power consumption for a vast class of big-data, HPC and streaming applications. We reviewed current work and outlined future research directions needed to help make hybrid networks a reality.

Acknowledgments

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Laurent Schares is a Research Staff Member at the IBM Thomas J. Watson Research Center, Yorktown Heights, NY, which he joined in 2004. His current research interests include optical networks and low-power optical interconnects for future datacenters and supercomputers. He has more than 80 technical publications. Dr. Schares received the Diploma and the Ph.D. degrees in physics from the Swiss Federal Institute of Technology (ETH) Zurich, Switzerland, in 1998 and 2003, respectively.

Petar Pepeljugoski received the Ph.D. degree from University of California, Berkeley, in 1994. He joined IBM as a Research Staff Member in 1994. His research work included design, modeling, prototyping, and characterization of multimode fiber LAN links and parallel optical and electrical interconnects. He has contributed to numerous Ethernet (IEEE 802.3z, IEEE 802.3ae, IEEE 802.3aq, IEEE 802.3ba) standards, as well as to the development of the specification of the OM3 fiber, and was subsequently recognized for his contributions. Dr. Pepeljugoski is an author or coauthor of more than 60 journal or conference articles.

Mihai Sanduleanu received his PhD degree from University of Twente, The Netherlands in 1998. In 2008, he joined the IBM Thomas J. Watson Research Center in Yorktown Heights. His current research interests include high speed low/medium resolution ADCs for ADC based IOs, wireless communication systems and circuits, mm-Wave and sub mm-Wave design techniques and fiber optic transceivers. Dr. Sanduleanu authored or co-authored more than 46 journal or conference articles and he holds 36 US patents.

Kostas Katrinis is a Research Staff Member at the IBM Exascale Collaboratory in Dublin, Ireland, working from a Systems perspective towards the next frontier in supercomputing. His research interests are in electronic/optical interconnects and network systems. Dr. Katrinis holds a PhD in Technical Sciences from ETH Zurich, Switzerland (2006) and a Diploma in Computer Engineering and Informatics from the University of Patras, Greece (2000).

Diego Lugones is a post-doctoral researcher at the DCU RINCE institute in Dublin, Ireland working under the IRCSET partnership scheme involving DCU and IBM. He has received the M.Sc. and Ph.D. degrees in computer science from the University Autónoma of Barcelona (UAB, Spain) in 2007 and 2009, respectively. He has been a contingent worker at the Exascale Computing Lab, HP-Labs, in 2008. His research interests include high-performance computing and, particularly, modeling, dimensioning and design of interconnection networks and routing algorithms.

Martin Collier received the B.Eng. and M.Eng. degrees in electronic engineering from the National Institute for Higher Education, Dublin, Ireland, in 1986 and 1988, respectively, and the Ph.D. degree from Dublin City University (DCU), Dublin, Ireland, in 1993. Currently, he is a Senior Lecturer with DCU, where he runs the Switching and Systems Laboratory. He established the Research Institute for Networks and Communications Engineering (RINCE), DCU, in 1999. His research interests include programmable networks, quality of service, and advanced switching techniques.

Eugen Schenfeld holds a BSc in Computer Engineering and an MSc in Electrical Engineering from the Technion, Israeli Institute of Technology; and a PhD in Computer Science from the Hebrew University in Jerusalem awarded in 1982, 1986 and 1990 respectively. He is a Research Scientist at the IBM T.J. Watson Research Center in Yorktown Heights, NY. Dr. Schenfeld has published over 100 papers in journals, and conferences, 2 book chapters. He was the founder of the IEEE MPPOI conference and has served as guest editor for Applied Optics and Subject Area Editor for the Journal of Parallel and Distributed Computing. His current interests include datacenter network architectures, stream processing, and optical interconnects.

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