

WIPER: A Multi-Agent System for Emergency Response *

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ABSTRACT

This paper describes the proposed WIPER system. WIPER is intended to provide emergency planners and responders with an integrated system that will help to detect possible emergencies, as well as to suggest and evaluate possible courses of action to deal with the emergency. The system is designed as a multi-agent system using web services and the service oriented architecture. Components of the system for detecting and mitigating emergency situations can be added and removed from the system as the need arises. WIPER is designed to evaluate potential plans of action using a series of GIS enabled Agent-Based simulations that are grounded on realtime data from cell phone network providers. The system relies on the DDDAS concept, the interactive use of partial aggregate and detailed realtime data to continuously update the system and allow emergency planners to stay updated on the situation. The interaction with the system is done using a web-based interface and is composed of several overlaid layers of information, allowing users rich detail and flexibility.

Key Words:

Emergency Response System, GIS modeling, Multi-Agent Systems

INTRODUCTION

The current cell phone network provides an existing sensor network that can be used to detect and respond to crisis situations. Current uses of realtime cell phone data center around traffic management [AP, 2005], as the data collected from current cell phones is limited to location, movement and call activity information. In the near term, we can determine higher order information on crowd movement and behavior from this information. In the future, cellular networks may provide more varied information to emergency response planners. Researchers at UC Berkeley are currently developing small sensor packages that could be integrated into cell phone handsets to turn cell phone networks into sophisticated mobile sensor networks[Metz, 2005].

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In order to fully utilize the large volume of dynamic information that will flow in from cell phone networks, emergency planners will need new, sophisticated tools. We believe that WIPER will be one important tool in that arsenal.

Numerous software tools have been developed to aid emergency responders. Several recent examples are EVResponse and the COMBINED project [Thomas et al., 2005, Tatomir and Rothkrantz, 2005]. These tools provide methods of gathering information on the current status of crisis situations. They provide emergency response planners with detailed, high-quality information, but with a high cost in terms of personnel and deployment. (PDAs and wireless infrastructure must be purchased, personnel trained and both need to be sent to crisis sites.) WIPER would act as a low-cost, highly available monitoring system. Its deployment would be automatic, as anyone with a cell phone in the area is a participant. No special training would be required for phone users, but balancing this, the quality of information from each person is low. Limited to location and activity information, it may not be clear what type of crisis is occurring. We hope that it is possible to use machine learning techniques to infer information about the state of the area (i.e. to distinguish a fire from a traffic jam) from the location and call activity information that we collect. WIPER would convey three distinct and useful pieces of information to emergency responders via the web-based console:

- It provides near-real time information on the location of cell phone users in an area, plotted on a GIS-based map of the area.
- It detects potential anomalies, such as traffic jams, roving crowds and call patterns indicative of a crisis.
- It proposes custom-tailored mitigation strategies, such as potential evacuation routes or barricade placement, suggested by computer simulations.

The prototype WIPER system is intended to address specific needs in the Emergency Response community, specifically the ability to view the development of a crisis in realtime, the ability to propose and evaluate response in near-real time and the ability to collect and analyze streaming information from an ad-hoc sensor network. The WIPER system will use dynamic data from cellphones and analyze the data in realtime, providing the ability to detect a crisis as it emerges. An online classification system will help to predict crises before they happen by recognizing familiar patterns in group behavior. Responding to events from the anomaly detection system, GIS-based simulations of the region will be launched and results collated and presented to planners. Finally, the web-based console will allow Emergency Planners to quickly examine the current state of the environment, see possible predicted outcomes from the simulations and evaluate courses of action.

WIPER is designed to work with the current level of information available from the cell phone network, yet it aims to provide a set of functionality far more advanced than is currently available. The system will utilize dynamic streaming information from cell phone providers to monitor and detect anomalies and predict crisis events. The simplest form of potential crisis events would be traffic disturbances, but by utilizing temporal data mining, historical knowledge of crisis events and call patterns and realtime social network calculations, WIPER should be able to predict, detect and propose responses to a wide range of emergency situations. WIPER would detect crowds and demonstrators at public events, monitoring such events to determine if they are degenerating into riots. This monitoring will consider both location information and call activity.

LEVERAGING THE EXISTING CELL PHONE NETWORK FOR CRISIS DETECTION AND MONITORING

As proposed in several previous projects, the existing cell phone network can be used both as a tool for detecting the state of the environment [AP, 2005, Ratti and et al, 2005] as well as communicating directly with those affected by crisis events [Wood, 2005, Zimmermann, 2005, Clothier, 2005]. WIPER is intended to push the boundary of crisis detection and monitoring with the current cell phone network. The WIPER

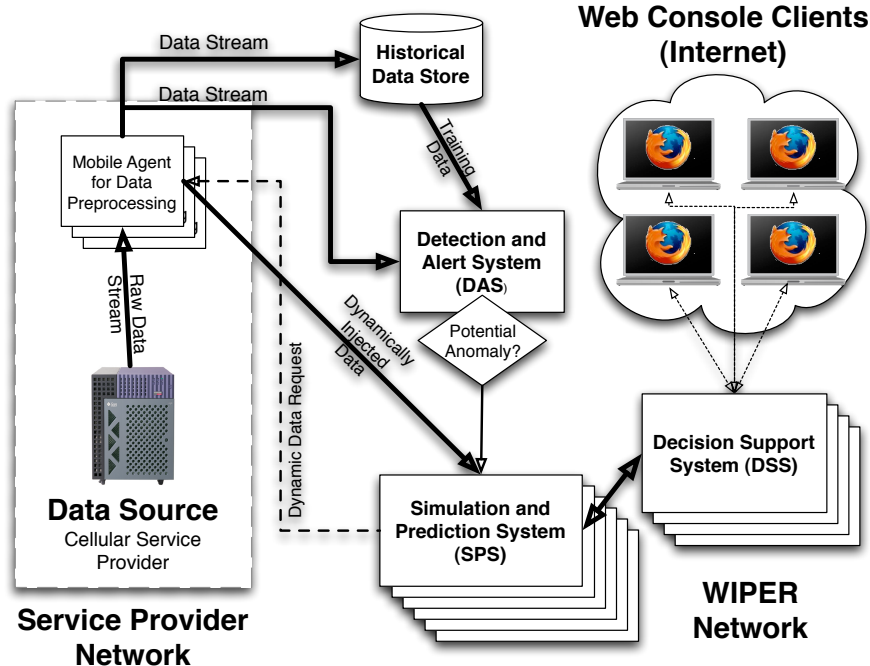


Figure 1: An overview of the prototype WIPER system.

system will receive a feed of realtime information from cell phone providers. This is expected to be a sample of the incoming data, as the full data stream would be prohibitively difficult to transmit. The incoming data would be monitored for anomalies, which include the obvious spatial and temporal aggregation, as well as call patterns and movement discrepancies that can signal the impending onset of a crisis event.

PROPOSED WIPER SYSTEM ARCHITECTURE

Figure 1 shows the overall system architecture of WIPER. The WIPER system will be a distributed system combining traditional methods of composition (RMI) with newer, more robust methods (Service Oriented Architecture, Web Services, Intelligent and Mobile Agents). WIPER is composed of three layers:

- Data Source and Measurement
- Detection, Simulation and Prediction
- Decision Support

The Data Source and Measurement layer handles the acquisition of realtime cell phone data, as well as the fixed transformations on the data, such as the calculation of triangulation information for providing more accurate location information on legacy handsets. The Detection, Simulation and Prediction layer analyzes incoming data for anomalies, attempts to simulate the anomaly to predict possible outcomes and suggests actions to mitigate the event. Finally, the Decision Support layer presents the information from the other layers to end users, in terms of summaries of traffic information for commuters, real time maps and simulations on the anomaly to first responders and potential plans for crisis planners.

These layers are further divided into components that handle highly specific functions, as described in the following sections.

DATA SOURCE AND MEASUREMENT LAYER

This layer contains three modules, all of which have functionality related to the management of the real time cell phone data. The Real Time Data Source (RTDS) collects information from one or more cell phone providers, fuses the information into a unified data stream and redirects the data stream into components in the Detection, Simulation and Prediction (DSP) layer. The data fusion is done by first dispatching software agents for preprocessing to the cell phone provider. The software agent handles converting the data stream from the service provider's format into a summarized form. This agent removes personalized information such as phone number and customer id and replaces it with a coded value that is internally consistent within the WIPER system but cannot be used to identify the user. The data streams are fused in the RTDS by applying a window for reordering the data streams as described in [Babcock et al., 2002]. For training purposes, snapshots of the data are occasionally stored on a server and become part of the Historical Data (HIS) module. The HIS streams historical data in the same format as the RTDS for training and testing the Detection and Simulation modules in the DSP layer. The Triangulation Information module handles converting the rough location information associated with a cell phone into a more precise location which is needed by the Simulation and Prediction System. On newer handsets, GPS sensors can provide the cell phone provider with precise location information, but only if the feature is enabled and the cell phone provider is equipped to monitor it.

DETECTION, SIMULATION AND PREDICTION LAYER

The Detection, Simulation and Prediction (DSP) layer handles the monitoring on the streaming data and uses automatically generated computer simulations to determine whether perceived anomalies represent potential crisis events and what actions can be taken to mitigate these events. The Detection and Alert System (DAS) will use a combination of established techniques for detecting anomalous patterns of spatial activity, as well as new methods of real time social network analysis to detect call patterns that may indicate emerging crisis activity. Upon detection of a potential anomaly, the DAS will transfer information about the event to the Simulation and Prediction System (SPS). The SPS will use the information to create a GIS-based computer simulation that will attempt to model the outcome of the event. The SPS will create an ensemble of Agent-Based simulations that are run on a computational grid. The simulations will be monitored by the SPS and ranked according to their ability to correctly predict the progression of the actual event. The SPS and each of the simulations will interact with the RTDS to acquire more detailed information concerning the potential anomaly area. For more information on the SPS see [Madey et al., 2006].

DECISION SUPPORT SYSTEM LAYER

The Decision Support System (DSS) acts as a front end for the WIPER system. It is the main portal for disseminating the information from WIPER to crisis planners and responders, public safety personal and the general public. The DSS will aggregate information from the SPS and present the real time system status and any predicted anomaly information in a web based interface. There will be options for crisis planners to specify and evaluate mitigation plans through the web interface. These plans will be evaluated with Agent-Based simulations and the results will be accessible from the web based interface. This web interface will only allow access to authorized users and will use encryption to prevent snooping. The DSS may also be configured to allow certain information to be publicly accessible. This could mean providing a near-real time picture of the traffic situation or predictions of traffic congestion.

MULTI-AGENT SYSTEM DESIGN

Several elements of the WIPER system will benefit from Multi-Agent System concepts. As described above, the RTDS benefits from using mobile agents to anonymize and preprocess the data stream at the cellular service provider. For the Detection and Alert System, it is advantageous to build data mining and anomaly detection agents, which can be migrated directly to the cell phone providers. This would allow the data to be

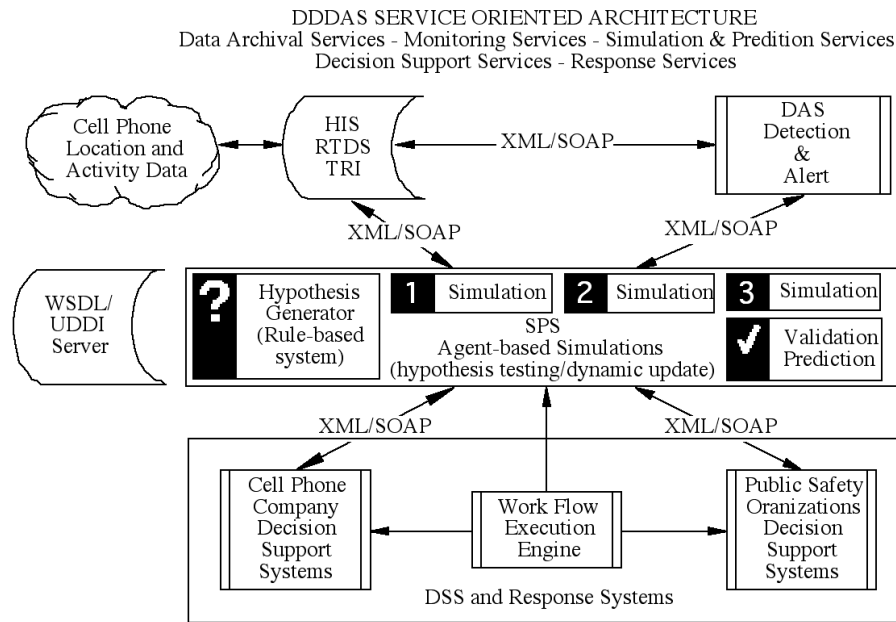


Figure 2: The proposed Service Oriented Architecture of the WIPER system.

analyzed at the source, reducing the overall network traffic and improving performance. Also, as improved algorithms are developed or specialized detectors are called for, they can be easily substituted. The Simulation and Prediction System will initially be used to predict simple movement and traffic patterns, but in the future the SPS may be extended to model the dispersion of chemical agents in the air and through the ground with additional layers of GIS data along with real time weather information or the transfer of infectious agents with epidemiological components. Mobile Agents may be used to wrap the heterogeneous simulation components and handle their scheduling and migration to computational resources and allow monitoring and interaction with the SPS, a technique borrowed from high performance computing [Schoenharl et al., 2005].

WEB SERVICES

The use of Web Services and the Service Oriented Architecture allows WIPER to be composed of standards-compliant modules and simplifies the development of the system. The proposed SOA for the WIPER system is demonstrated in Figure 2. This also allows the system to easily incorporate new information sources such as GIS, weather monitoring or news feeds, as well as giving the end user options for customizing the display formatting.

PRIVACY AND ETHICAL CONCERNS

Concern about government monitoring of cell phone location and call activity may present a challenge for the deployment of the WIPER system [Singel, 2005, Richtel, 2005]. In order to address any concerns about privacy, the WIPER system is designed so that all personally identifiable data is removed from the data stream before it leaves the cell provider's network, ensuring that there is no potential for sensitive data to be abused. The software agents that handle the preprocessing reside on the servers of the cellular service provider and ensure that all data that is streamed across the internet is anonymized and encrypted. The WIPER system itself uses only aggregate data from the data streams and is not designed to allow the monitoring or tracking of individual handsets. We will continue to examine the potential impacts of such

systems on personal privacy, especially in the context of location-aware systems such as WIPER that utilize GIS systems and technologies [Armstrong, 2002, Armstrong and Ruggles, 2005]

SUMMARY

We have presented the proposed architecture for the WIPER system. It is designed as a distributed, multi-agent system built on open standards to address events in the real world. WIPER brings cutting edge social network modeling algorithms, anomaly detection, sophisticated GIS-enabled Agent-Based simulation and web-based interaction and visualization tools together in one package to enhance the decision making process of Emergency Management professionals. The system will interface with the existing cellular telephone network to allow cell phone activity to be monitored in aggregate, essentially creating a large scale, ad-hoc sensor network. The stream of incoming data will be monitored by an anomaly detection algorithm, flagging potential crisis events for further automated investigation. Agent-Based simulations will attempt to predict the course of events and suggest potential mitigation plans. And the system will display output at every level to human planners so that they can monitor the current situation, oversee the software process and make decisions. When completed, the WIPER system is designed to integrate into a crisis response workflow, adding an important component to the toolbox of Emergency Response professionals.

References

- [AP, 2005] AP (2005). Tracking cell phones for real-time traffic data. <http://www.wired.com/news/wireless/0,1382,69227,00.html>.
- [Armstrong, 2002] Armstrong, M. P. (2002). Geographical informational technologies and their potentially erosive effects on personal privacy. *Studies in the Social Sciences*, 27:19–28.
- [Armstrong and Ruggles, 2005] Armstrong, M. P. and Ruggles, A. (2005). Geographical information technologies and personal privacy. *Cartographica*, 40:63–73.
- [Babcock et al., 2002] Babcock, B., Babu, S., Datar, M., Motwani, R., and Widom, J. (2002). Models and issues in data stream systems. In *PODS '02: Proceedings of the twenty-first ACM SIGMOD-SIGACT-SIGART symposium on Principles of database systems*, pages 1–16, New York, NY, USA. ACM Press.
- [Clothier, 2005] Clothier, J. (2005). Dutch trial sms disaster alert system. <http://www.cnn.com/2005/TECH/11/09/dutch.disaster.warning/index.html>.
- [Madey et al., 2006] Madey, G., Szabo, G., and Barabási, A.-L. (2006). Wiper: The wireless integrated phone based emergency response system. In Sloot, P. and Dongarra, J., editors, *Proceedings of the International Conference on Computational Science*.
- [Metz, 2005] Metz, R. (2005). Saving the world with cell phones. <http://www.wired.com/news/wireless/0,1382,68485,00.html>.
- [Ratti and et al, 2005] Ratti, C. and et al (2005). Senseable city project. <http://senseable.mit.edu/projects/graz/>.
- [Richtel, 2005] Richtel, M. (2005). Live tracking of mobile phones propts court fights on privacy. *The York Times, Late - Final ed.*
- [Schoenharl et al., 2005] Schoenharl, T., Christley, S., and Thain, D. (2005). Patisserie: Support for parameter sweeps in a fault-tolerant, massively parallel, peer-to-peer simulation environment. In Yilmaz, L., editor, *Proceedings of the 2005 Agent-Directed Simulation Symposium*, volume 37.

- [Singel, 2005] Singel, R. (2005). U.s. cell-phone tracking clipped. <http://www.wired.com/news/print/0,1294,69390,00.html>.
- [Tatomir and Rothkrantz, 2005] Tatomir, B. and Rothkrantz, L. (2005). Crisis management using mobile ad-hoc wireless networks. In *Proceedings of the Second International ISCRAM Conference*.
- [Thomas et al., 2005] Thomas, M., Andoh-Baidoo, F., and George, S. (2005). Evresponse - moving beyond traditional emergency response notification. In *Proceedings of the Eleventh Americas Conference on Information Systems*.
- [Wood, 2005] Wood, M. (2005). Cellalert, for government-to-citizen mass communications in emergencies. In *Proceedings of the Second International ISCRAM Conference*.
- [Zimmermann, 2005] Zimmermann, H. (2005). Recent developments in emergency telecommunications. In *Proceedings of the Second International ISCRAM Conference*.