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?

⇩

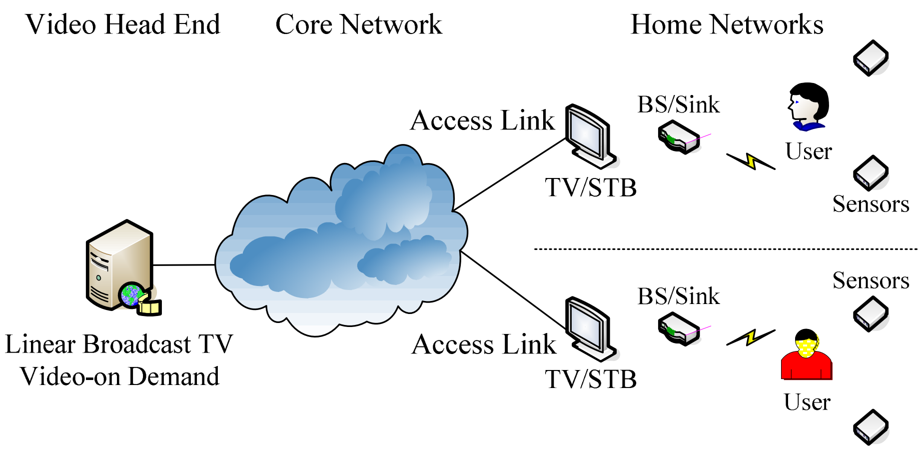
Wireless Sensor Networks

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

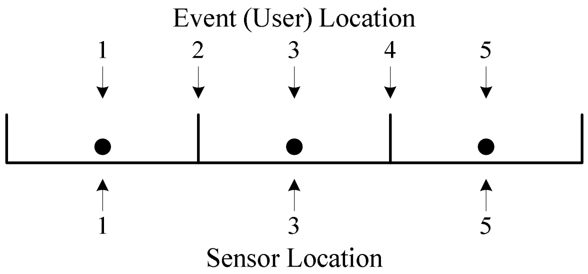
- Basic Data Collection Strategies
  - Continuous reporting
    - The sink has a complete picture of the network at all times
    - It incurs the cost of all nodes sending messages continuously
  - Event-driven reporting
    - Information is sent only when required
    - A clear static threshold must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

Solution Design

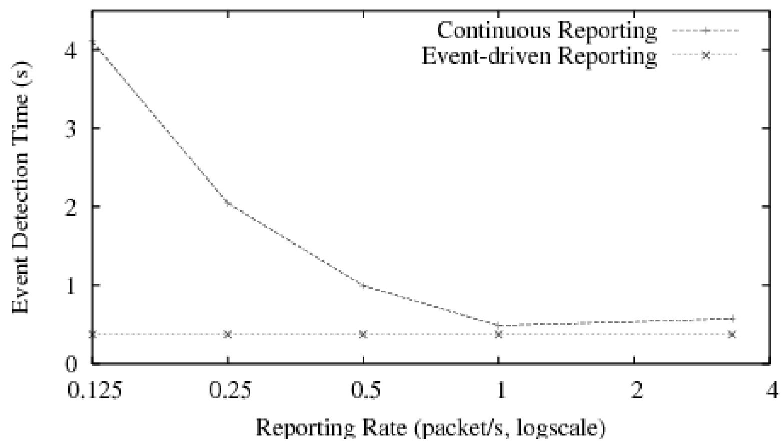
- Timeliness/Robustness Trade-off
  - Timeliness
    - The property of detecting an event and conveying it to the sink with the minimum delay
  - Robustness
    - The property of detecting an event of interest reliably even in the presence of other sources that affect detection
  - Trade-off
    - Continuous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

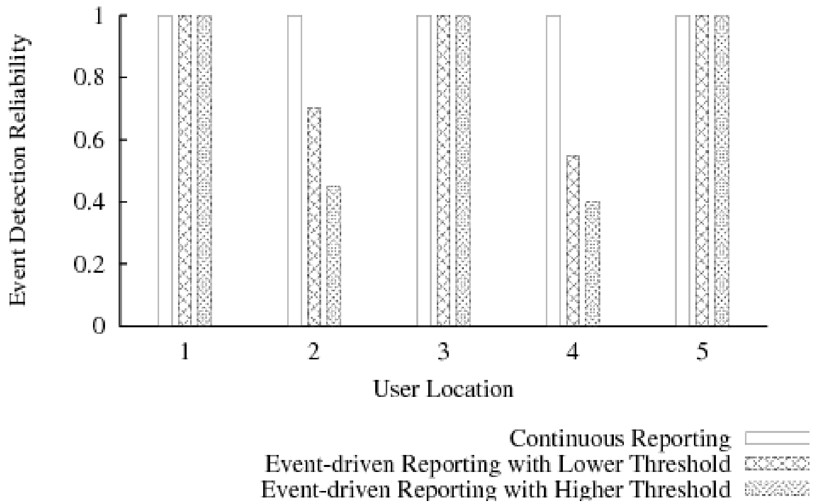
Solution Design - Trade-offs

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



  - Results





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 *overheard* 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

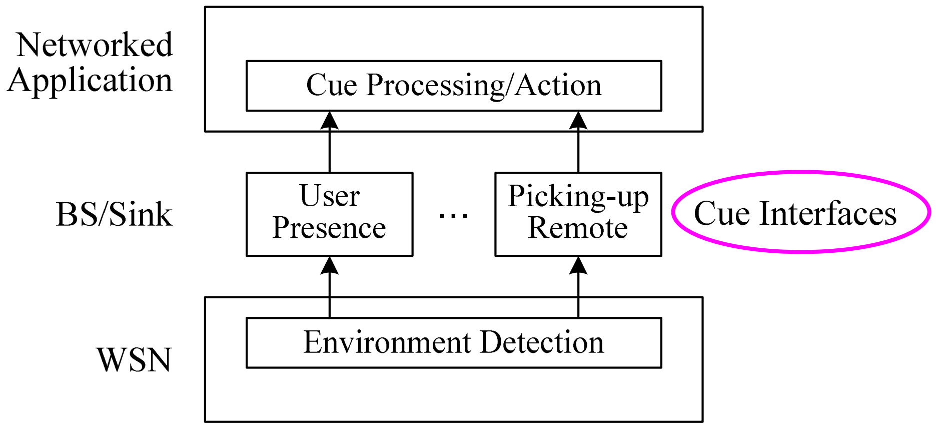
- Algorithm
  - When a node detects a change in sensed value, it calculates the probability according to a probability function given by:

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

    - Where ΔSi *is the change in the sensed value for sensor i*
    - *ΔSi 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 ΔSj 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

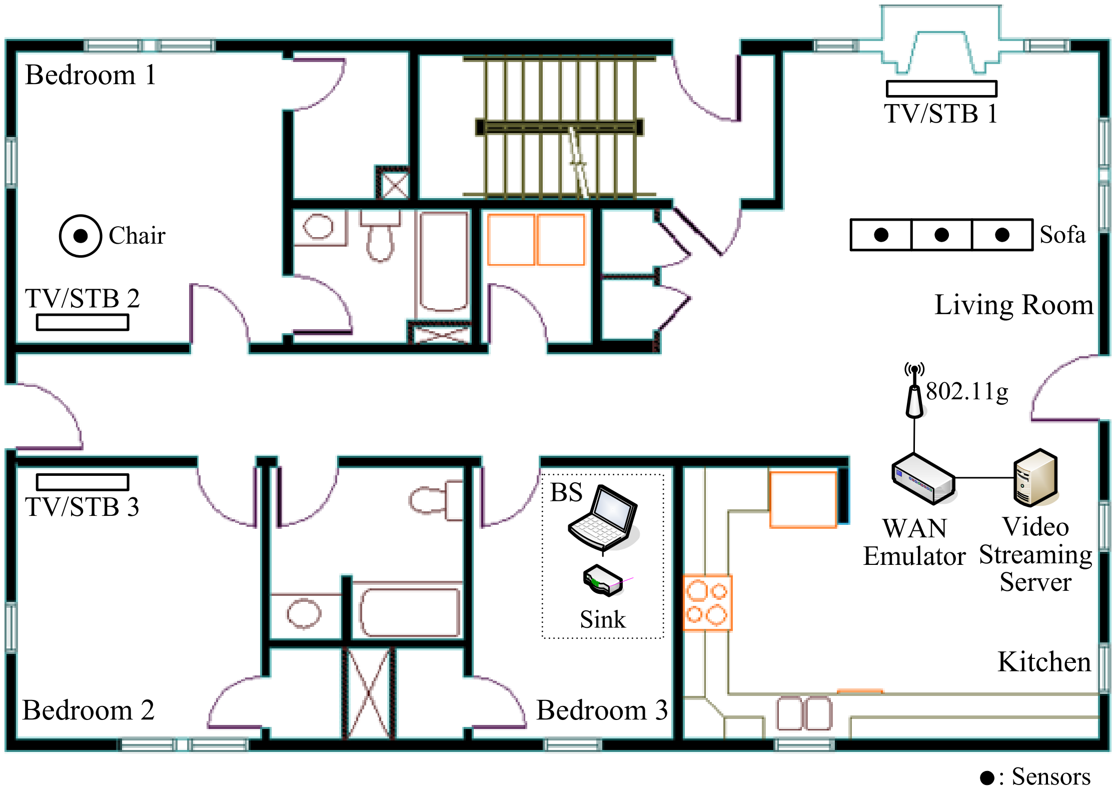


Performance Evaluation

- 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

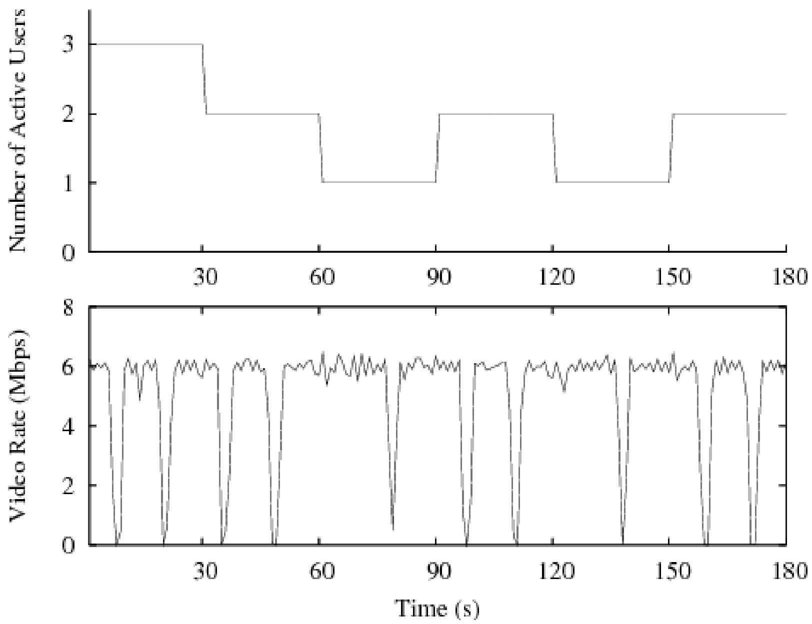
Performance Evaluation

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

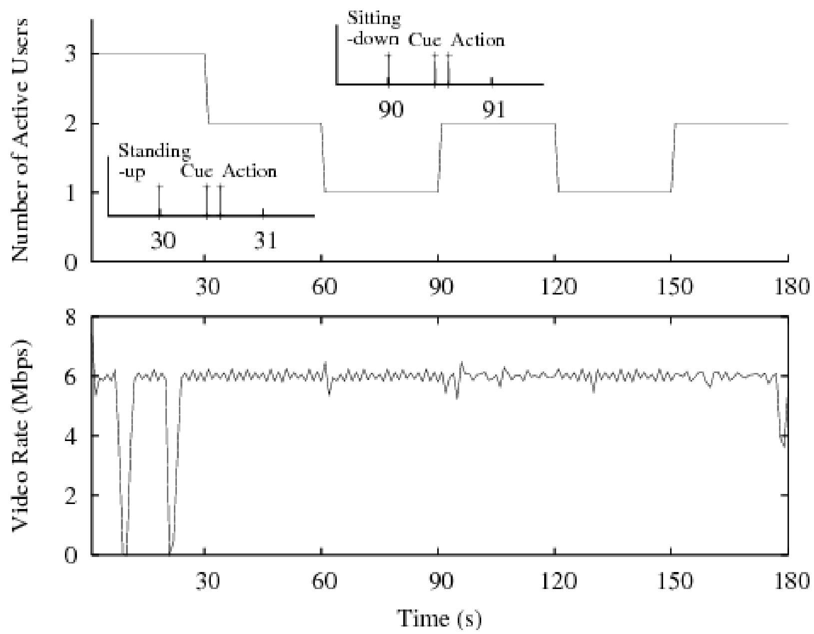


Performance Evaluation

- Macroscopic Results
  - Bandwidth Management



Without optimization

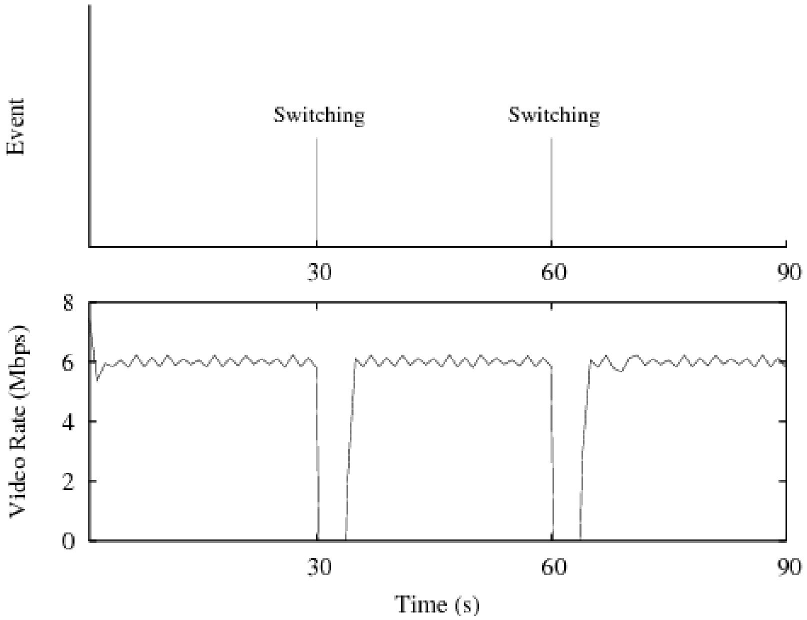


With optimization

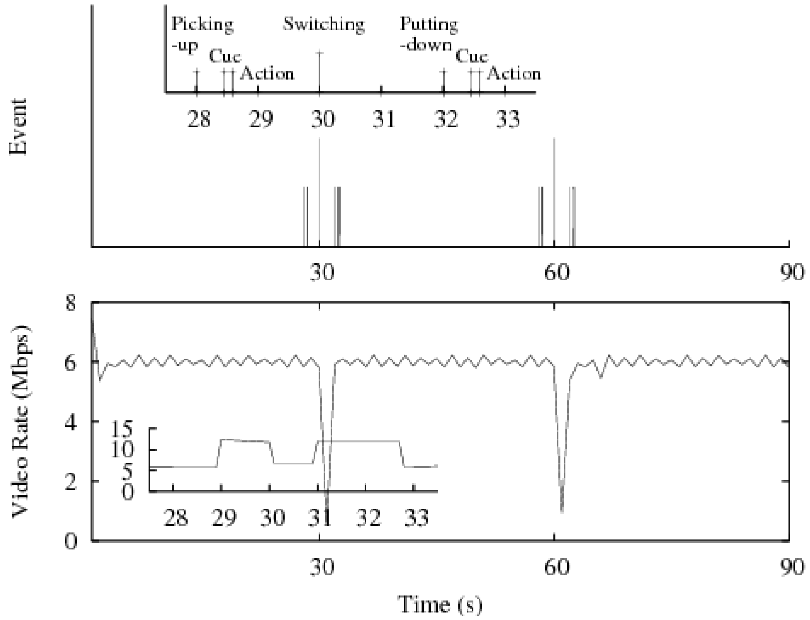
When the number of active TVs is less than three, the video rate drops are eliminated with the *CBN* solution

Performance Evaluation

- Macroscopic Results
  - Channel Zapping Delay



Without optimization

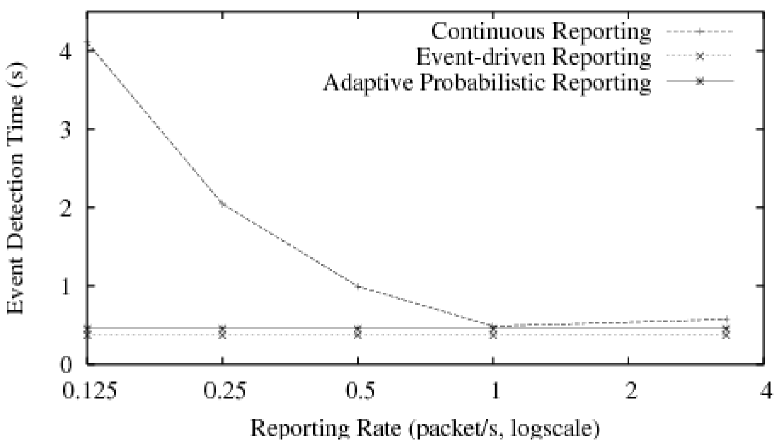


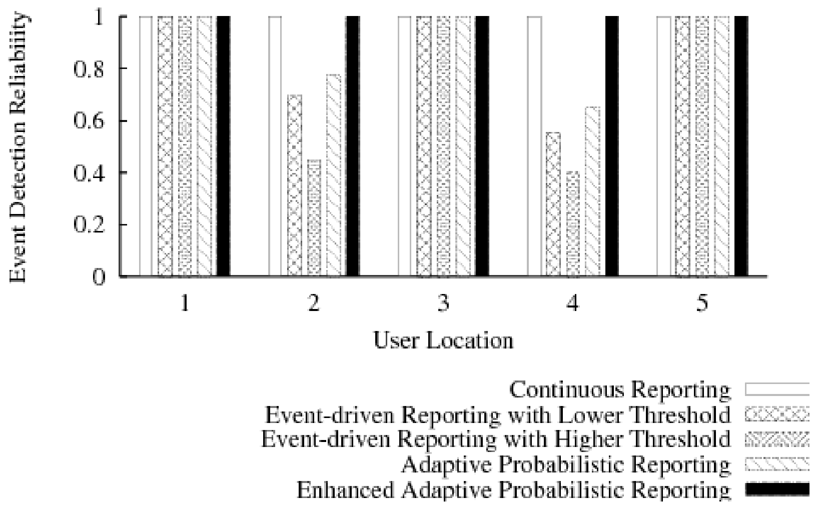
With optimization

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





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, othertraffic on wlan
  - Better video standards
  - Channel zapping delays still remain
  - Bottleneck not on wireless link