Green Networking Systems

Basem Shihada

CEMSE, KAUST
Bell's Law*: Every decade sees a change in the class of computing devices

- 1990s saw the emergence of the laptop;
- 2000-2010 saw the mobile phones;
- Next decade, desktops will disappear. End-user computers will be almost entirely laptops & tablets.
- Data and applications will live in the cloud.

Ubiquitous high-speed wireless connectivity is a must.

- Dense, small-range wireless access points (AP) will become more important than today.
- Spectrum is limited, neighboring APs will likely have to operate on the same spectrum.
- Interference between neighboring APs will become the dominating factor.
- Small cells connectivity and load will fluctuate rapidly, both in space and time.

* Bell's Law of Computer Classes formulated by Gordon Bell in 1972, describes how types of computing systems (referred to as computer classes) form, evolve and may eventually die out.
ICT Energy Consumption Trends

• Information and Communication Technology (ICT) alone consumes 2-10% of the world’s generated power.
• ICT sector produces about 2-3% of the total emissions of greenhouse gases.
• Current figures are expected to double by 2020, with PCs being the major contributor!
Energy in Wireless Networks

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Mobile WiMAX</th>
<th>HSPA</th>
<th>LTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital signal processing</td>
<td>$P_{el/proc}$</td>
<td>100 W</td>
<td>100 W</td>
</tr>
<tr>
<td>Power amplifier SISO (1x1)</td>
<td>$P_{el/amp}$</td>
<td>100 W</td>
<td>300 W</td>
</tr>
<tr>
<td></td>
<td>$\eta$</td>
<td>10 %</td>
<td>6.67 %</td>
</tr>
<tr>
<td></td>
<td>$RF_{out}$</td>
<td>40 dBm</td>
<td>43 dBm</td>
</tr>
<tr>
<td>Power amplifier MIMO</td>
<td>$P_{el/amp}$</td>
<td>10.4 W</td>
<td>10.4 W</td>
</tr>
<tr>
<td></td>
<td>$\eta$</td>
<td>11.54 %</td>
<td>11.54 %</td>
</tr>
<tr>
<td></td>
<td>$RF_{out}$</td>
<td>30 dBm</td>
<td>30 dBm</td>
</tr>
<tr>
<td>Transceiver</td>
<td>$P_{el/trans}$</td>
<td>100 W</td>
<td>100 W</td>
</tr>
<tr>
<td>Signal generator</td>
<td>$P_{el/gen}$</td>
<td>384 W</td>
<td>384 W</td>
</tr>
<tr>
<td>AC-DC converter</td>
<td>$P_{el/conv}$</td>
<td>100 W</td>
<td>100 W</td>
</tr>
<tr>
<td>Air conditioning</td>
<td>$P_{el/airco}$</td>
<td>690 W</td>
<td>690 W</td>
</tr>
<tr>
<td>Microwave link</td>
<td>$P_{el/micro}$</td>
<td>80 W</td>
<td>80 W</td>
</tr>
</tbody>
</table>

Sparse area using diesel generator operated mobile BS, Vodafone uses excess of 1 million gallons diesel per day.

About 10% of the energy drawn from the electric grid is converted to Radio Frequency. Mobile Operator Cost and User Satisfaction Tradeoff!!
Our Objective

It is not easy being green! Why?
- If we increase the network traffic, we increase the revenue.
- If we reduce the energy we cut the revenue.
- Optimization and tradeoff!

Our ultimate goal is to develop practical solutions for green networking:
1. Investigate how easy being networking green?
2. Develop a sustainable green networking system while considering traffic growth.
3. Obtain a vision along with plan for future sustainable networking.
4. Develop energy-efficient resource allocation schemes for wired and wireless networking.
5. Obtain new and expanding business areas for green networking.
Application Domains
Cellular and Wireless Packet Networks
Superposition Coding Multicasting

Implemented a Superposition Coding Multicasting to solve user diversity problem using NI-PXIe emulators\textsuperscript{1,2,3}.


Delays in Wireless Mesh Networks

- The **objective** is to optimize buffer sizes to balance the throughput and delay requirements\(^1\),\(^2\),\(^3\).
- Proposed a distributed, neighborhood buffer, that is sized for saturating the channel while minimizing queueing delays.
- We **proved** that using small buffers (1-4 packets) improves delay by up to 10x\(^1\).
- We **implemented** our scheme in a Linux testbed WMN deployed on the 4\(^{th}\) floor of Building 1\(^2\).

---

Frame Aggregation & Buffering in 802.11n

- The **objective** is to understand the impact of frame aggregation and buffer size on 802.11n\(^1,2\)
- Smart aggregation mechanisms can reduce **end-to-end delays** by over 10x
- Measurement, characterization, and implementation on a Linux based testbed
- Results show frame aggregation can **improve end-to-end delays**.

---


Energy Optimization in Wireless Multi-Hop Networks

- The **objective** is to minimize the energy consumption at the energy-critical nodes and the overall network transmission delay\(^1,3\).
- The transmission rates of energy-critical nodes are adjusted according to its local packet queue size.
- We **proved** that there exists a threshold type control which is optimal\(^1\).
- We **implemented** a decentralized algorithm to control the packets scheduling of these energy-critical nodes\(^2\).

---

Summary

- Implement Superposition Coded Multicasting for scalable video over WiMax
- Invent an optimal buffering scheme for wireless mesh networks
- Improve wireless mesh network delay and fairness
- Optimize frame aggregation schemes for 802.11n
Wireless Cognitive Radio Systems
Cognitive Radio Resource Management

- Huge demand for wireless communication will saturate channels’ capacities in the unlicensed band.
- **Dynamic Spectrum Access (DSA)** is a fair solution for spectrum utilization.
- Cognitive radio is not only DSA. It can be used for radio resources management.
- Build systems that can sense, observe, reason and adapt to wireless environment conditions (Mitola’s Vision).
Energy Efficient Cognitive Radio Utilizing Sensing Information

- The **objective** is to minimize the EPG metric subject to\(^1,2\):
  1. Rate constraint.
  2. Interference constraint.
  3. Peak Power constraint.
- The optimal resource allocation is done while combining the **soft sensing information**.
- Soft sensing information is the knowledge we obtain about the PT before making the detection decision.
- We generalized the targeted scenarios into PU **Exists** and **Absent** with a certain probability\(^2\).

- We proved the **convexity** of the problem.
- We utilized the calculus of variation theory to obtain an optimal and sub-optimal solutions.

---

Energy Efficient (EE) Beamforming Utilizing Sensing Information

In this system model we considered optimizing two metrics:\textsuperscript{1,2}

1. Maximizing \textit{SINR} subject to:
   a. Peak power constraint.
   b. A \textit{statistical interference} constraint.

2. Maximizing \textit{EE}, subject to:
   a. Peak power constraint.
   b. A \textit{statistical interference} constraint.
   c. \textit{Rate} constraint.

Converted the non-convex problem into a \textit{SDP} problem, (which guarantees a global optimal solution).

Both problems are solved while utilizing hard sensing information (sensing information after taking the detection decision).


Summary

- Implemented a CogWNet framework
- Uses CogWNet for 802.11 Home devices
- Uses CogWNet for LTE
Wireless Sensor Systems
Sensors at the Glance

• Characteristics
  o Low-cost, low-power, light weight
  o Densely deployed
  o Prone to failures
  o Two ways of deployment: randomly, pre-determined
  o Motes are tiny, self-contained, battery powered computers with radio links, which enable them to communicate and exchange data with one another, and to self-organize into ad hoc networks

• Objectives
  o Monitor activities
  o Gather and diffuse information
  o Communicate with global data processing unit
Adaptive Power Actuators

• Implement a real-time vehicular guidance system for effective disaster management\(^1\).

• Maintaining the system’s energy efficiency using statistical, correlation, and confidence for determining actuator decision on each node.

• Implement an adaptive energy scheme to prolong the system lifespan.

• Deploy an experimental testbed using Telos motes and toy cars.

---

\(^1\) I. Boudellioua and B. Shihada, "Energy Efficient Wireless Vehicular-Guided Actuator Network", in Proc. IEEE International Conference on Computer Communications and Networks - The Sixth International Workshop on Sensor Networks, Accepted, 2013.
Optimal Underwater Sensor Placement

- **Surface Gateways (SG):** acoustic transceivers
- **Relay Nodes (RN):** homogenous transceivers
- Uniform transmission power
- Each node forms a communication sphere of radius $r$
- Two nodes are connected if inter-distance is less than or equal to $r$
- Nodes are statically placed and maintain their positions
- Ocean is divided horizontally into regions based on the depth
- Propagation characteristic is different in each region

---

Towards Optimal Event Detection and Localization

• We identify and solve the problem of Event Detection and Localization in Acyclic Flow Networks\(^1,2\).

• We proved that Event Detection problem is NP-hard and provide a heuristic algorithm to solve it.

• We presented Beacon Placement and Event Localization algorithms for Event Localization.

• We evaluated our algorithms in simulation.

• We developed a flow learning algorithm.

• We evaluated the algorithms on bigger graphs

---


Towards Optimal Frame Fragmentation

- A single bit error → frame retransmission → Waste of bandwidth and energy
- Frame fragmentation, but how many fragments?
- More fragments → increased overhead
- Less fragments → bigger chunks for retransmissions

Proposed Dynamic Frame Fragmentation Schemes

- MAC Layer Approach
- Propose iFrag, Hi-Frag and Green-Frag as new energy-efficient schemes for WSNs that combines an adaptive transmit power mechanism with a frame fragmentation technique.
- Experimentally determine the most energy-efficient frame fragmentation technique.
**iFrag**

- **Dynamically adjusts block size based on channel condition**\(^1\)
- **Network delay and energy are considered**
- Depending on iFrag mode, data frames are composed of one or more block(s)
- 4 implemented iFrag modes, iFrag 1, iFrag 2, iFrag 4 and iFrag 8, where 1, 2, 4 and 8 represent # of blocks in a frame

---

Hi-Frag

- Dynamic partial packet recovery protocol based on heterogeneous block sizes (Hi-Frag\(^1\))
- Hi-Frag manages to reduce block internal overhead by 50%
- In severe cases, Hi-Frag overhead is 2.5x less than iFrag, and it maintains an average of 35% lower overhead in low interference environments

---

Green-Frag

- Energy efficient scheme that combines a frame fragmentation technique with an adaptive power mechanism\(^1\).
- Green-Frag achieves the least energy consumption in all environment situations.
- It is capable of selecting the best transmit power according to the channel conditions.

Summary

- Implemented an energy efficient vehicular guided actuator network using statistical approach
- Implemented an optimal deployment of underwater sensors
- Implemented an optimal scheme for event detection in acyclic flow networks
- Implemented three novel frame fragmentation schemes called iFrag, Hi-Frag, and Green-Frag
Wireless Delay Tolerant Networks
DTNs at the Glance

- A network of regional networks supporting interoperability among them
- An overlay on top of regional networks, including the Internet
- Accommodate long delays between and within regional networks
- Routers need persistent storage for their queues
Message Scheduling Framework

- Developed an analytical framework for message scheduling and dropping in DTNs\(^1\,\,2\) called SAURP-based Forwarding and Dropping (SFDP).
- Validate it with a mobility model and real mobile traces.
- Outperforms its counterpart when the network is congested.


Contestation Aware Routing

- Develop a novel multi-copy routing protocol, called Predict and Forward (PF), which aims to explore the possibility of taking mobile nodes as message carriers for end-to-end delivery of the messages.
- Decision is made by manipulating the probability of future inter-contact and contact durations and buffer availability.
- Implemented and compared PF with a number of existing routing approaches in terms of delivery delay, delivery ratio, and the number of transmissions.

3 A. Elwhishi, P-H. Ho, K. Naik, and B. Shihada, "Contention Aware Routing for Intermittently Connected Mobile Networks", in Proc. International Conference on Advances in Future Internet (AFIN), pp. 8-15, 2011. (Received Best Paper Award)
Summary

• Implemented a novel message buffering scheme for congested DTN.
• Implemented a novel multi-copy routing scheme for message delivery in DTN.
• Implemented a novel message scheduling scheme for DTN.
Passive Optical Networks
Green Bandwidth Allocation in Ethernet Passive Optical Networks

- The objective is to develop a green resource allocation scheme for Ethernet Passive Optical Networks (EPON)\(^1,2\).

- We proposed a novel sleep-time sizing and scheduling framework called Sort-And-Shift for green bandwidth allocation in EPON\(^1\).

- We determined the optimal sleeping-time sequence in every cycle while maintaining low network latency\(^1,2\).

- The sleep-time sizing can be based on upstream traffic\(^1\) or downstream traffic\(^2\).

---


Upstream-based Sleep-time Sizing

- The OLT assigns each ONU the maximum possible sleep-time to achieve the QoS delay requirements.
- Sort-And-Shift mechanism job is to shift ONU active period to avoid collisions from multiple ONUs.
- Results shows great energy saving compared to UCS, while achieving the target average packet delay.
Downstream-based Sleep-time Sizing

- OLT will determine the ONU sleep-time based on downstream traffic load.
- Results shows good energy saving.

- To integrate both upstream and downstream schemes, a smart agent layer can be above the sleep-time sizing layer.
- The layer job is to switch between upstream and downstream on traffic load basis.
Threshold-based Downstream Sleep-time Sizing

- The ONU will sleep/doze till its downstream buffer, located at OLT, reaches a certain threshold of packets\(^1\).
- The threshold is determined according to the required QoS delay requirements.
- OLT uses separate control plan to awake sleeping ONU's.
- ONU will schedule its upstream data to be sent within downstream data reception.

This work achieves the maximum energy gain: \(1 - \rho_c - \rho_d\)

---

Summary

• Introduced a novel energy efficient bandwidth allocation scheme for EPON
• Calculated the optimal sleep-time sizing for ONUs
• Considered the packet delay metric in addition to the jitter.
Networking Gear

• Two WiMax emulators for video coded multicasting over WiMax project.

• 20 Sensor nodes for fault tolerance and partial packet recovery project.

• 20 Mesh nodes for buffer sizing project.
• 6 USRP-2 cognitive radio for CogWnet resource management awareness project.
Collaborators

Prof. Kang Shin  Prof. Pin-Han Ho  Prof. Philip Levis
               Prof. Fouad Tobagi  Prof. Radu Stoleru
Thanks!

http://netlab.kaust.edu.sa
www.shihada.com