Enabling Resilient Situational Awareness in Disasters: A Cross-Layer Approach

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Industry Partners - IBM, Motorola, Yahoo, HP, Google, Nokia Research Labs, Deutsche Telecom Research, Sigfox Inc., SenseWare, Deltin Corporation
- **SRI Inc.**
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- **Imagecat Inc**
  - Paul Amyx, Charlie Huyck, Ron Eguchi

- **Honeywell Inc.**
  - Raj Rajagopalan, Steve Gabel, Wing Au

Government Agencies
- **National Fire Protection Agency, County of LA Fire Dept., Newport Beach Fire, Orange County Fire Authority, Ontario Fire Dept., Montgomery County Fire**
- **Montgomery County, Maryland, City of Ontario, City of Los Angeles, State of CA OES, City of Irvine, County of Orange, City of Gainesville**
- **Washington Suburban Sanitary Commission, LA Dept. of Water and Power, DC Water, Orange County Public Works, Irvine Ranch Water District, DC Water**

SAFIRE: Situational Awareness for Firefighters

CYPRESS
Cyber Physical RESilience & Sustainability
Project RESCUE (2003-2009)

Transforming the ability to collect, analyze, share and disseminate information within the responding organizations and the public

On-site 1st Responders

Mobile Command & Control

EOC

Response Network

Response Effectiveness
- lives & property saved
- damage prevented
- cascades avoided

Quality of Decisions
- first responders
- consequence planners
- public

Quality & Timeliness of Information

Situational Awareness
- incidences
- resources
- victims
- needs

Right Information to the Right Person at the Right Time can result in dramatically better response

Collection ➔ Analysis ➔ Sharing ➔ Dissemination
Why are cities/communities interesting?

Urban population – Economies of the future
• 54% of global population (2014), majority (2050)

Communities Need Infrastructure and Services
• Functional - operation of lifelines, societal processes
• **Non-functional** - Efficient, Dependable, Cost-effective, Flexible, Predictable, Secure, Privacy Protecting

Many stakeholders with varying tradeoffs
service providers, consumers, administrators, businesses, organizations
Systems that empower everyday physical devices to connect to the internet to send & receive messages

- Over 50 billion devices connected by 2030
- Expected to reach a trillion by next decade

6 billion devices by 2020
- Mobile traffic to exceed 15 exabytes of data by each month by 2018

180 zettabytes of data (or 180 trillion gigabytes) in 2025 from <10 zettabytes in 2015,
- $203 billion big data analytics market in 2020?

New Systems, New interactions, New vulnerabilities?
The Internet of “Broken” Things

IoT has reached its hype peak — Gartner

- Massive scalability
- Heterogeneity/Interoperability
- Security/Privacy
- DEPENDABILITY is key!

NO DEPENDABILITY, NO INTERNET OF THINGS

For the Internet of Things to become a reality the sensor networks which form its backbone must provide dependable real-time information all the time, on time. The RELYonIT project team is working to ensure dependability by testing possible solutions on FIRE’s test beds.

“The term resilience refers to the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents - President Policy Directive 21 - Critical Infrastructure Security and Resilience February 12, 2013
IoT-Enabled Smart Communities - Sample Projects

 SCALE: Safe Community Awareness and Alerting

 SciFIRE: Fire Situational Awareness in Smart Buildings

 AquaSCALE: Resilient Community-Scale Smart Water Infrastructure
Extending the Internet of Things to Everyone: Residents of an affordable housing complex who cannot otherwise afford broadband are given smart community sensors. A resident, possibly elderly, is in distress and the sensor sends a signal to the nearest base station.

County Facility Equipped with Antenna

Within minutes first responders arrive without any need for manual action by the person in distress.

Emergency validated via mobile device; alert is sent to the dispatch center and a first response unit is sent to the resident in distress.
What We Learned (and are learning) from these experiences

What can go wrong?

- **Infrastructure component errors/failures**
  - Device Failures, Network Failures, Congestion and Overloads

- **Data Interpretation errors/uncertainty**
  - Uncertainty in Processing (e.g. speech/image processing)
  - Contextual errors (e.g. conclusions to a light sensor)

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- [http://scale.ics.uci.edu](http://scale.ics.uci.edu)
SCALE Resilient Multinetwotking: Infrastructure Resilience

Resilient Overlay Networking (GeoCRON)
Route around failures in underlying infrastructure by creating geo-aware overlays and passing message to a known reachable intermediate peer, which then forwards to destination (cloud server).

SDN Enabled Edge Server
OpenFlow capable switch will redirect the sensing data to local server when there are network failures that leave the cloud server unreachable.

Local Adhoc Mesh Network
SCALE client nodes are connected with to neighbors to form a local wireless mesh network to buffer sensing data and exchange traffic for local data analysis and aggregation.
Techniques for Information Dependability

Data Interpretation errors/failures - Uncertainty in Processing (e.g. speech/image processing), Contextual errors (e.g. occlusions)

Smart Video Surveillance

Data Cleaning via Entity Resolution/Disambiguation
- Face Recognition is challenging in a resource-constrained environment
- Connect the problem of person identification with entity resolution using ReIDC (a graph-based entity resolution framework)

Semantics-based Actuation for Event Detection
- Balance event capture vs. accuracy
- Implement a lightweight, real-time scheduler applied in zoom-enabled camera network

Recalibration for perturbations
SCALE Architecture

Cyber Plane

Monitor

- IoT Object Profiles
- Raw Sensor Virtual Sensor Data
- Floor plan segments

Activity/Fault Recognition

- Sensor sequence
- Activity sequence
- Location sequence
- Time

(Re)Configuration

Physical Plane

Smart home IoTs

- Motion sensor
- Smart pad
- Mobile
- Wearable Sensor
- Camera
TIPPERS (Testbed for IoT-based Privacy Preserving PERvasive Spaces) - A DARPA Brandeis Project

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University of California Irvine

Raj Rajgopalan
Honeywell Research

+ a large team of TIPPERS researchers & developers at UCI CS + Calit2 + Honeywell
Bren Hall: TIPPERS Instrumented Building

- 6 Story Building
- 90,000 sq. ft classroom
- 125 Faculty Offices
- 90 Research Labs
- Lecture Halls
- Departmental Offices

Diverse set of sensors installed

New opportunity, new trend
MIXING building data with individual centric data
TIPPERS Sensors & Higher Level Observations

IoT data management & middleware technology empower applications on sensor data.

Presence Table (75 million rows since 1/2/17)

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<th>Confidence</th>
<th>Location</th>
<th>Timestamp</th>
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Energy Usage Table

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<tr>
<td>...</td>
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</tbody>
</table>

Using: Wi-Fi AP, BLE Beacon

Physical Sensors

- Wifi Access Point
- Beacon
- Mobile Phones
- Power Outlet
- HVAC Data
- Video Camera
- PC Based Sensor

Transformation/semantic interpretation

Using: WeMo Power Outlet Meter

- 64 access points producing Connectivity data continuously
- 100s covering 2nd floor → Several hundreds soon
- Few so far, but soon to be 100s
- 216 temperature points
- 116 HVAC points, vent control data
TIPPERS System

A data management middleware that supports:

- **dynamic representation** of the smart space by integrating diverse sensors
- **Semantic abstraction** of sensor data to represent data at the conceptual level
- **Policies for capture, analysis, sharing, and retention** of data
- **Plug-n-Play architecture** to support integration of different privacy technologies
  - encrypted data representation, differential privacy, and CMU’s IoT and IRR technologies
Testbed: Applications

Users
- Faculty, staff, students, building admins, people admins, visitors

Services
- **Real-time awareness** of resources, people, events
- **Analytics on historic data**

Self-Awareness app (SAPP)

Hackathon apps: ZotBins and CoffeeTime

Open APIs will lead to more applications.
SAFIRE (Situational awareness for Firefighters – 2011) Sensing -> Sensemaking for the Fire Practice

- **Sensor Data Ingest Unit**
  - Sensor Data Collection
  - Multimedi a Data Collection

- **Sensor Stream Processing Module**
  - Virtual Sensors for Media Level events
  - Sensor Fusion
  - Multisensor Event Extraction

- **Visualization & Decision Support Services**
  - (Alerts, Queries, Replay, Triggers)

- **Raw Data DB**
  - Raw Sensor data (sensors, speech, video)

- **Event DB**
  - Semantically Enriched Event Data

- **Sensor/Incident Storage & Archival**

- **Visualization & Display**
  - Available GIS layers
  - Receive /display alert messages.

- **External Data Access**
  - GIS layers
  - Firefighter Status Dashboard
  - Mapping and Localization

**Goal:** Reliable Timely SA over Unpredictable Infrastructure
• **Smart FF** fuses sensor data and computing power/analytics
  • Sensors in buildings, on FF or their apparatus, IoT devices, smartphones, security cameras, social media, etc.
  • Building management systems (BMS) grant access to data, devices, and infrastructure

• **Goals** involve many stakeholders:
  • Minimize injuries/death to building occupants
  • Improve FF safety/health
  • Enhance operational efficiency & effectiveness
  • Minimize property loss and business interruption

• **Data-driven** approach to FF:
  • Targeted inspections for prevention
  • Post-incident forensics e.g. insurance
  • Real-time data provides situational awareness to Incident Commander (IC)
  • Create an *Electronic knoxbox* and *analytics sandbox* functionality...
SciFIRE: Fire Data Exchange to enable IoT Dataflows for Smart Firefighting

Monitor
- Data Acquisition
- FireDEX
- Network/Device state
- Smoke/Temperature
- Human input

Data Exchange

Analysis
- Pub-sub semantics
- Data representation
- Prioritize data

Decision Support
- Situational awareness
- Regional emergency response mgmt.

Emergency Dispatch

Fire Department

Incident Command Post

Fire Fighting & Evacuation

Emergency Actions

Data Exchange & Analysis

Smart Building Infra.

IoT-enabled Building

Forensics ‘Black Box’

SciFIRE: Fire Data Exchange to enable IoT Dataflows for Smart Firefighting

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Smart Building Infra.

IoT-enabled Building

Forensics ‘Black Box’
Mobile and in-situ sensing in a fire scenario

Augmenting in-situ sensing with mobility

• Flexibility and extended sensing coverage (i.e. covers larger areas with more sensor types)
• Lower dependency on communication infra. that could be congested or destroyed in disasters
• Facilitates data exchange

SCALECycle platform

• A network-enabled multi-sensor box on a bike with GPS, battery, and various sensors (air quality, gas, camera, microphone, etc.)
• Conducted measurements in multiple testbeds: (1) UCI campus, (2) Victory Court Senior Apartments in Montgomery County, MD, and (3) NTHU (Taiwan) campus. Collected Wi-Fi RSSI/quality and air quality. (4) Dhaka, Bangladesh – using limited dataplans

New Problems

• Fire awareness in IoT Islands
• Novel Calibration using mobile and insitu sensors
System Architecture

- Server-focused Computing:
  - Data from sensors migrates to server and stored into a database (could be on cloud)
  - Application code & system code runs on the server.

- Trust Assumption:
  - Server and sensors are trusted

- Flexible distributed computing: sensor, edge devices, local servers, and cloud collaboratively execute system and application code.

- Trust Assumption:
  - Diverse mixed trust environment.
Smart Buildings and Smart Firefighting

Cyber Plane

Monitor
- Data Acquisition
- Fire Data Exchange

Analysis
- Pub-sub semantics
- Data representation
- Prioritize data

Decision Support
- Situational awareness
- Regional emergency response mgmt.

Physical Plane

Smart Building Infrastructure
- Floor Map
- Wifi
- Camera
- Mobile Phone
- IoT Sensors
  - Smoke/CO/
  - Explosive gas

Static Spatiotemporal Information
- Office Assignment
- Office Hour
- Class/Meeting Schedule
Resilient IoT- Based Community Water Infrastructures
Water is a precious natural resource

- A critical resource and lifeline service to communities worldwide.
- Water infrastructure has been developed over decades (centuries sometimes).
- Become large, complex and vulnerable to failures (operational degradation, disasters).
Community Water Infrastructures
Operational Vulnerabilities, Disaster Resilience

Water Main Breaks & Leaks
Breaks and leaks for the reporting month are unconfirmed, pending field verification.

Source: WSSC

- FY 2015 Actual
- FY 2014 Actual
- 5-Year Avg. by Month

Water Pipe Burst Under Sunset Boulevard in L.A. (July 30, 2014)

Hurricane Sandy (Oct. 25, 2012)

Northridge Earthquake (Jan. 17, 1994)
The AquaSCALE Framework

Middleware
- Resilience Methods
- What-if Analysis
- Event + Cascades Detection
- Pub/Sub Data Exchange
- Data Acquisition (e.g., IoT/feeds)

Database

Monitor
- Data Collection
- Pub/Sub

Analyzer
- Representation
- Translation
- Synchronization
- Integration

Adaptor
- Systems Adaptation
- Pub/Sub

Flood Prediction
- BreZo Flood Modeling

First Response
- Evacuation Modeling

Base Systems
- EPANET++
- G-WADI
- InLET

Human Sensing
- AQUA APP

Observe
- Hydraulic Model + IoT/Sensor
- Observable Hydrometeorological Data

Adapt
- Earthquake Damage Estimation
A Composite Multi-leak Identification Approach

Phase I

- Generate the profile model offline using extensive measurements and plug-and-play machine learning.
- Features include the topology of the network and changes in pressure heads and flow rates.

Phase II

- Aggregate multiple data sources to infer leak locations.
- IoT measurements and ambient temperatures are relatively periodic.
- Use IoT and temperature streams to infer leak events.
- Human inputs, though aperiodic and coarse-grained, enhance the knowledge of leaks.
- Incorporates additional human inputs to enforce the predicted event consistency.

Experimental Study (WSSC)

Scenario: winter at east coast
- # of training samples: 20,000
- # of test cases: 2,000
- # of leak events ~ U(1, 5)
- Freeze probability: 0.3
- Human inputs ~ Poisson Dist.
- Arrival rate: 1 / 15 minutes

1. IoT Data
2. IoT + Weather + Human Data
3. Coarser Twitter Data
4. Increasing # of Leaks
Middleware for Managing Water Infra

**Cyber Plane**

- **Monitor**
  - Data Acquisition
  - Data Exchange
  - Database
    - Network/Device state
    - Water flow/quality
    - Human input

- **Model Based Analyzer**
  - What-if Analysis
  - Policy Engine (Rules)
  - Formal Methods
  - Hydraulic Model
  - Hydrological Model
  - Earthquake Model

- **Logic Based**

- **Physics Based**

- **Decision Support**
  - Failure Detection
  - State Estimation
  - Forecast
  - Infrastructure Retrofit

**Physical Plane**

- **Smart Water Infrastructure**

- **External Observation**
  - Temperature
  - Precipitation
  - Seismic report

- **Organization & Human**
  - Water agency
  - Domain expert
  - Community

**Observe**

**Adapt**

**Plug & Play**

Modeling tools, Policies, Algorithms

- Devices/Actuators
IoT-Enabled Smart Communities

SAFER – Perpetual IoT for Personal Safety

TIPPERS: Testbed for IoT-Based Privacy Preserving Pervasive Spaces

AquaSCALE: Resilient Community-Scale Smart Water Infrastructure
New Directions

• Decentralization
  • Pushing OAA to the edge; to the device

• Human centric approach - semantic
  • Build communities for humans (not cars or devices)
  • Semantically driven vs. device- control
  • Privacy and Security

• Open Architectures
  • Integrate and absorb
  • Standardization – Help or hindrance?

• Assured Behavior
  • Enabling safe Composition of non-functional needs
  • Designing for optimality may reduce adaptability for resilience.
References

• Websites of interest
  • Nalini Venkatasubramanian – http://www.ics.uci.edu/~nalini
  • Project SCALE – http://scale.ics.uci.edu
  • Project TIPPERS – http://tippersweb.ics.uci.edu
  • Project AquaSCALE -- http://www.ics.uci.edu/~dsm/aquascale/

• Relevant Publications
EXTRA SLIDES