Efficient Resource and Energy Allocation for Networking Systems

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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

About 10% of the energy drawn from the electric grid is converted to Radio Frequency

Mobile Operator Cost and User Satisfaction Tradeoff!!
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.
Energy Saving Approaches

- Low Power Electronics
- Efficient Battery Technology
- Not ‘Always on’ devices
- Recycling

Wireless
- Optimized Transmission and Access Techniques (modulation schemes, coding schemes, etc)
- Distributed Antennas
- Multi-Carrier
- Adaptive Channel Allocation

Wired
- Optical Fibers (FTTH PON, FTTCab)
- Power Management

Network Planning and Dimensioning
- Power Management Techniques
- Base Station Technology (equipments and installation types)
- Intelligent Site Solutions (tower mounted radios, etc.)
- Renewable Energy Sources
- Remote Monitoring
- Protocols
- IP Communications

Efficient Communication for Basic needs
- High Sharing Ratio of Servers
- Efficient Equipments (MSCs, GSN, SGSNs, MMGs...)
- Optical Fibers
- Protocols
- IP Communications

Eco Server (Green Data Centers)
- Energy Management
- Optical Fibers
- Digital Compression, IP Communications
- Virtualization
- Protocols
Cellular and Wireless Packet Networks
Base Station Power and User Diversity

- **Sparse area using diesel generator operated mobile BS, Vodafone uses excess of 1 million gallons diesel per day.**
- **Power consumption per subscriber depends on subscriber density**
Superposition Coding Multicasting

Implemented a Superposition Coding Multicasting to solve user diversity problem using NI-PXIe emulators\(^1,2,3\).

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The objective is to optimize buffer sizes to balance the throughput and delay requirements. 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. We implemented our scheme in a Linux testbed WMN deployed on the 4th floor of Building 1.

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Fairness in Wireless Mesh Networks

- The objective is to “fairly” allocate channel resources among WMN nodes\(^1\),\(^2\),\(^3\).
- Proposed a distributed MAC layer protocol, called T-MAC, which extends Lamport’s mutual exclusion algorithm to frame scheduling in WMN.
- Using analytical modeling of TCP streams, we derive a closed-form solution for throughput\(^2\).
- T-MAC implemented in ns-3. Our results achieve fairness while maintaining high network utilization\(^3\).

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Frame Aggregation & Buffering in 802.11n

- The objective is to understand the impact of frame aggregation and buffer size on 802.11n\textsuperscript{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.


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 (EECR) is proposed to solve:

1. Overcome the scarcity of the spectrum.
2. Overcome the inefficient utilization of the spectrum.
3. Reduce the unnecessary extra energy consumption.
4. Enable smart radios.
5. Facilitate Dynamic Spectrum Access (DSA).
CogWNet

- CogWNet\(^1\) is a cognitive radio resource management (CRRM) architecture to allocate channels, reconfigures radio transmission parameters such as transmission power, modulation, bandwidth, etc. to meet QoS requirements, ensures reliability, and mitigates interference.

- **Why CogWNet is Superior?**
  - **Awareness**: Aware of spectrum status
  - **Adaptability**: Transmission parameters optimization.
  - **Portability**: can fit with different wireless environments.
  - **Cooperative Decision-making**: negotiate with other nodes.
  - **Generic**: can be implemented with any optimization tool.
  - **Modularity**: Consists of independent modules that reduce complexity and reduce the effort for malfunction detection.
  - **Policy Awareness**: maintains spectrum regulations.
  - **Comprehensive**: receives input from all TCP/IP stack layers to provide more consistent radio parameters configuration.

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CogWNet Layers

**System Layers**

1. **Communication Layer**
2. **Decision-Making Layer** (Repository and Parameter Mapper)
3. **Policy Layer**

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CogWNet for IEE802.11 and LTE

- **Home Network IEEE802.11** *(very heterogeneous).*
- CogWNet adapts channel width, center frequency, modulation order, symbol rate, transmission range and contention window for each hop.

- **Long Term Evolution (LTE)** → **limited and unsteady radio resources conditions.**
- CogWNet controls sub-carrier assignment, power allocation, modulation adaptation and interference mitigation\(^1\).

Summary

• Implemented a CogWNet framework
• Uses CogWNet for 802.11 Home devices
• Uses CogWNet for LTE
Sensors at the Glance

- **Characteristics**
  - Low-cost, low-power, light weight
  - Densely deployed
  - Prone to failures
  - Two ways of deployment: randomly, pre-determined
  - 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**
  - Monitor activities
  - Gather and diffuse information
  - 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.

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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**

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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

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Towards Optimal Frame Fragmentation

- A single bit error $\rightarrow$ frame retransmission $\rightarrow$ Waste of bandwidth and energy
- Frame fragmentation, but how many fragments?
- More fragments $\rightarrow$ increased overhead
- Less fragments $\rightarrow$ 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**

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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

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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 a 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
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\(^2\).

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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 ONUs.

• ONU will schedule its upstream data to be sent within downstream data reception.

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

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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.
Team

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Alumni
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!

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