Cue-based Networking using Wireless Sensor Networks: A Video-over-IP Application

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Outline

- Introduction and Background
- System Overview, Operations and Design
- Algorithms and Implementation
- Performance Evaluation
- Conclusion
# Introduction

- Wireless Sensor Networks (WSNs) - conventionally focussed on sensing a phenomenon and communicating to some node in a wireless manner with *specific application scenarios such as temperature monitoring, soil humidity monitoring and so on.*

- **As an orthogonal development, optimizing the behaviour of application and network protocols has been a continuing endeavour.**

- This class of networked applications has a great potential to benefit from sensor networks.

- *How can WSNs be used to optimize networked application performance, what benefits can WSNs give to networked applications and how do the two relate?*
Background

- **Cue based Networking (CBN)**
  - **Cues**
    - Hints or signals about target environmental characteristics (especially those that are not otherwise available to the application)
  - **Examples of cues**
    - Whether a certain wireless channel is currently utilized
    - Whether the application user is present in the environment or not
  - **CBN**
    - Involves the use of *cues* about the environment/phenomenon of interest to *optimize* the performance of the networked application

How can the cues be generated and converted into application usable form?

↓

Wireless Sensor Networks
Background

- **Wireless Sensor Networks (WSNs)**
  - Underlying platform for cue generation
    - Active sensors sense various physical phenomena
    - Smart techniques must be designed to obtain accurate cues from dumb sensors

- **Networked Application: Video Delivery over IP**
  - **Bandwidth Management**
    - A sustained bandwidth of at least 18 Mbps (6 Mbps encoded HDTV and 3 TVs) per home is needed
    - Average throughput of the popular IEEE 802.11g WLAN (in an urban environment) is under 18 Mbps
  - **Channel Zapping Delay**
    - The time taken for the current video channel stream to end and a new channel to be displayed
    - Acceptable threshold value is around 1 second
## System Overview and Operations

### System Architecture

- **Video delivery application**
  - Video is served from video head end to clients at home through the wired core network, the access link, and home networks (WLAN)

- **Ecosystem of sensors forming WSN**

- **Unique characteristics of Video over IP:**
  - Unlike analog cable TV, cannot broadcast all channels at a time due to bandwidth limits
  - Channel change takes time since all channels are not on the wire
System Overview and Operations

- Specific Operations
  - Video delivery application
    - Detecting inactive streams: When the absence of user is detected, the streaming should stop (or de-prioritized) to utilize the bandwidth efficiently
    - Intelligent Pre-fetching: When user intend to switch the channel, pre-fetching should be performed to reduce the channel zapping delay
  - WSNs
    - When a person sits on a sofa, the light intensity or accelerometer orientation change
    - When a person pick up a remote, the accelerometer orientation changes
  - Cues
    - User watching the TV
    - Remote control position
Solution Design

- Basic Data Collection Strategies
  - Continuous reporting
    - The sink has a complete picture of the network at all times
    - It incurs the cost of all nodes sending messages continuously
  - Event-driven reporting
    - Information is sent only when required
    - A clear static threshold must be known a priori
    - Limited idea about the network
    - Higher probability of missing events on losses
Solution Design

- Timeliness/Robustness Trade-off

  - Timeliness
    - The property of detecting an event and conveying it to the sink with the minimum delay
  - Robustness
    - The property of detecting an event of interest reliably even in the presence of other sources that affect detection
  - Trade-off
    - Continuous reporting model unnecessarily increases detection time although allowing higher robustness
    - Event-driven model achieves significantly reduced detection delay at the cost of unreliable detection
Solution Design - Trade-offs

- Experimental Results illustrating the trade-offs
  - Setup
    - *Surge* application using 20 MICAz motes
  
- Results

![Graph showing event detection time vs. reporting rate for continuous and event-driven reporting with different thresholds.](Image)

![Bar chart showing event detection reliability by user location for continuous and event-driven reporting with lower and higher thresholds.](Image)
Algorithms and Implementation

- Adaptive Probabilistic Reporting
  - Goal:
    - Performing an intelligent reporting
      - that provides energy and delay benefits close to that of the event-driven model
      - but also provides significant reliability using multiple sensor views
  - Main idea
    - Adapting transmission decisions based not just on each sensor’s perception but also on the information heard from transmission of other sensors
  - Implementation:
    - Generate a random number for each change in sensor value to decide on transmission based on a suitable probability
**Algorithms and Implementation**

- **Algorithm**
  - When a node detects a change in sensed value, it calculates the probability according to a probability function given by:

  \[
  P_i = \begin{cases} 
  \min(1, \frac{\Delta S_i}{TH - \sum_{k=1, k \neq i}^{n} \Delta S_k}) & \text{if } \sum_{k=1, k \neq i}^{n} \Delta S_k < TH, \\
  0 & \text{else},
  \end{cases}
  \]

  - Where \( \Delta S_i \) is the change in the sensed value for sensor \( i \)
  - \( \Delta S_i \) is estimated as the change between the average of the previous value and the current value
  - \( TH \) represents a static threshold
  - **If the change is sufficient to cross the threshold, it transmits**
  - **Nodes overhear other node transmissions to identify the \( \Delta S_j \) in the denominator of the equation of other nodes that have transmitted**
  - **In this way, nodes that have sensed an event partially, transmit while balancing the number of nodes that transmit.**
System Overview and Operations

- System Architecture
  - Cue interfaces
    - The sink is connected to a base station (BS) that aggregates all the data from the sink and generates the necessary cues about user behavior from the raw sensor information.
    - BS/Sink (cue interfaces) can be viewed as a middleware solution for the various problems of the target application that the CBN serves.
    - Additionally, generic interfaces can be used across multiple applications.
Performance Evaluation

- Prototyping Testbed Setup
  - Systems
    - 3 TV/STBs (Linux)
    - 1 Video streaming server (Linux)
    - 1 BS/Sink (Windows)
  - Networks
    - 1 WAN emulator (Network Nightmare)
    - IEEE 802.11g WLANs
  - Sensor networks
    - MICAz motes with light and accelerometer sensors (Crossbow)
  - Video codec/streaming - VideoLAN Server/Client
    - MPEG-2 encoding
    - MPEG-4 streaming
Performance Evaluation

- Prototyping Testbed Setup
  - Aware Home Research Initiative (AHRI) at Georgia Tech
Performance Evaluation

- Macroscopic Results
  - Bandwidth Management

When the number of active TVs is less than three, the video rate drops are eliminated with the *CBN* solution.
Performance Evaluation

- Macroscopic Results
  - Channel Zapping Delay

When the remote is picked up, the other channel is pre-fetched and the zapping delay is reduced considerably with CBN solution.
Performance Evaluation

- Microscopic Results
  - Timeliness
    - The time taken in the proposed algorithm is very similar to the case of simple event-driven approach
  - Robustness
    - The proposed algorithm has the reliability of the continuous reporting approach

![Graph](image)
Conclusion

- **Summary**
  - We present a new approach called *cue-based networking (CBN)*
  - We develop the CBN solutions in the specific application context of video delivery over IP using wireless sensor networks
  - We demonstrate and evaluate the developed solution using a prototype implementation in a real home environment

- **Ongoing Work**
  - Extending the WSN platform to include both passive sensors (such as RFID) as well as active sensors (such as MICAz motes)
  - Handling additional video delivery challenges such as targeted content delivery using the proposed architecture
Thank You

For more details visit:
www.ece.gatech.edu/research/GNAN
Backup – differences from ubiquitous

- User experience vs network performance
- Mostly single-hop vs multi-hop
- Application specific vs general primitives
- Experimental details
Experiments

- How is the video rate measured in the experiments? Does VLC provide the instantaneous video rate?
- How are the delays measured?
- How does the WSN data get fed into the VLC? Using Inter Process communication. provide details
  - i.e WSN has a socket program or receive program (Xserve or xlisten?)
  - Using surge as the routing protocol or Xmesh?)
  - Socket program on Sink laptop opens sockets to the VLC server and issues start/stop/pause commands
- How many runs? 10 runs
- Why 3.5 seconds delay? Application setup times, leave, join commands, network delays
Algorithm illustration

- Light sensor amplitude as a function of distance from the sensor is approximated well as an additive function.
- When the sum of the changes cross a threshold, it can be used to detect the event although each of the sensors value themselves have not crossed a threshold.
- Leverage this property in determining the probability of transmission.
- For another sensor the sensor law might not be linear, but can be estimated from the sensing function during manufacture of the sensor.
- The total change in sensor value must cross a threshold for detecting partially sensed events.
Why these sensors and not others?

- Using accelerometer and light is an example of how one can detect humans with dumb sensors.
- Sophisticated sensors such as cameras cost more and are probably overkill for user detection.
- In cases where cost is not a concern Video or IR cameras can be used.
- Our solution uses simple sensors but guarantees a high success rate with low false alarm.
- Depending on cost, accuracy required the exact sensors can be chosen.
- Irrespective of the type of sensors used, the tradeoffs described hold.
802.11n
- Data, other traffic on wlan
- Better video standards
- Channel zapping delays still remain
- Bottleneck not on wireless link