Towards a Tailored Sensor Network for Fire Emergency Monitoring in Large Buildings

Rochan Upadhyay
Athanasia Tsertou, David Laurenson, Steve McLaughlin
Presentation Topics

- Introduction to the FireGrid project
- Fire Scenarios and Applications
  - Smoke Movement Monitoring
  - Fire Growth Monitoring
- Initial Communication Architecture
- Clustered Architecture Based on Fire Statistics
- Key Features of a Suitable Algorithm
- Conclusions
Wireless Communications in FireGrid

- Smoke/CO sensors
- Smoke Particle Velocity sensors
- Temperature pressure sensors

Wireless links
- WiFi/Zigbee/other

WiFi/Radio

FireGrid

TCP/IP
- Building status/Fire prediction

Local/Remote Database

TCP/IP
- Command & Control Coordination of Actuators

WiFi

WiMax
Drawbacks of a wired infrastructure

- Large buildings of the future that use FireGrid would require a network of 1000s of sensors
- For a wired infrastructure, data is transmitted reliably (no congestion or multi-path fading) but ...
- Wiring is vulnerable to fire
- Wiring cost is not predicted to drop
- Wired sensors are not easily reconfigurable
- Key challenge: Extend and complement the existing wired infrastructure with **Wireless Sensors**
Why Wireless Sensor Networks?

Enabled by the convergence of
- micro-electro-mechanical systems technology
- wireless communications
- digital electronics

- Extended range of sensing
- Redundancy
- Improved accuracy
- Cost expected to go down
Research Challenges and Approach

Research Issues
- Dense sampling and frequent transmitting causes packet losses due to collisions / energy depletion
- For critical events such as a fire packet losses / latency cannot be tolerated

Approach
- Use spatial and temporal correlations in the sensed data to reduce transmission
Fire Scenarios: Smoke Monitoring

3 rooms with corridor
(Rack with 4 thermocouples in each room)

4 rooms with corridor
(Rack with 4 thermocouples in each room)

8 rooms with cellular architecture
(4-thermocouple rack in each room)

Thermocouple racks used to monitor the movement of smoke
Network Simulation (NS2) Results

3 room and 4 room topologies used with 4 thermocouple sensors per room

Single Hop, Flat architecture with all sensors speaking to a sink

Constant transmission rate of 1 packet per second

Significant packet losses due to collisions
Fire Data Characteristics

Temperature reading of topmost thermocouples of each room in 3 room scenario

Same for 8 room scenario

- Similar temperature profiles in each room but lagged in time
- Sensors in other rooms need not transmit for certain time intervals
- Time sliding effect can be exploited to reduce transmissions
Correlation Structure in Multiple Room Fires

Example: Dynamic Correlation Structure

- Sensors that are correlated can be clustered together
- Correlations among sensors change with time
- Similar phenomena at different rooms but with a time lag

NC: NOT Correlated
C: Correlated

Time $t_1$
C: Correlated
NC: NOT Correlated

Later time $t_2$
C (with time lag)
NC

Room 1
Room 2

FireGrid
Clustered Network Architecture

How to group the sensors into clusters?

What is the error in sensor field representation at the sink?

**NEED TO EXPLOIT CORRELATIONS IN THE FIRE DATA FOR CLUSTERING!**
Dense coverage by wireless sensors provides very early detection, precise localisation of fire and continuous monitoring of growth.
Direct one-hop uplink traffic from every sensor to the sink.

Packet size 11 octets, constant rate of transmission of 1 sample/second.

- WiFi (802.11) has LOW Packet Loss but SHORT Lifetime.
- Zigbee (802.15.4) has HIGH Packet Loss but LONGER Lifetime.
Various stages of fire growth and spread

Stage 1: Ignition and Growth of Fire in the Main Room

Stage 2: Secondary Fire ignites in the corridor

Stage 3: Secondary Fire grows
Difficulties in signal processing

Highly non-stationary signal to be measured:

Neither differencing nor log-differencing result in stationarity!
Example of Signals measured by Wall Sensors

- Heat Flux / Temperature directly above the fire peaks first and a front propagates along the walls.
- Spatio-Temporal Correlations of advancing front can be leveraged in the communications protocol.
Suppose a Centralized Medium Access Control Scheme is used in a single hop network with star topology…

- Sink should dynamically select a subset of sensor nodes based on a minimum distortion criterion
- Correlations change with time and the number and optimal selection of sensors depend on them
- Sink should be able to determine when the correlations change and assign appropriate nodes to transmit
Conclusions

- FireGrid concept requires a highly dense network of sensors and wireless seems to be an attractive option.
- Dense sampling + high transmission rates cause degradation of performance of widely used communication protocols.
- Correlations in the fire data can be used to reduce transmissions.
- Clustering is a method of exploiting these correlations.
- Key features of a suitable algorithm were discussed.
Thank You