Enhanced Situational Awareness: Application of DDDAS Concepts to Emergency and Disaster Management

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Overview

- Motivation - Need for improved Situational Awareness
- Using Cell Phones as ad-hoc Sensors
- The WIPER/DDDAS System
  - Detailed description of system
  - Anomaly detection
  - Agent simulation
  - Evaluation plans
- Discussion
- Summary

Problem Domain

- Disasters, crises, emergencies, civil disorders, humanitarian relief efforts, transportation disruptions, … events involving large numbers of people.
  - Natural origins: hurricanes, tornados, earthquakes, tsunami, snow storms, floods, volcanoes, epidemics, …
  - Human origins: terrorists attacks, political unrest, civil unrest/disorder, industrial accidents, transportation accidents, …

Emergency Response Management

- Problems
  - Communication
  - Co-ordination
  - Situation Awareness (SA)
  - Sharing SA
- Information Needs
  - Alerts - Has something happened?
  - Location - Where, extent?
  - Numbers - How many people?
  - Movement - Stationary, moving?
  - What is nature of the event?
  - How should we respond?
- Enhanced Situational Awareness: Calling activity and cell phone locations can help with these information needs

Animation
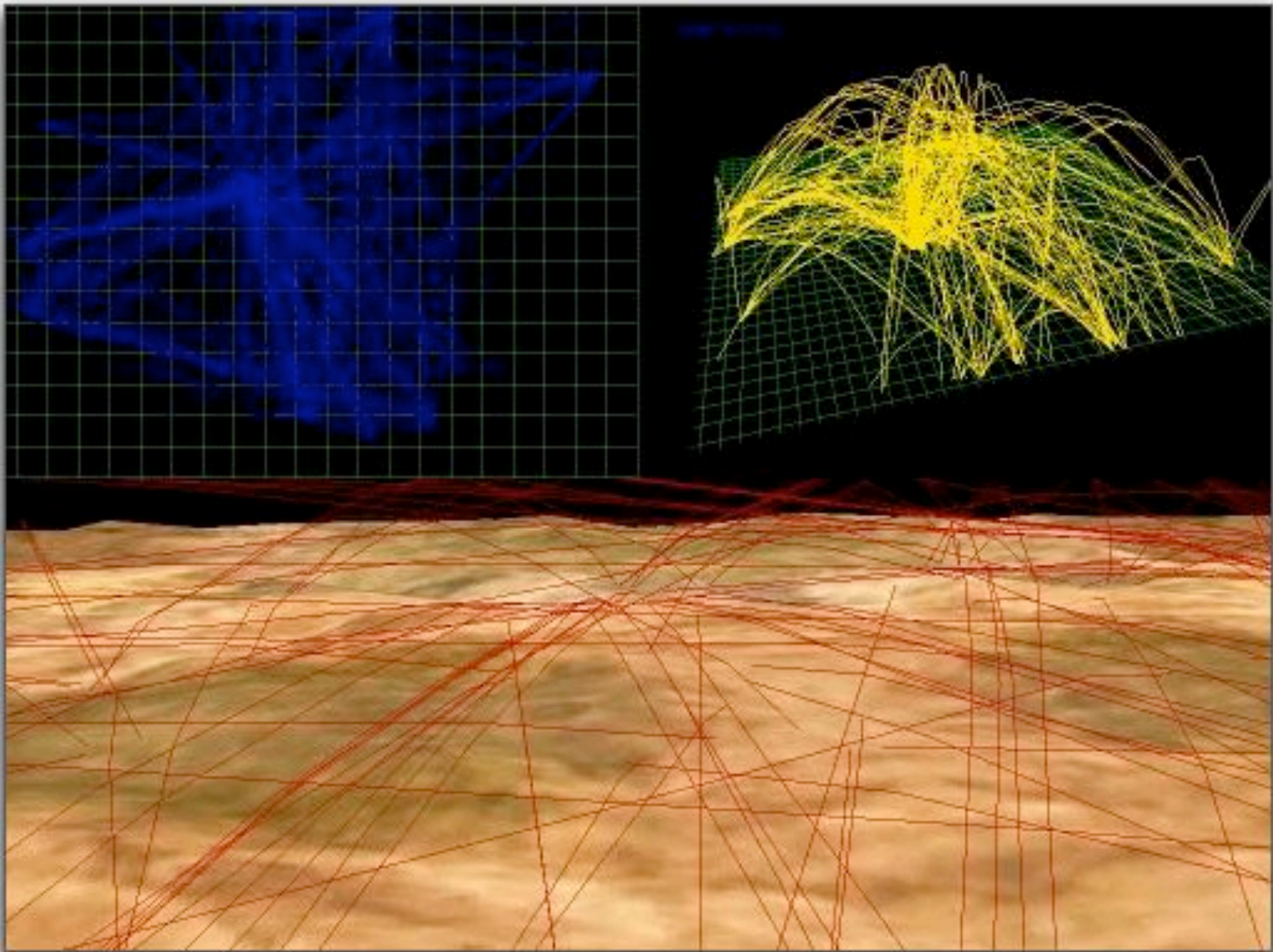
Animation
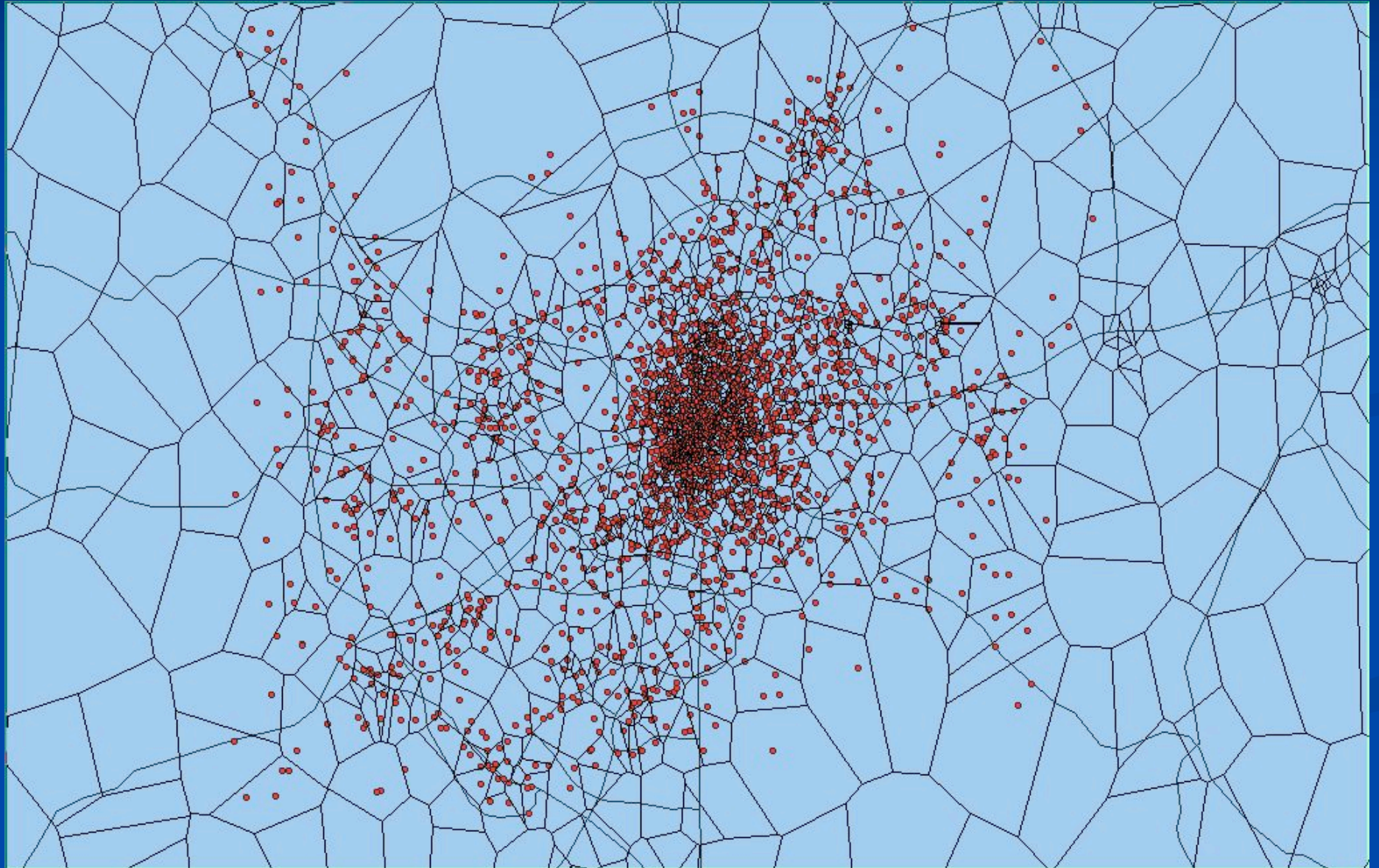
Cell Phones: An In-Place Mobile Sensor Network

- Increasing ubiquity in urban areas
- Approaching +100% in some regions
- Often more popular than wired systems, especially in developing economies
- Cell tower and handset continually exchange "signal strength" info
- Location data
    - Closest cell-tower cells, distance estimates possible
    - Ability to triangulate
    - Growing availability of GPS data
- Collective knowledge of the location, numbers, calling activity and movement of a large sample of population in a region is potentially available
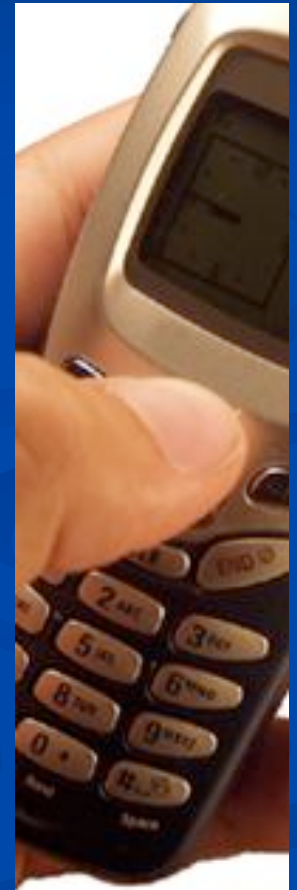
WIPER

- Wireless Integrated Phone-Based Emergency Response System
- Ties into the existing cellular phone infrastructure to detect, monitor, predict anomalies
  - Fact: people make cell phone calls during a disaster
  - Family, friends, E911
  - New calling patterns
  - Increased numbers of calls placed
- Streaming data
  - Calls placed per cell tower
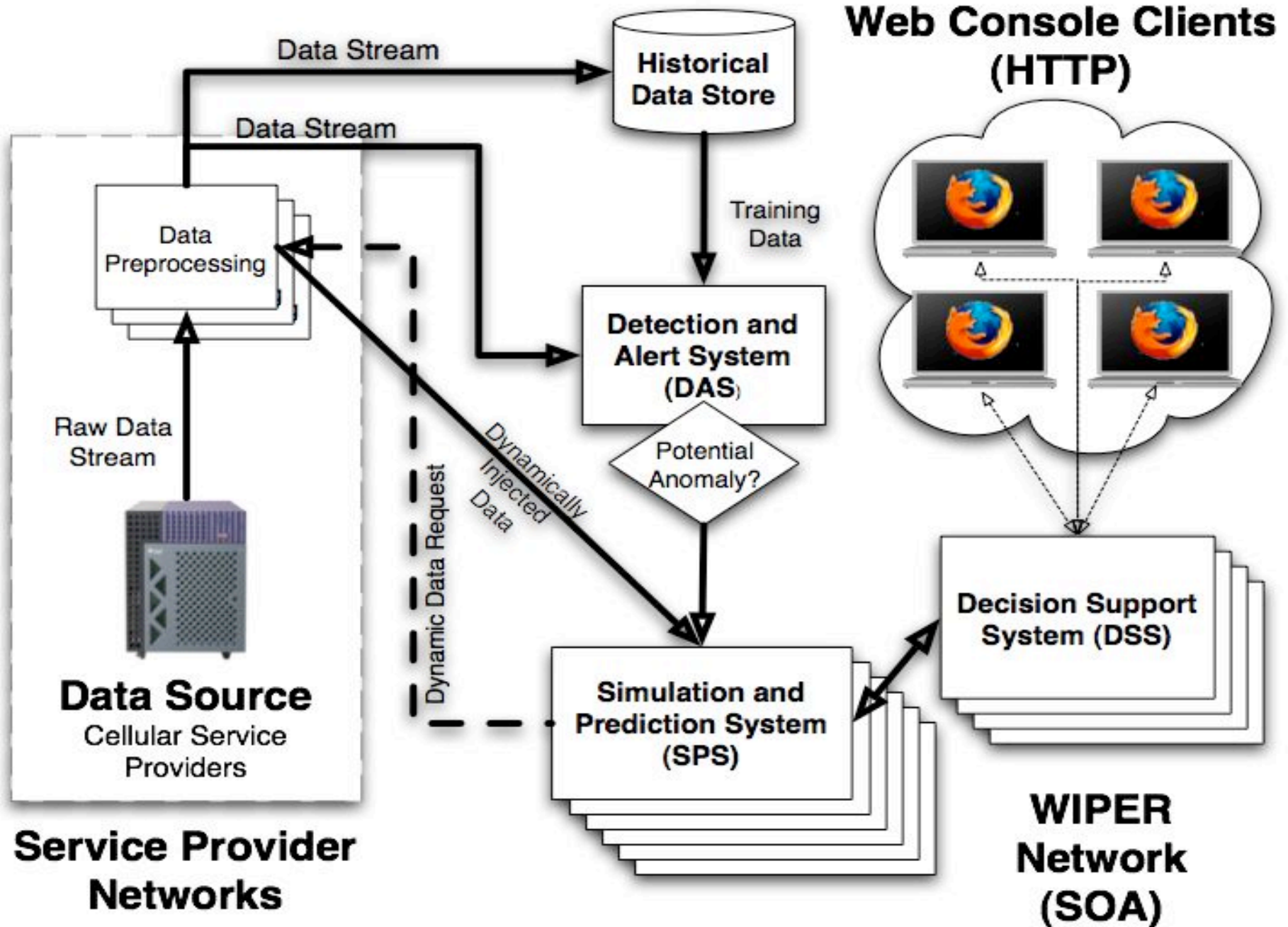 - Calling patterns & volume
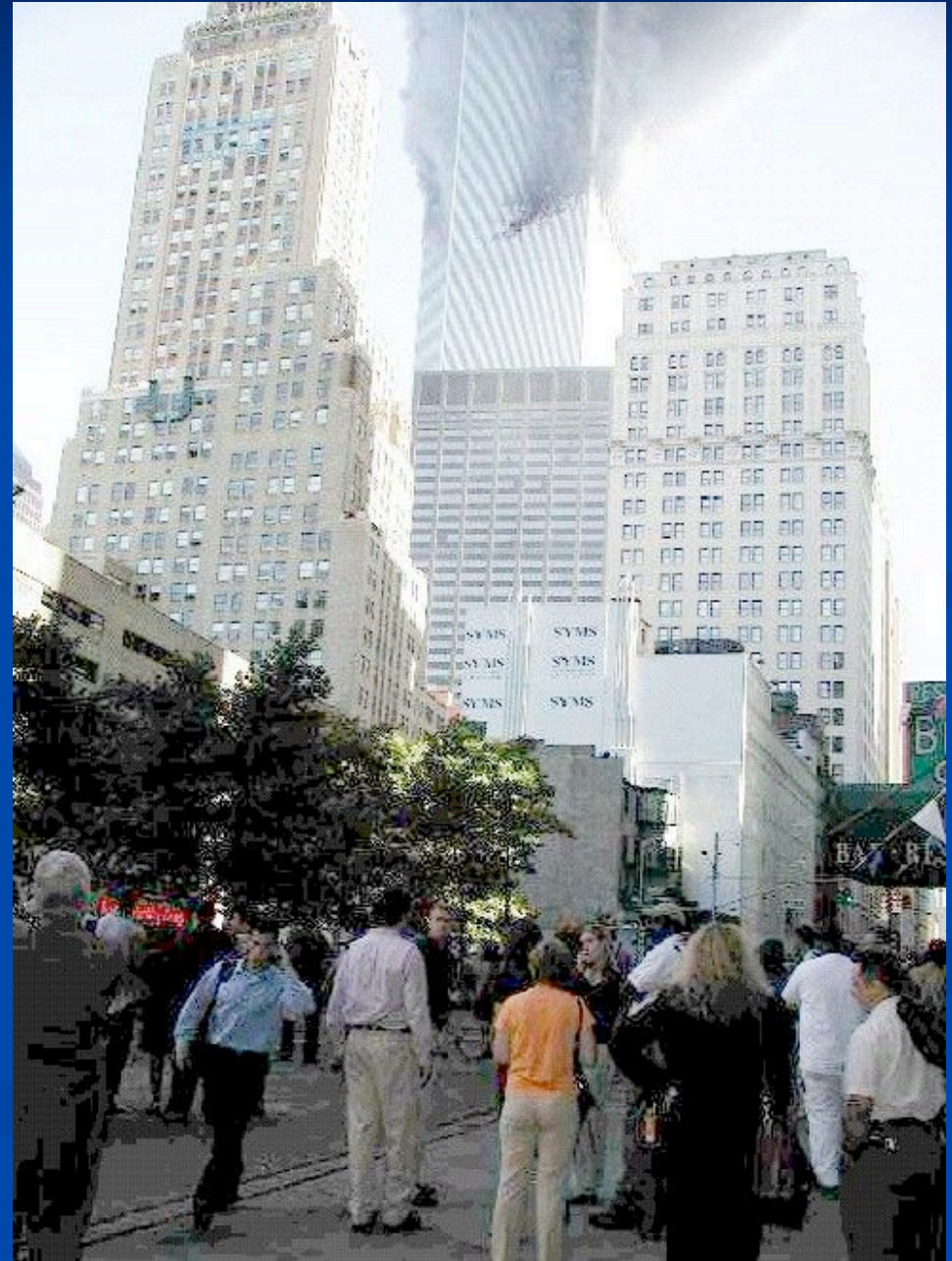
WIPER/DDDAS Distributed System Structure

- **Real Time Data Source**
    - Historic data from cellular service provider
    - Eventually will use live data streams
- **DAS - Detection and Alert System**
- **SPS - Simulation and Prediction System**
- **DSS - Decision Support System**

Emergency Operations Center (EOC)

WIPER/DDDAS Design

WIPER - Data Source

- Data collection occurs at the cellular service provider
- WIPER receives anonymized, pre-processed, encrypted data
- No personally identifiable information leaves the service provider's network
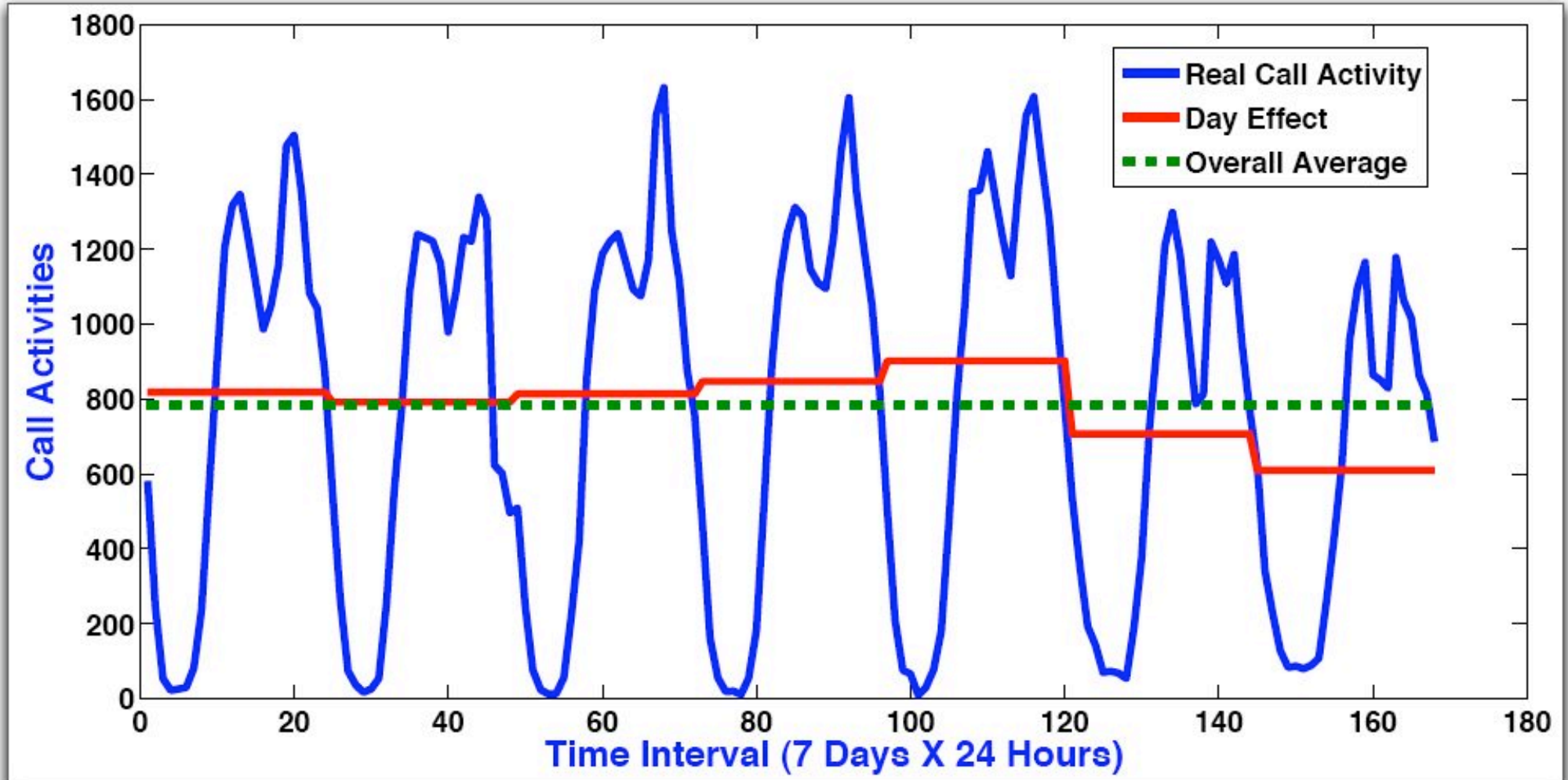
WIPER - Detection and Alert

Location and Activity View

Real World

Social Network View
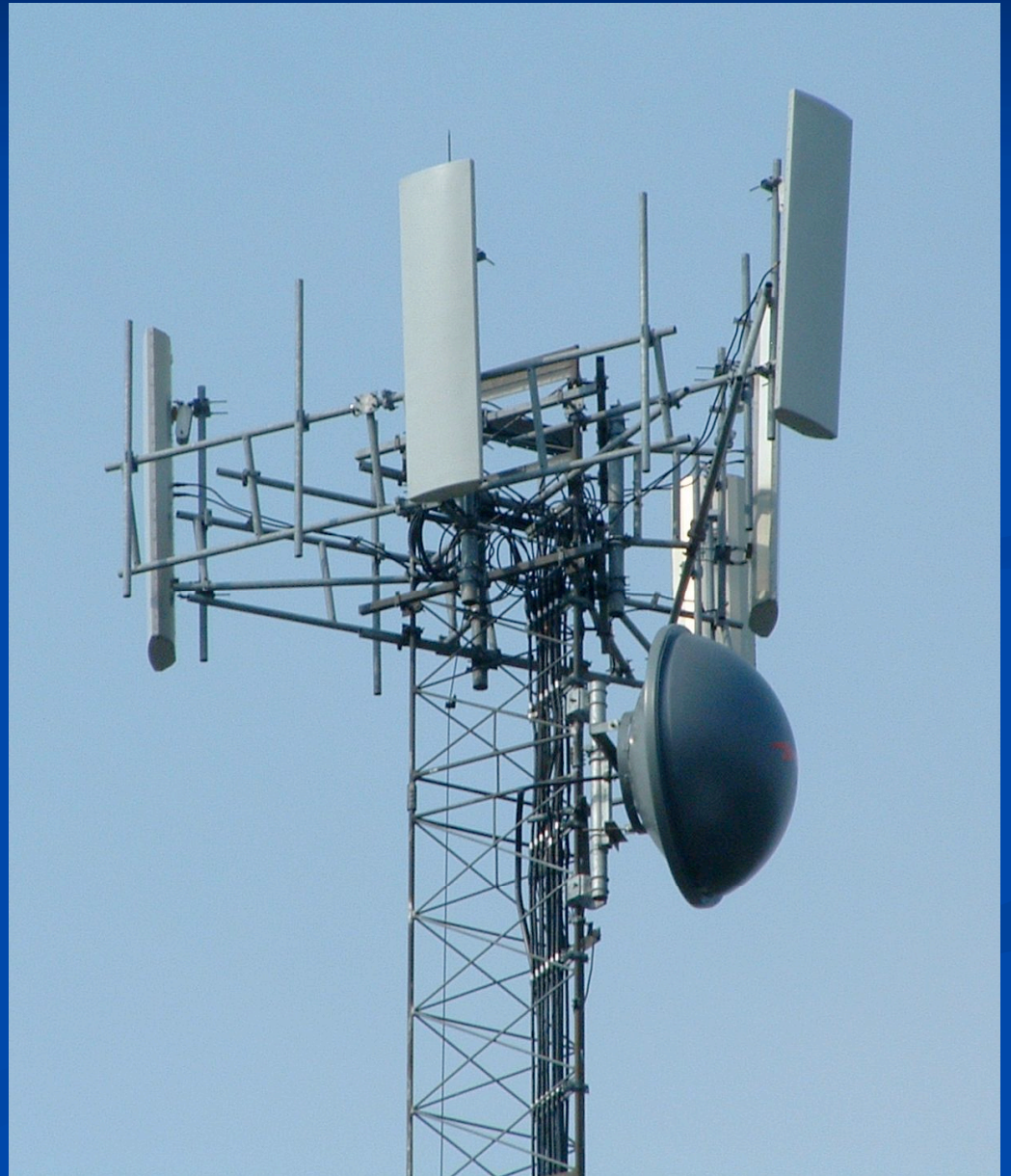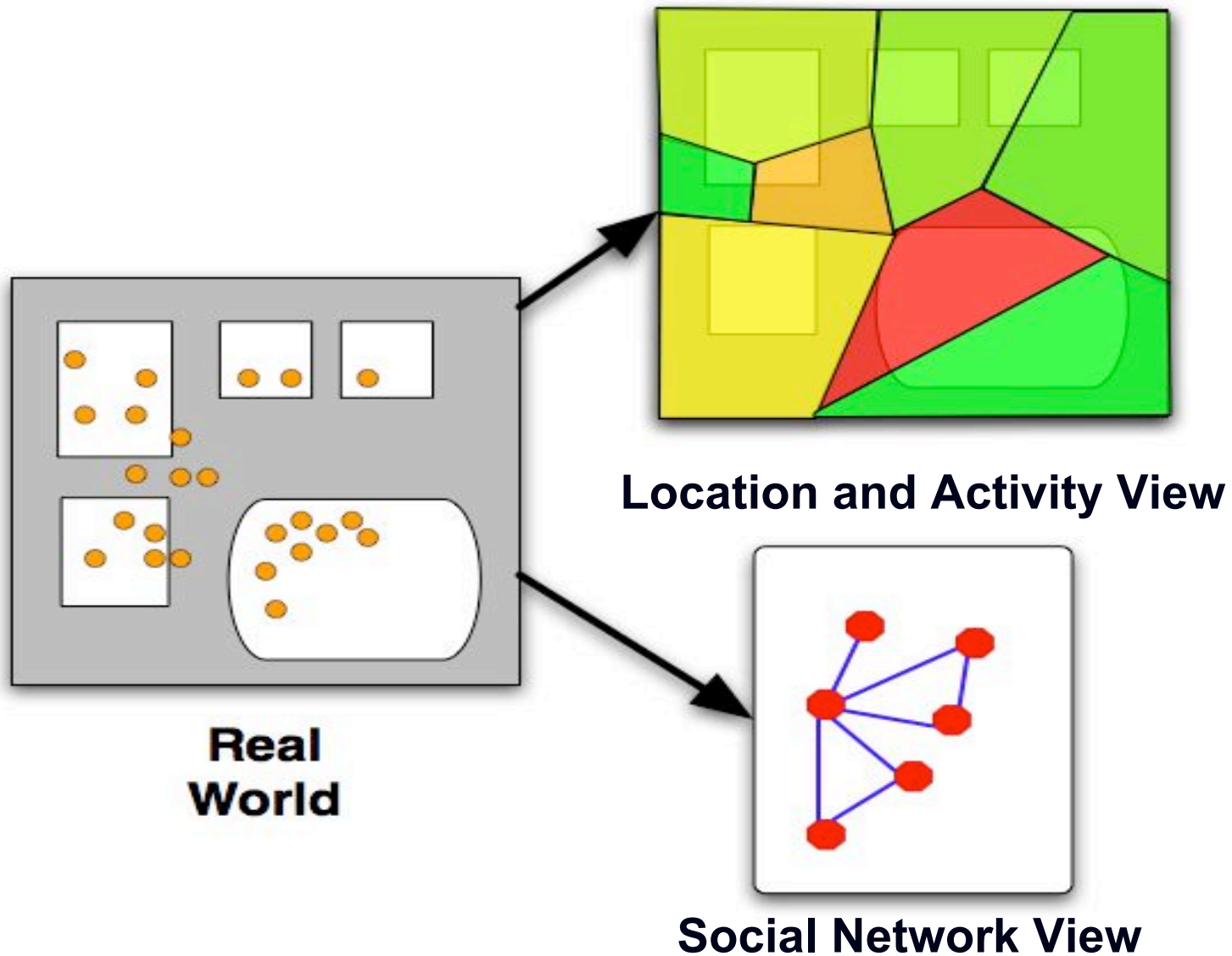
Detection and Alert System

- Uses data stream mining to detect crisis events
  - Online clustering
  - Link sampling - anomalous link detection
  - Markov Modulated Poisson Process (MMPP)
- Monitors call activity, location, social network for anomalies
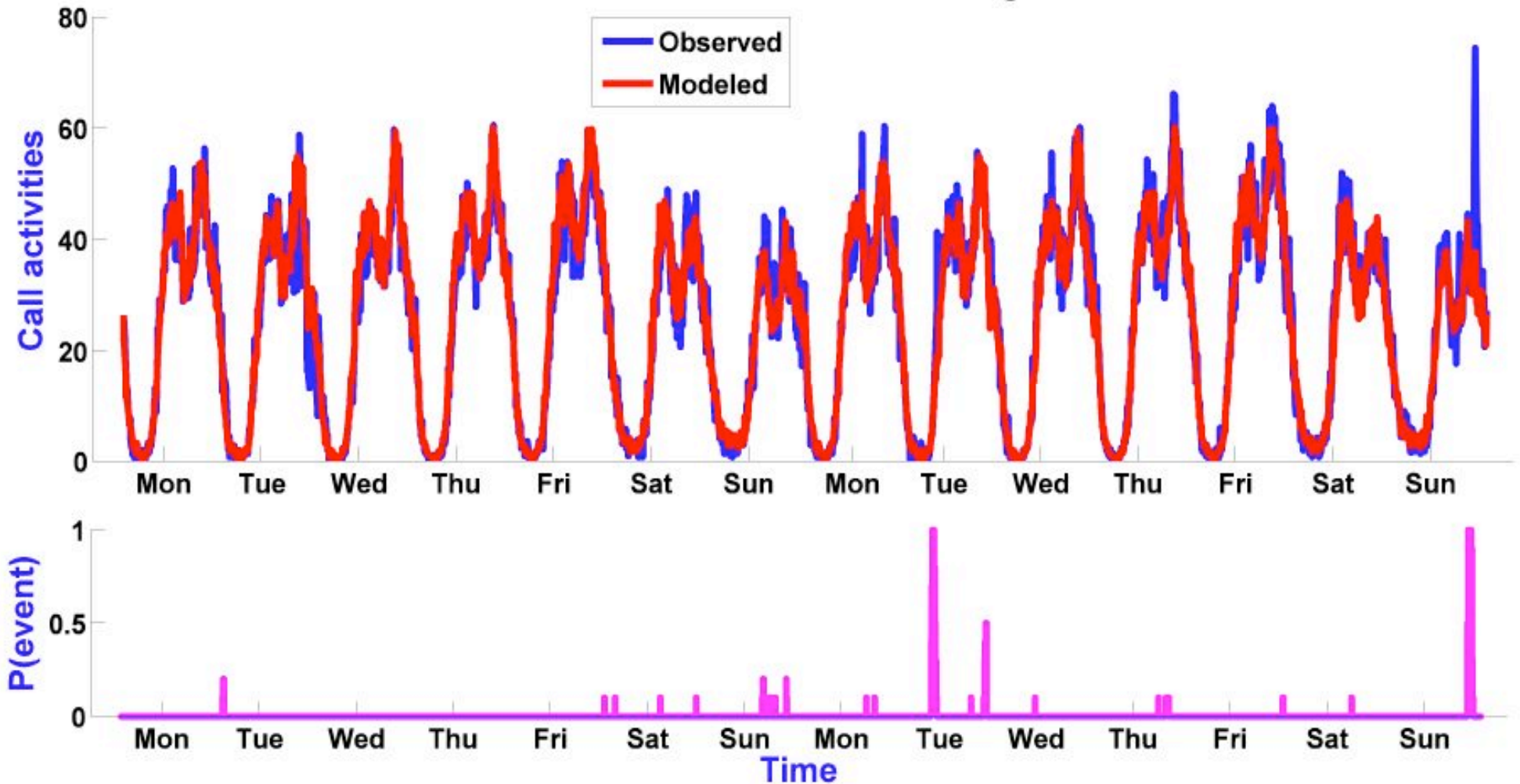- When an anomaly is detected, alert is raised, state is passed on to SPS
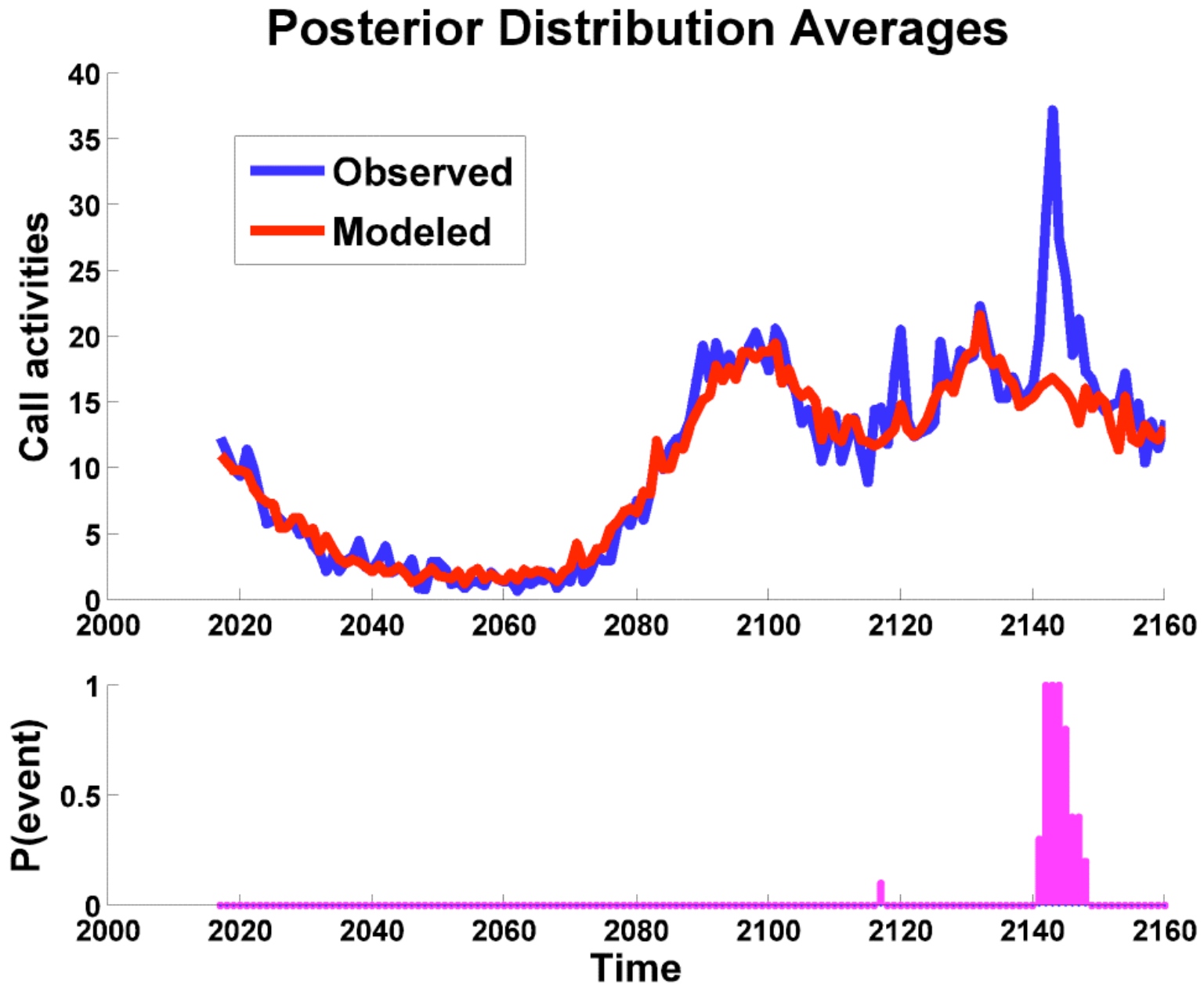
Detection and Alert System

Day and Time Effects

Detection and Alert System

Posterior Distribution Averages

Detection and Alert System
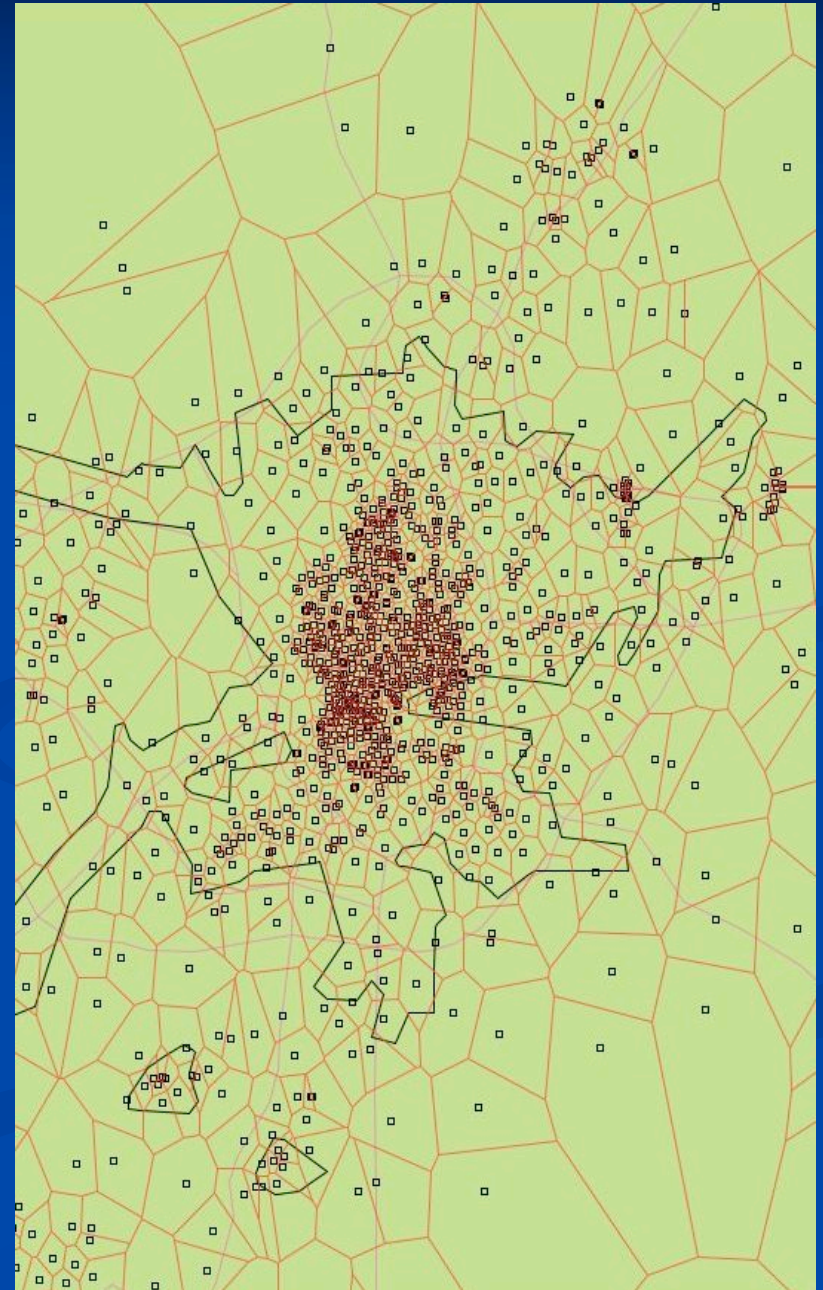

Posterior Distribution Averages

Simulation Prediction System

- For all alerts, WIPER generates an ensemble of Agent-Based Simulations

- Simulations used to determine nature of anomaly, predict evolution of event

- Simulations use direct stream of information to monitor real world and dynamically validate/update simulations
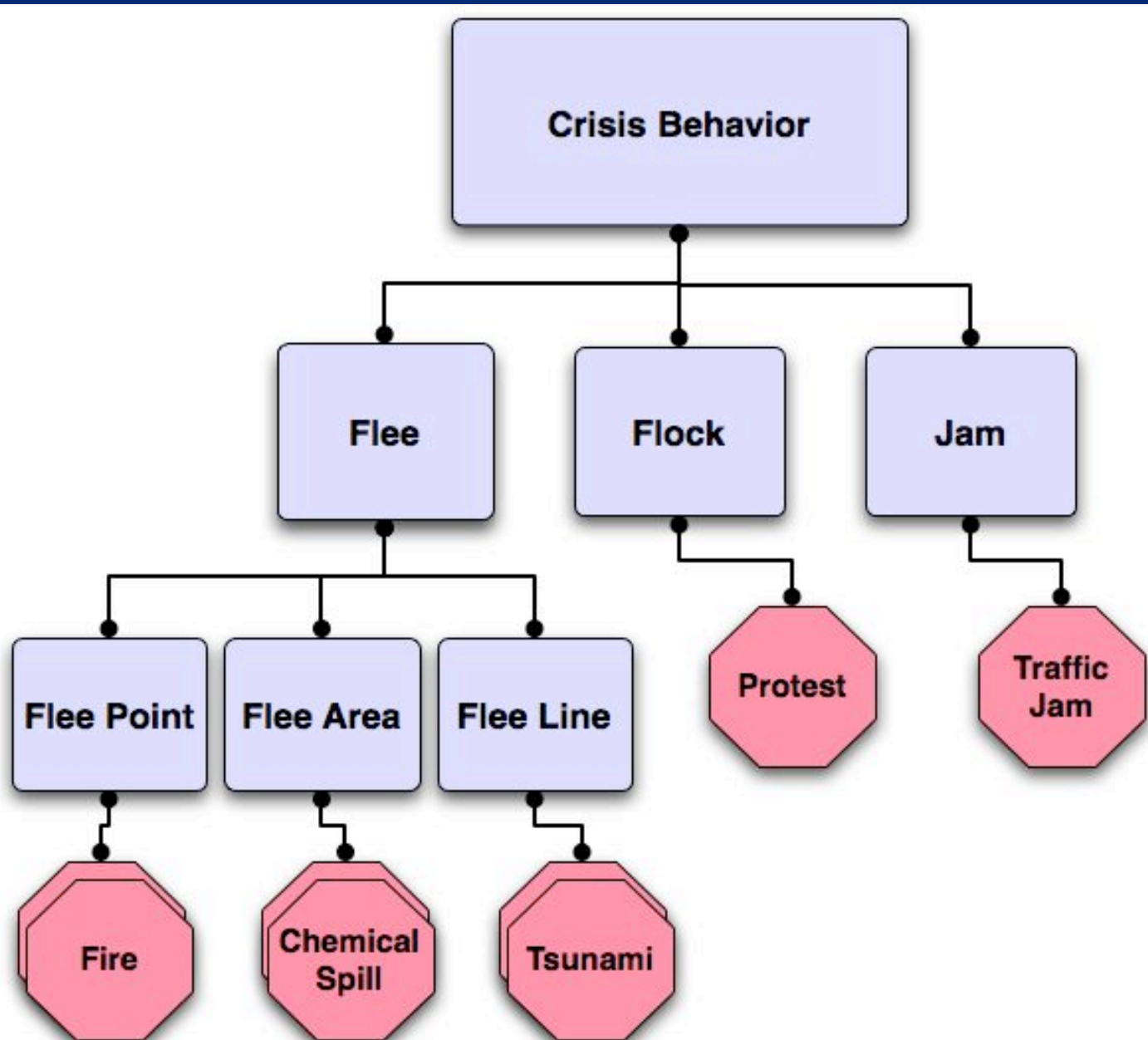
Simulation Prediction System

- Agent-Based/GIS-Based Simulations used to test hypotheses about real-world phenomena
- Geo-spatial constraints embodied in the simulations
  - Rivers, roads, coast-lines
  - Accurate cell-tower coordinates
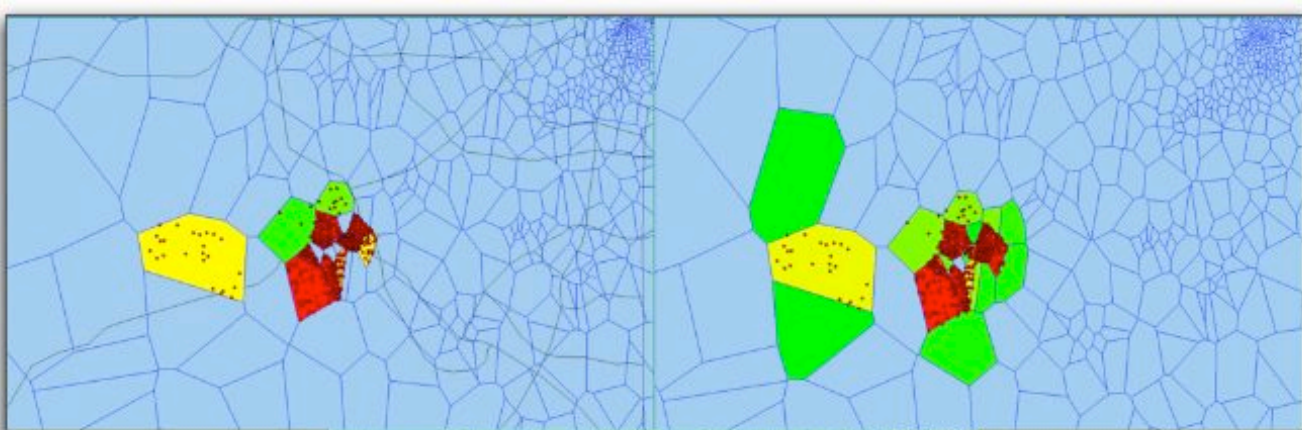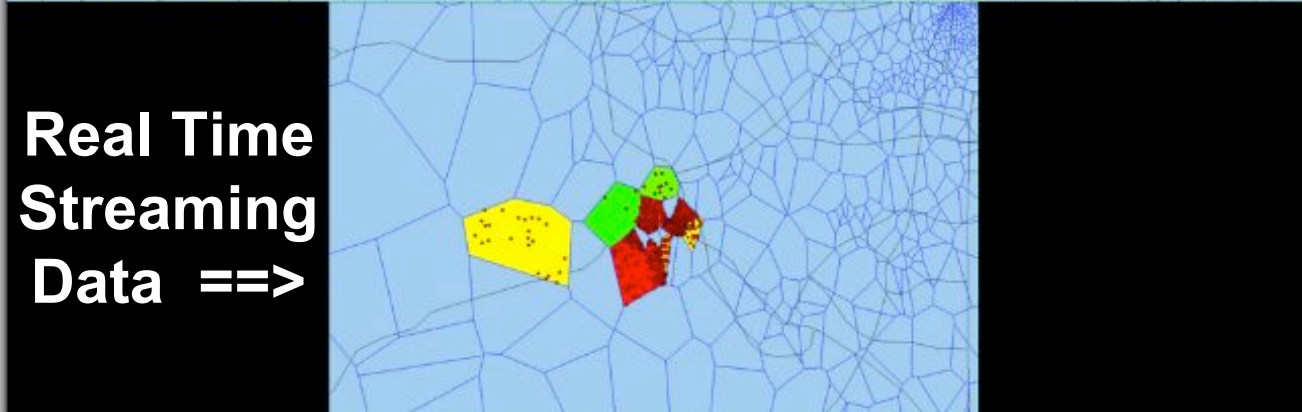 - Overlaid on maps to support emergency response managers
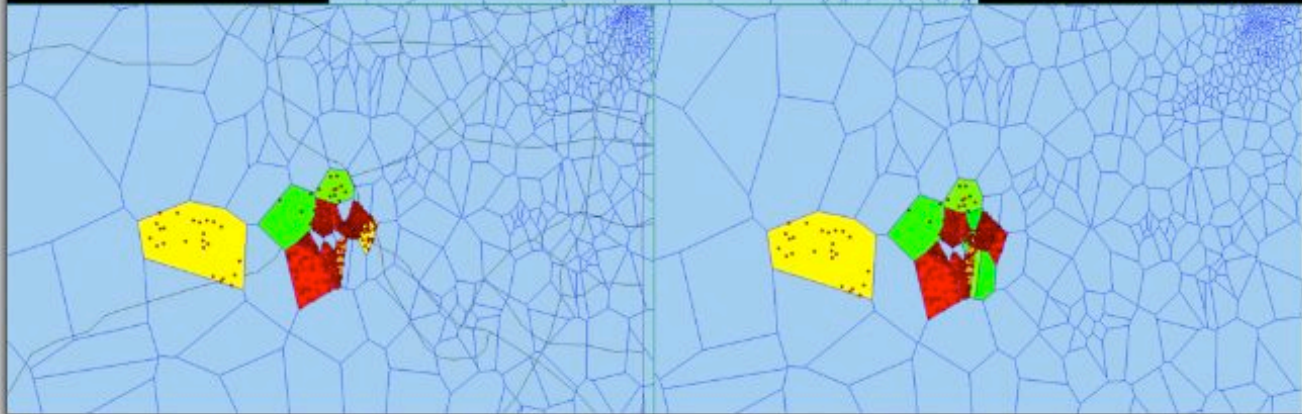
Crises Taxonomy

Animation

Decision Support System

Decision Support System

- Web-based console that provides access to real-world info, results from simulations
- Emergency responders can compare the real-world information with the simulation predictions, decide course of action
- If desired, console can be shared with responders in the field over encrypted web connection
- Alerts could be sent from DSS directly to cell phones in affected area

- Geo-spatial data - maps of crises area
- Temporal data - timelines, events
- Numerical data - graphs, charts, tables
- Predictions - animations

Evaluations Planned at Miami-Dade EOC

Miami-Dade EOC Full Activation Drill

Miami-Dade EOC Evaluation

Discussion

- WIPER System provides complimentary tools for monitoring and predicting crisis events - improved Situation Awareness
- Connection to cellular service provider allows multi-modal monitoring of real time events without need for new sensor infrastructure
- Architecture protects privacy while providing access to information, but potential for privacy concerns
- Open standards/software - Service Oriented Architecture and AJAX
- Computational challenges: real-time detection, faster-than real-time agent-based GIS-based simulations
- Limitations of cell phones during prolonged power outage

Summary

- WIPER is a demonstration project using existing cell phone system in a mobile sensor network
    - Evaluations planned at Miami-Dade EOC
- Employs DDDAS principles
    - Simulation prediction system
    - Large amounts of streaming data
    - Simulation system adapts to new data
    - Simulation system requests higher fidelity data for dynamic validation of simulations
- First WIPER/DDDAS dissertation to be defended this June
    - Three additional dissertations in process
- Four papers: *Science, International Journal of Intelligent Control and Systems, CMOT,* and *PNAS;* five under review
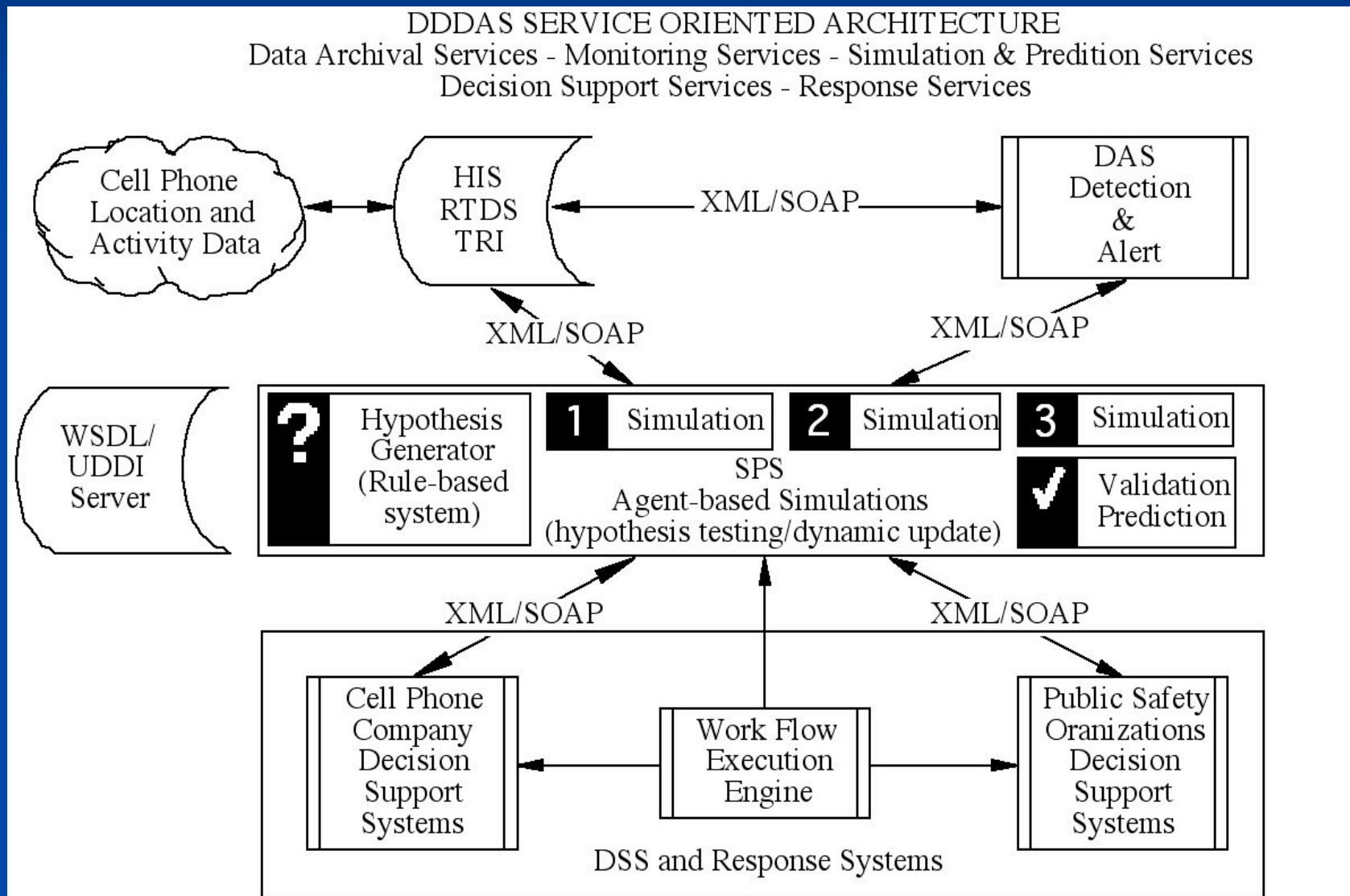- Five conference proceedings

Thank You

Questions?
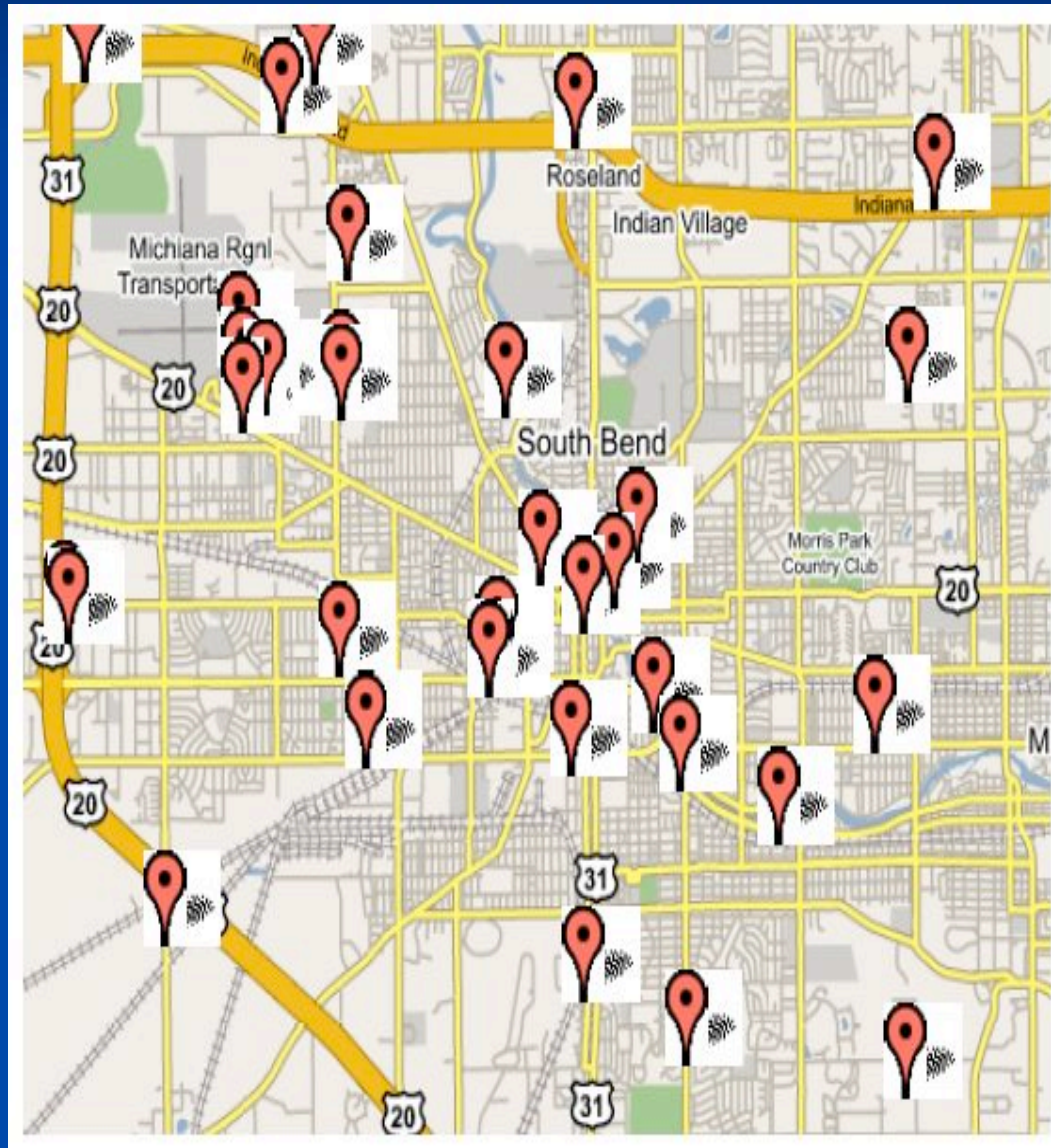
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Bullets

- More work needed on dynamic validation
- More realistic agent simulations
- Field demonstration - Miami-Dade EOC
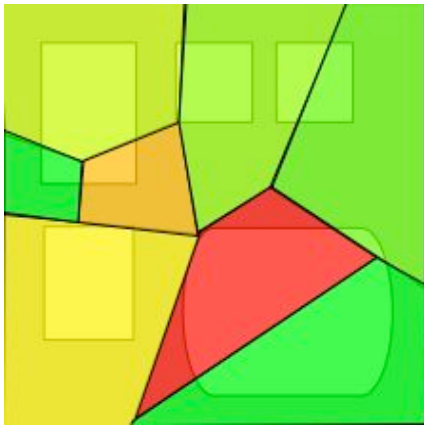
WIPER - Service Oriented Architecture

DDDAS SERVICE ORIENTED ARCHITECTURE
Data Archival Services - Monitoring Services - Simulation & Predition Services
Decision Support Services - Response Services

Cell Tower Locations

Decision Support System

Activity View

Simulation Output

Simulations Dispatched

Evaluating Potential Anomaly….

Possible Match Found: Benign Pedestrian Event

Validation:

   KS Test Value

   Chi-Square Value

Continuing to Track Anomaly…

System Log

Potential Anomaly Detected

Time – 2006-04-15

Location – Lat XX.XXX Long YY.YYY

Console User

Simulation Prediction System

- WIPER uses DDDAS concepts
- Dynamic, Data-Driven Application Systems:
  - Couple simulations with sensors
  - Use streaming data to refine simulations
  - Allow simulations to steer sensors, adapt data collection

Katrina Evacuation