Context-aware framework to support situation-awareness for disaster management

Aicha Aid* and Idir Rassoul

LARI Laboratory of Computer Science,
Mouloud Mammeri University of Tizi-Ouzou,
Tizi-Ouzou 15000, Algeria
Email: aid_aicha@hotmail.fr
Email: idir_rassoul@yahoo.fr
*Corresponding author

Abstract: When a crisis event occurs, there is a strong need for any involved decision maker to gather in short time frames relevant situational information from different available data sources, to better understand the caused disruptions. Technological devices proliferation and ICT efficiency in timely information sharing did not leave a choice to responders only to adopt them, supporting their operations. This paper proposes a framework that aims to solve challenges brought by this new paradigm of information sharing. Based on service oriented architecture, our framework relies on web service standard for Devices to make pervasive situation-awareness (SA) environment that allows seamless integration of heterogeneous devices. It also provides solutions to filter in real time received information by taking into account the decision maker's context. This context-aware mechanism plays an important role in making the data source intelligent that delivers personalised view of the situation, relevant to decision maker current needs.

Keywords: pervasive computing; context-awareness; SA; situation-awareness; disaster management; web service; ubiquitous computing; semantic web; information filtering; event extraction; emergency response.

Reference to this paper should be made as follows: Aid, A. and Rassoul, I. (2017) 'Context-aware framework to support situation-awareness for disaster management', *Int. J. Ad Hoc and Ubiquitous Computing*, Vol. 25, No. 3, pp.120–132.

Biographical notes: Aicha Aid is a PhD candidate at the Computer Science Department of the Electrical Engineering and Computer Science Faculty within the Mouloud Mammeri University of Tizi-Ouzou. She holds an MSc (2011) in Computer Systems and Networks from the same department. Her research interests include pervasive information systems, situation-awareness for disaster management, ICT for emergency response, context-aware services and applications of web services on ubiquitous environments.

After his studies at the University of Paris IX Dauphine (France) where he obtained the doctorate 3rd cycle in computer science, Idir Rassoul joined the Mouloud Mammeri University of Tizi-Ouzou, where he works now in his capacity as university teacher/researcher as Lecturer empowered to conduct research in computer sciences. Head of a research team at the Laboratory of Research in Computer Science (Lari) in the field of software engineering and information systems, he is currently developing collaboration in geographic information systems including pervasive computing and decision-making in emergency situations with colleagues of Department of Civil Engineering.

1 Introduction

According to Endsley (1995) model, situation-awareness (SA) can be divided into three separate levels: perception, comprehension, and projection. The first level involves processes of gathering and collecting information that describe the current state of elements constituting the affected area. Comprehension involves integration and interpretation of this set of information to picture a comprehensible view of the current situation. Finally, projection predicts the future status of the same environment's elements, in order to support early decision making.

These three SA levels reflect the importance of the valuable resource that transits from level to another, which is information. Its accuracy, timelines and reliability will have a strong impact on the quality of decisions to be taken (Mehrotra et al., 2003). In fact, the decision making process requires the provision of accurate, detailed and up-to-date information from damaged sites to assess, understand and engage appropriate response actions based on the current situation state.

In natural and man-made disasters, such as hurricanes, typhoons, earthquakes and floods, SA is considered as a crucial and essential part that enables making quick and effective decisions to enhance the response phase efforts of the disaster management cycle. To achieve this critical part, several response units are sent on-the-ground once a disaster is reported to collect, gather and deliver large amount of actionable information to better understand what is happening in the affected areas. In such scenarios, information provenance could be from different sources, like government agencies, citizen, media, nongovernmental organisation, or voluntary associations, working in different emergency sectors, providing different kind of situational reports via their smartphones, tablets or even sensor networks. All these teams are supposed to cooperate, coordinate and communicate together, to achieve the common goal, which is saving human lives and minimising economic losses.

The proposed framework in this paper offers a new solution to these heterogeneous data sources to be integrated as web services for devices (DPWS) (Chan et al., 2005), forming a ubiquitous environment. DPWS specification is used to enable machine to machine communications. It defines secure web service messaging, discovery, description, control, and eventing between environment's devices. Devices are playing a role as either Event Sink devices or Event Source devices, and a given device may play both roles. An Event Sink can thus subscribe to available Event Sources in order to be notified in real time about available situational information. As in web services architecture, messaging is based on SOAP and exchanged data is described using XML schema. For this purpose, and to manage information heterogeneity and integration problem, our framework relies on semantic web techniques and ontologies to model data in RDF triples serialised in XML.

The rapid integration of Information and Communications Technologies in disaster management processes has changed the characteristics of the collected situational information with making their volume huge, their access pervasive and their dissemination behaviour dynamic. Hence, the need of effective information management and delivery is incontestable, especially for SA, where decision makers are under time pressure to take critical decisions. This involves to select among a large amount of information useful ones from their producers and to deliver them directly to the right consumers to avoid information overload: information filtering. According to (Hristidis et al., 2010), information filtering systems filter data based on

- the similarity between a decision maker profile and the content of situational event
- the decision maker relevance feedback.

The profile is usually expressed as a set of context information that describes the decision maker and its environment. Context-aware systems are thus able to take into account this contextual profile and adapt their behaviour accordingly.

In our proposed framework, we have used these information filtering techniques and context-aware technologies to return only relevant information to decision makers contextual profile. Relevance is in terms of location, team/organisation affiliation and professional activity sector. Indeed, considering that decision maker is more interested by events describing the current situation of his surrounding, location-awareness has been selected. Affiliation relevance has been used to support teamwork and community management between members belonging to the same team/organisation/hierarchy. Professional activity sector relevance is about delivering data relevant to the emergency management sector, called Cluster, of the decision maker, such as health, logistics, search and rescue, etc.

To manage time constraints of decision makers, information extraction and natural language processing (NLP) techniques are also used to extract events from shared situational reports. Extracted events are modelled in 5Ws model (i.e., What, What-about, Where, Who and When). In short, relying on this framework, the system exploits all data sources to retrieve the right actionable information, at the right time, to the right person.

This paper is divided as follows. Section 2 reviews related work. We outline in Section 3 key challenges identified from the literature in SA for disaster response. Proposed framework, its architecture and its layers are discussed in Section 4, before we detail our implementation and evaluation results in Sections 5–7.

2 Related work

There has been a lot of work on supporting disaster managers with new pervasive information management and analysis solutions. Attracting various research communities, disaster management projects and initiatives come up with many research directions, including those focusing on a specific disaster class: natural (e.g., earthquakes, floods, wild fires, etc.) or man-made (e.g., political upheaval, hazardous materials, etc.); those focusing on a specific phase of emergency management life cycle, like in Luqman and Griss (2010), which relies on open multi-agent system and context information to facilitate collaboration in response phase; or those focusing on a specific category of responders, like firefighters (Monares et al., 2011).

Another researches proposed crowdsource platforms to integrate information provided by citizens (Okolloh, 2009), and others proposed frameworks to extract useful situational information from social media channels like Twitter (Vieweg et al., 2010; Abel et al., 2012). Different projects support decision makers with solutions about map visualisation (Nobrega et al., 2008) and multi-touch user interfaces (Zibuschka et al., 2011) to handle teamwork coordination.

The European project WORKPAD (Mecella et al., 2006) provides two-level framework that intends to improve the collaboration during the response and short recovery phases. A back end peer-to-peer community (servers, databases, web based, etc.) providing services, and a front-end peer-to-peer communities constituted by in-the-spot responders handling mobile devices, providing data. In this project, only the official responding teams can capture and share situational data about the disaster. Truong et al. (2007) present, in case of WORKPAD project, a peer-to-peer framework named ESCAPE that exploits context information to provide adequate services to front-end peers in emergency situations. Context information is described in XML.

The CIMS framework (Iannella and Henricksen, 2007) describes a generic framework that provides a complete ICT processes for information sharing in emergency management. However, it does not take into account the ubiquitous aspect of such scenarios. Finally, the RESCUE project, discussed by Mehrotra et al. (2003), develops information technology solutions that dynamically store generated situational data and disseminate them to decision makers in appropriate forms. It uses an event-based approach, organised along four inter-related activities: information collection to gather information, information analysis to extract situational information, information sharing to share information between decision makers, and information dissemination to deliver information over the network (Mehrotra et al., 2003).

Generally speaking, these presented frameworks do not offer an accurate solution for information filtering, in order to deliver personalised situational information to decision makers, relevant to their current information needs. In fact, due to time constraints, and enormity of data, decision makers do not have the possibility to read and process all generated data, dispersed across diverse data sources. Add to this, due to dynamicity of data acquisition in SA, situational reports have a streaming nature (Ashish et al., 2008). Hence, it requires development of effective strategies for information filtering and real time delivery. Some of architectures, like (Iannella and Henricksen, 2007), are not either suitable for resource constrained handheld devices, and others do not keep the system flexible to integrate additional devices, which is frequent in disaster response scenarios. Our proposed framework aims to contribute filling these gaps.

3 Challenges and vision

Hristidis et al. (2010) surveyed data management and analysis in disaster management in order to explain how last information technologies fit into data flow process. They identified the following ones: data integration, ingestion and fusion at data management side, and information extraction, information retrieval, information filtering, data mining, and decision support at information analysis side. During the research on each technology, we have identified several problems from literature that meet any decision maker during SA scenarios. Our framework focuses on these ones:

- *RQ1: How to integrate dynamically heterogeneous devices and data sources?* Nowadays, disaster management systems are integrating multiple types of data providers that collect different forms of information. Individuals and teams belonging to different organisations from different emergency sectors, are equipped with mobile devices, laptops, smartphones, tablets, deployed distributed sensors, but also UAVs, like in DeBusk (2010). They share useful situational information, to assist recovery actions to be taken by decision makers. They act dynamically in the network, by joining it or leaving it at any moment.
- *RQ2: How to picture an effective overview of the disaster status from the huge volume of data?* The fast penetration of handheld devices, like mentioned above, has made the volume of shared data huge, thus hard to process by an interested decision maker, which could also be equipped by these resource-constraints devices. Indeed, collected disaster data may be situational reports, damage assessment reports, warning about an incident, a call for a help, casualties reports, a donation, or information about logistics and traffic reporting. Forwarding all these produced information will eventually cause information overload that could delay the decision making process (Bharosa et al., 2010).
- *RQ3: How to use context information to support pervasive SA paradigm in disaster management?* Context-aware system refers to the capability of its components to sense their physical environment by collecting context information, and adapt their behaviour accordingly. Context information may be location, time, user's profile, device or a combination of these types. Many context-aware middlewares and frameworks were proposed in literature, surveyed by Baldauf et al. (2007). Most of them are not suitable for SA scenarios.
- *RQ4: How to deliver in real time a comprehensive overview of the situation to the decision makers?* In rapidly changing environments, like in disaster events, situational information are constantly produced to supply the best up-to-date information to decision makers (Turoff and Chumer, 2004). These dynamic environments make it also hard to any individual in predicting what is going to happen, when and where. Thus, aiming to support involved decision maker to take immediately the right decisions related to his response effort, right information have to be provided at the right time (Bharosa et al., 2010).

Based on these research questions, five technological characteristics have been extracted and used to compare the proposed framework solutions to five other approaches described in the previous section. Table 1 outlines this comparison analysis.

4 Proposed framework

As firstly introduced by Weiser (1991), pervasive computing technologies provide 'anytime, anywhere' computing by decoupling users from devices and viewing applications as entities that perform tasks on behalf of users (Gu et al., 2005). To allow user to concentrate on his tasks, applications and services have to be aware of his context and automatically adapt to his changing contexts-known as context-awareness (Gu et al., 2005). Many definitions of context were given

Table 1 Situation-awareness for disaster management solutions comparison

Solution	*Device heterogeneity*	*Intelligent data source*	*Semantic web*	*Event extraction*	*Real time delivery*
Monares et al. (2011)	No	No	No	Yes	Yes
WORKPAD (Mecella et al., 2006)	Yes	No	No	Yes	Yes
Truong et al. (2007)	Yes	Yes	No	No	No
CIMS (Iannella and Henricksen, 2007)	No	No	No	No	Yes
Mehrotra et al. (2003)	No	No	Yes	Yes	Yes
Proposed	Yes	Yes	Yes	Yes	Yes

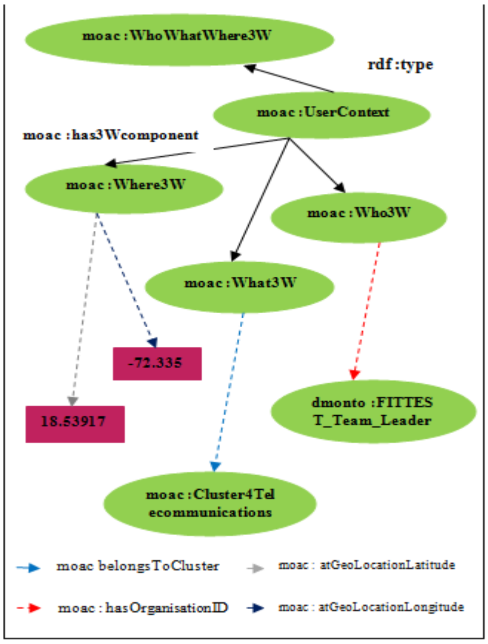
in literature. The most popular one refers to context as any information that can be used to characterise the situation of any entity, whether it is a person, a place or an object (Abowd et al., 1999).

Pervasive computing and context-awareness are the heart of this proposal. Indeed, our vision is to make SA system completely ubiquitous, where entities are connected together through pervasive network as distributed web services, based on service oriented architecture, to support context-aware filtering of situational information returned to decision makers. DPWS is considered as the most promising solution in this new device communication space (Jammes et al., 2005). It uses open web services standards to handle interoperability and hide communications complexity between heterogeneous devices. It offers platform-independent protocols enabling available web services to be dynamically discovered and information to be easily exchanged.

As in DPWS device categorisation, we define two types of entities in our architecture: those who collect and deliver situational data, named *Event Producers*, and those who receive situational data relevant to their contexts, named *Event Consumers*. Each Event Consumer has a contextual profile, constructed from three context dimensions: location, team/organisation affiliation and professional activity sector of the decision maker. The contextual profile is a set of RDF triples (subject-predicate-object). These triples are grouped as RDF graph and described using ontologies, as shown in Figure 1. Event Consumer subscribes to available Event Producers and shares with them his contextual profile, in order to receive context-relevant situational data proposed by these Event Producers. Therefore, once new situational data are collected, Event Producer extracts events from raw streams in 5Ws format. Then, each extracted event will be modelled in RDF through ontologies as RDF graph of five triples. This event will be compared to contextual profile of every Event Consumer subscriber, and delivered to ones which is relevant. All these extracted events will also be stored in triplestores. Interaction between these different entities is handled by DPWS WS-Eventing and messaging protocols. After the subscription process, entities can exchange data through event notifications. First, Event Producer sends a solicit-response notification to every Event Consumer subscriber. The solicit notification is expressed in a SPARQL query to ask for the contextual profile of the subscriber and the response notification is the SPARQL answer to this query. Then, each Event Consumer will be notified through one-way messages whenever a context-relevant event is extracted.

The proposed SA for disaster management framework is illustrated in Figure 2. It consists of six layers: extraction layer, modelling layer, filtering layer, query and delivery layer, semantic layer, and context management layer.

Figure 1 Example of contextual profile's RDF graph: a telecommunication manager belonging to World Food Program (see online version for colours)

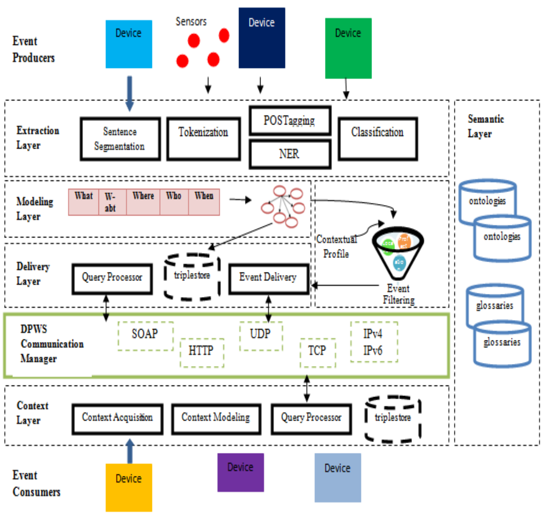


4.1 *Context management layer*

Context management layer, at Event Consumer side, handles context data acquisition that constitute the contextual profile, their representation in RDF triples and their transmission to available Event Producers.

Context-aware systems can be developed in different ways and a used approach depends on special requirements and conditions. Two relevant issues for the implementation of these systems are how to acquire context data and how to model them (Baldauf et al., 2007; de Freitas Bulcão Neto, R. and da Graça Campos Pimentel, 2005). Indeed, context acquisition concerns the way context data are gathered from the environment by using for example local sensors, middleware infrastructures, context servers, etc. Then, context models are used to represent, store and exchange these captured context data (Baldauf et al., 2007). According to the various researches that have been done in the past few years, ontology-based approaches remain the most expressive, formal and standard approach in modelling and reasoning about context data. Indeed, ontologies, which represent semantics, concepts and relations in the context data, provide a semantically rich formalism for their representation and their management. Otherwise, the proposed ontology-based context models in the literature are not enough for SA in disaster management because they are not designed to cover disaster scenarios and their specific situational information about response activities, decisions, teams, organisations, roles, etc (Truong et al., 2007).

Figure 2 The proposed framework architecture (see online version for colours)



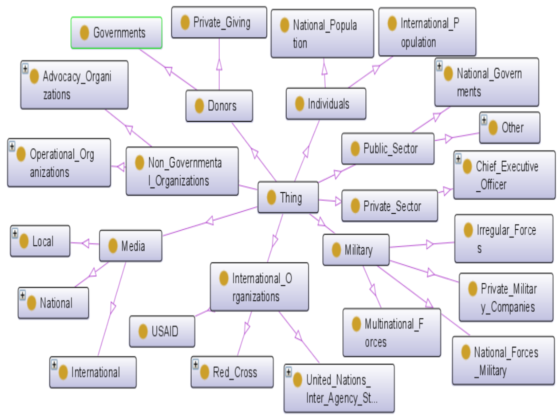
de Freitas Bulcão Neto, R. and da Graça Campos Pimentel (2005) propose a domain-independent ontology-based context model that provides a set of general classes, properties, and relations so lower ontologies can import them for particular domains. It uses the five semantic dimensions where, when, what, how and who, which represent respectively the basic concepts of location, time, activities, devices and actors with their roles, expertises, contacts, etc. Based on this W4H context model, a service infrastructure for context management Semantic Context Kernel is also proposed to handle storage, query and inference over semantic context.

We rely on the W4H semantic model to manage and design our ontology-based context model for SA in disaster response. The contextual profile used to support a context-aware event filtering is derived from this model by exploiting three of its context dimensions: what, where and who. Concepts and relations of existing and developed ontologies are used to semantically describe, infer and query these context data. Further, the RDF-based context data representation allows querying through the SPARQL declarative language. Therefore, triplestores are exploited to manage the storage of these context data.

Based on these relevant issues on context modelling and its management, we have designed the context dimensions that build the contextual profile as follows:

- *Who dimension:* Team/organisation affiliation and professional activity sector are indicated first by the decision maker (user inputs), then expressed and enriched semantically in RDF triples through ontological concepts. As situation awareness scenarios involve local, national and international response teams, affiliated with various agencies, government, organisations, and NGO's, our framework aims to support community management that allows stakeholders of the same team or organisation to stay in touch. For instance, a decision maker will be notified with situation events reported by his team members, his team leader, his company, his organisation affiliated with, his organisation's inferior or superior entity, etc. The framework utilises the Decision Makers ontology and semantic similarity measures to perform this task. The Decision Makers ontology, expressed in OWL, is developed under Protégé and is based on the Decision Makers taxonomy (Goentzel et al., 2012). This ontology structures all possible decision makers categories (as ontological classes) and classifies all response organisations, their team leaders and their team members (as ontological individuals) that could be involved in the crisis event into their appropriate category, as shown in Figure 3. One of this individual semantic data will constitute the affiliation context.

Figure 3 Part of the decision makers ontology (see online version for colours)



- *What dimension:* Decision maker response roles and responsibilities are tightly linked to his professional activity. Hence, our proposed framework aims to deliver situational data specifically relevant to decision maker activities, in order to be able to turn effectively information into rescue actions. The framework relies on the cluster approach (Steets et al., 2010) that groups similar professional activities involved in SA for disaster management scenarios into 12 professional sectors, named clusters: Health, Logistics/ Transportation, Search and Rescue, Food/Agriculture, Nutrition, Coordination, Protection/Security, Telecommunications/ICT, Water/Sanitation/Hygiene, Shelter/Non-food items, Education, and Funding/Donation. The cluster approach aims to coordinate partnerships and to clarify the division of labour among decision makers and better defining their roles within the key sectors of the response (Steets et al., 2010). Management of a crisis (MOAC) ontology (Limbu, 2012) is used to represent this cluster context of the decision maker through ontological concepts.

- *Where dimension:* A multitude of different location sensors are available so that the position data of a given decision maker could be collected easily and in real time. In such outdoor scenarios, global positioning system (GPS) is largely used to capture physical coordinates of decision makers location. Therefore, location context is represented by its geographic coordinates (latitude, longitude) described through the MOAC ontology.

4.2 Extraction layer

As indicated, collected disaster data may be situational reports, damage assessment reports, warning about an incident, a call for a help, casualties reports, a donation, or information about logistics and traffic reporting. Extraction layer looks for finding structured situational events from these instructed or semi-structured textual data streams. The reason of using an event approach is that events could provide an accurate presentation and perception of any situation. A situation is thus described by a set of events that cover questions like: What happened? Where did it take place? When? Who is involved? Etc.

Our event is modelled as in 5Ws principle: event type (What), cluster (Wha- about), location (Where), time (When), organisation (Who). Event extraction is divided into multiple processing: sentence segmentation, tokenisation, part-of-speech (POS) tagging, named entity recognition (NER), and classification. We use DBpedia Spotlight (Bizer et al., 2009) to recognise location, time, and organisation entities that will constitute respectively the Where, When, and Who fields.

We use glossaries and vocabularies to detect entities relative to clusters and record them in a vector (What-about vector). To deduce the appropriate cluster(s) of the event from these detected entities, vector space model techniques are used. Indeed, each cluster's glossary and What-about vector are represented with 0–1 weighted vectors. Then, cosine similarity measure is calculated between the weighted What-about vector and every weighted cluster vector. We adopt threshold approach to deduce the appropriate cluster(s).

The same vector space model process is used to deduce the event type (What). It utilises Stanford POSTagger to detect verbs in the event, and vector of VerbNet classes (Schuler, 2005) for each type instead of glossaries. According to Quarantelli and Dynes (1977); Vieweg (2012), an event in SA scenarios is categorised as follow: warning message, organisational mobilisation message, inventory of damage message, preventative action message, and significant damage message.

4.3 Modelling Layer

This layer takes as input the extracted 5Ws events streams. Events are then enriched semantically through ontological concepts and modelled in RDF triples. We use MOAC ontology for event type and cluster, Geonames ontology (Vatant and Wick, 2012) for location, and our Decision Makers ontology for organisation. The constructed RDF graph (i.e., event) is forwarded to Filtering Layer to support real time delivery, and recorded in a triplestore for subsequent queries. The motivation of using triplestores is to manage data integration in our pervasive environment through distributed databases principles (Franklin et al., 2005; Gripay et al., 2009). Thus, data sources are abstracted as a triplestore databases, and queries are formulated using SPARQL.

4.4 Filtering layer

The main role of the Filtering layer is to compare contextual profile of each subscribed Event Consumer with extracted events stream, based on three filters (i.e., What-about to cluster context, Where to location context, and Who to affiliation context), in order to support context-aware event delivery. It has the aim of selecting from the stream the possible matching events that answer decision makers information needs.

To fulfil information filtering schema in this proposed framework, the contextual profile will represent the query and the produced events will be considered as the information stream. Indeed, the filtering needs are captured in a query derived from the current contextual profile and the filtering task is to deliver proactively the events that best match the current query (Brown and Jones, 2001). Whenever a new event is produced and shared, it is compared to each contextual profile and a matching score is computed between both of them. Then, the event is delivered to those decision makers whose contextual profile is matched.

Usually, each event is accompanied with a score that gives a weighting of how well it matches: a relevance score (Brown and Jones, 2001). Then, any event that passes a relevance threshold is automatically returned to the decision maker. The literature distinguishes two major matching approaches. In Boolean matching, the computed relevance score could take only two values: 1 if the profile matches the event and 0 if not. In the best-match matching, the computed relevance score gives the probability of how well the profile matches the event. A threshold is fixed to set the minimum relevance score that considers the matched event as relevant.

In our case, to deduce the relevance of a given event, three sub-relevancies scores are calculated first as follows:

- *Cluster relevance:* Boolean matching approach is applied in this case. If the cluster concept of the decision makers context belongs to the What-about conceptual vector of the event, then this event is considered as cluster-relevant and 1 is assigned as a value to the cluster relevance score. For example, if a produced event describes the telecommunication state of the current situation (i.e., What-about = (Cluster4Telecommunications)), then this event has to be delivered to all decision makers that joined the network and work in the telecommunication field (i.e., cluster context = Cluster4Telecommuncations) by matching as mentioned above the What-about vector and the cluster context of the decision maker profile.

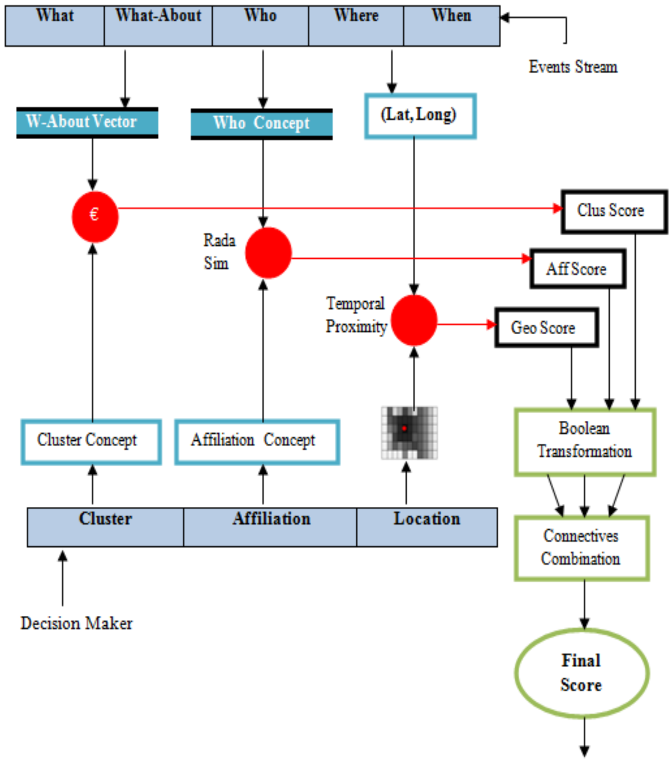
- *Affiliation relevance:* First, we exploit Rada semantic similarity measure (Rada et al., 1989) to compute the affiliation relevance score of a given event. Indeed, as the affiliation context of a decision maker and the Who field of an event are both concepts of the Decision Makers Ontology, semantic similarity is used to match between the two of them. Semantic similarity among concepts is a measure that defines, based on their properties and their relationships, the degree of their likeness. Rada measure relies on the shortest path length to compute the similarity between the target concepts. This semantic distance is computed by counting the minimum number of edges that separate the matched concepts. This path-length-based semantic similarity measure suits the "is-a" Decision Makers ontology used in this proposed framework. Then, as the semantic similarity values range from 0 to 1, it leads us to apply best-match approach to deduce the affiliation relevance of the event. Indeed, the event is considered as affiliation-relevant for the matching decision maker if its affiliation relevance score is superior to a pre-fixed threshold.
- *Geographic relevance*: Various assumptions were proposed in the literature about how information is relevant to geographic context of the user. In our case, due to time constraints that characterise SA scenarios, we retained the temporal proximity filter, where locations that can be reached in a shorter period of time are considered as more relevant. These relevant locations form the accessibility surface that could be defined by a raster grid around the users location, where each cell of the grid represents the time taken to travel from the origin (i.e., location context) to the destination (i.e., event location) (Mountain and Macfarlane, 2007). Values of these cells, which represent the geographic relevance scores, vary from 0 (i.e., too far to be relevant) to 1 (i.e., same location, thus relevant) depending on the travel time. Therefore, best-match approach is applied and a threshold is set to define the minimum geographic relevance score necessary to consider the compared event as relevant. In summary, a given event is filtered as geographically relevant if the travel time between the context location and the event location does not exceed the threshold time.

Then, the final relevance score will be deduced relying on Boolean algebra operations. First, the three sub-relevancies scores are transformed in Boolean values: 1 if it's sub-relevant and 0 if not. Then, these values are combined together through Boolean connectives. If the final result is equal to 1, then the event is considered as relevant, and so, delivered to decision maker. Figure 4 summarises these filtering steps.

4.5 *Query and delivery layer*

This layer handles the different interactions between participating entities. The SPARQL query processor formulates and parses SPARQL queries and answers to ask for context profile and to respond with relevant situational events. Actionable events are thus delivered to the right decision maker in real time or retrieved from triplestores. Received events are map-based visualised, represented in 5Ws format through geotagged tooltips.

Figure 4 Event filtering process illustration (see online version for colours)



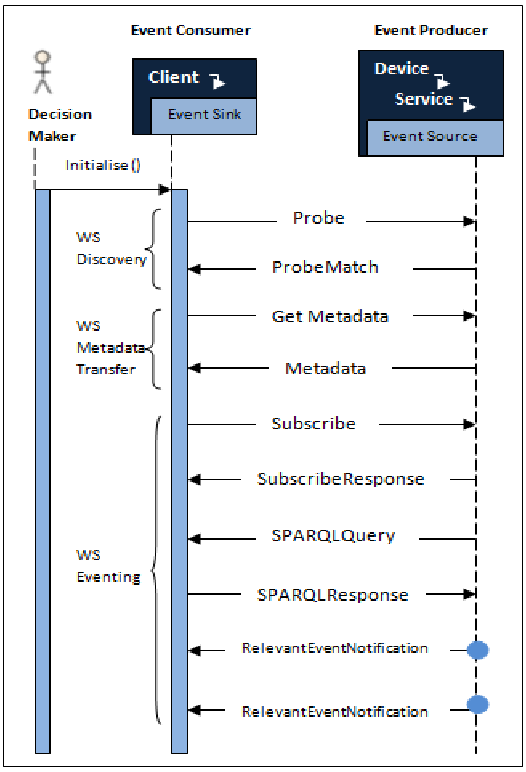
5 Implementation

This proposed context-aware framework has been implemented using the open source WS4D Java Multi DPWS Stack (JMEDS, 2008) lightweight framework. JMEDS allows implementing and running web services based on the DPWS specification in Java based environments. It also offers testing and simulation tools like DPWS Explorer and Droid Commander that allows discovering and accessing DPWS devices and services deployed on the network. Therefore, each Event Consumer is implemented as a JMEDS Event Sink (i.e., Client) and each Event Producer is implemented as a JMEDS Event Source (i.e., Device/Service).

The JMEDS Search Manager handles WS-Discovery operations to allow clients subscribing to devices and services via probe messages and message listeners. Figure 5 shows an example of the process of discovering devices and exchanging messages between an Event Consumer client and an Event Producer device. The JMEDS Communication Manager is used to transport one-way and solicit-response SOAP messages. For instance, in our framework, the message exchanged between two entities may be a SPARQL query, a SPARQL answer, or a relevant situational event. The framework utilises the core Jena RDF API (Seaborne et al.,

2010) to create and write RDF graphs serialised in XML, and uses the Jena ARQ as SPARQL query engine.

Figure 5 Event producers discovery and event delivery sequence diagram (see online version for colours)



6 Evaluation

The evaluation of the proposed framework consists of two levels: architecture evaluation and algorithm evaluation. Indeed, in order to illustrate the feasibility and the functionality of the framework and its different layers, a SA scenario was implemented and experimented. Then, sets of tests were carried out to verify the efficiency and the accuracy of the context-aware information filtering algorithms using standard evaluation metrics. For these tests, 2010 Haiti earthquake datasets were used. The earthquake, the strongest one to hit the region in more than 200 years, caused severe damages and involved national and international response organisations to help the entire affected population.

We collected randomly 37 situational reports from several involved emergency teams over a period of 2 weeks, from 12 January, 2010 to 25 January, 2010 representing the day of the earthquake until the day of the first official balance sheet communicated by the Haitian government. The information sources used in our experiments include

- situational reports from the Office for the Coordination of Humanitarian Affairs (OCHA) reporting the current status of the affected areas, ongoing response operations, recovery activities to be done and coordinating deployed emergency teams, clusters and organisations
- situational reports from the Caribbean Disaster Emergency Management and Haitian Civil Protection informing about search and rescue activities, identification of bodies, aerial assessments and logistics
- situational reports from the International Federation of Red Cross and Red Crescent Societies (IFRC) indicating the humanitarian needs, food and water distribution, and temporary camps locations;
- reports from Digicel about networks and telecommunications status
- tweets and media papers from The New York Times and the Washington Post reporting open/closure status of roads, bridges or hospitals, incidents, missing persons and calls for a medical aid.

These reports were pre-processed and cleaned to select, as a final dataset, 227 situational events that provide actionable information useful in our SA scenarios. Then, these selected events were tagged with information about their appropriate context to fulfil the 5W format, as illustrated in Table 2. All these situational data were collected from organisation websites and online humanitarian relief databases, like the ReliefWeb, which was established in 1996 by the United Nations.

6.1 Architecture evaluation

Aiming to illustrate the operation of the framework described in this paper, we simulated a SA environment as shown in Figure 6, containing DPWS-enabled devices: laptops with Intel processor 2.3GHz, 4-GB RAM and Android 4.4 devices with Qualcomm Snapdragon processor, 2-GB RAM. The environment consists of three Event Producers: a team leader from the Logistics Cluster, a team member from Digicel and a news reporter; and two Event Consumers: a team member telecommunication manager from FITTEST and a team member logistician from the Logistics Cluster. For example, the RDF model in Notation3 format of the logistician context is:

```
@prefix dc: <http://purl.org/dc/elements/1.1/>.
@prefix moac: <http://observedchange.com/moac/ns/#>.
@prefix dmonto: <http://www.owl-ontologies.com/dmonto/#>.

 moac:UserContext a moac:WhoWhatWhere3W ;
 moac:has3Wcomponent moac:What3W,
                moac:Where3W,
                moac:Who3W.

 moac:What3W moac:belongsToCluster
            moac:Cluster7LogisticsAndTansportation ;
 dc:title "Cluster Context".

 moac:Where3W moac:atGeoLocationLatitude "18.578371";
            moac:atGeoLocationLongitude "-72.280118";
 dc:title "Location Context".

 moac:Who3W moac:hasOrganisationID
              dmonto:LogisticsCluster_Team_Member;
 dc:title "Affiliation Context".
```

First, the logistician launches his SA application and starts discovering and subscribing to available data sources on the network after the construction of his contextual profile. Then, when a situational report is shared through a given data

Table 2 Selected situational events samples

Events	*What*	*What-about*	*Where*	*Who*	*When*
We continue to provide ICT services to the humanitarian community in the logbase. It is currently upgrading internet connectivity to accommodate the additional personnel who are arriving	Organisational mobilisation	Telecommunication	Bois Patate, Port-au-Prince, Haiti (18.532637, –72.323464)	Team leader, Digicel	14 January, 2010 at 10:52 am
The favourable climate and building structures have enhanced the survival chance of trapped victims, which indicates that the can continue longer	Organisational mobilisation	Search and rescue	UN Headquarters Christopher Hotel, Bourdon, Port-au-Prince, Haiti (18.539324, –72.311963)	Team leader USAR Team DPC (Haitian Civil Protection)	13 January, 2010 at 07:02 am
The following priorities are identified: treatment of people with large traumatic wounds; prevention of infection of wounds; and ensuring that nursing infants is not discontinued	Organisational mobilisation	Health	Place Boyer, Peguy Ville, Port-au-Prince, Haiti (18.512682, –72.282161)	Team Leader Place Boyer Camp Team, MSF Medecins Sans Frontieres	13 January, 2010 at 04:40 pm

source (the Logistics Clusters team leader data source in this scenario), this source will ask for the contextual profile of its subscriber in order to adapt its event delivery behaviour. For instance, the RDF model in Notation3 format of a produced situational event is:

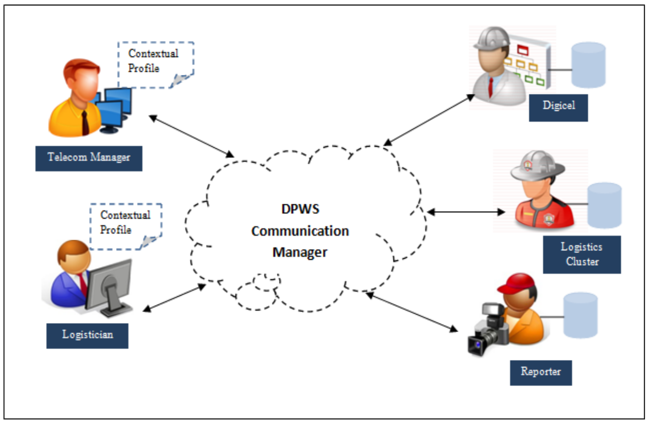
```
@prefix dc: <http://purl.org/dc/elements/1.1/>.
@prefix moac: <http://observedchange.com/moac/ns/#>.
@prefix dmonto: <http://www.owl-ontologies.com/dmonto/#>.

 moac:Event a moac:Incident ;

 dc:title "The  availability of refuelling, cargo and
 aircraft handling equipment is not yet known.
 It is understood that the Port-au-Prince international
 airport will be open for humanitarian air flights only"

 moac:affiliation dmonto:LogisticsCluster_Team_Leader ;

 moac:category "Reporting Message" ;

 moac:date "11h43, January 13, 2010" ;

 moac:description moac:Cluster7LogisticsAndTansportation ;

 moac:latitude "18.560639" ;
 moac:longitude "-72.346777" .
```

And the SPARQL query sent to this Event Consumer is:

```
PREFIX  moac:  <http://observedchange.com/moac/ns/#>.
SELECT ?geolat ?geolong ?aff ?clus
 WHERE {
  moac:Where3W moac:atGeoLocationLatitude ?geolat.
  moac:Where3W moac:atGeoLocationLongitude ?geolong.
  moac:Who3W moac:hasOrganisationID ?aff.
  moac:What3W moac:belongsToCluster ?clus.
 }
```

Situational event is thus extracted from the shared report, modelled, and compared to the received contextual profile by calculating location, cluster and affiliation relevance scores. Based on these scores, the data source can deduce the relevance of the situational event.

Figure 6 Illustration of the implemented SA scenario (see online version for colours)



Later, the telecommunication manager joins the network by subscribing to these Event Producers. His contextual profile is also sent to every data source, in order to be notified with relevant situational events. The framework remains thus flexible to integrate new devices and data sources without any interruption of the processes.

6.2 *Algorithm evaluation*

To evaluate the relevance of the returned situational events in response to decision makers context, we followed the evaluation method proposed in Rhodes (2003) to test the effectiveness of proposed context-aware information filtering algorithms and see which context dimension improves relevance of the returned situational events.

For this purpose, we conducted five sets of experiments. In each experiment, three distinct Event Consumers and multiple Event Producers were randomly generated, producing and consuming a dataset of 227 tagged situational events. In each experiment, five different sets of relevant events are returned to Event Consumers based the desired context dimension: Cluster, Location, Affiliation, All-features and Control group. For example, situational events in the Cluster set are returned only by looking at similarity in the cluster context of the pair Event/Contextual-Profile; the other two dimensions are thus ignored. This means that only the cluster relevance score is retained to deduce the relevance of a situational event. In the All-features set, all context dimensions are used to deduce whether the situational event is relevant. First, cluster, location and affiliation relevance scores are calculated. Then, the final relevance score is deduced by combining these three relevance scores with Boolean connectives: Location AND Affiliation AND Cluster. The control group set follows the same process but consists of random context pairing: Location AND Affiliation, Affiliation AND Cluster, etc.

The effectiveness of the obtained results was evaluated based on how useful is a returned situational event to the Event Consumers current needs. Every returned situational event was rated, regarding to the decision maker needs, as follows: definitely useful, probably useful or useless. Therefore, each event is verified and its usefulness is deduced depending on the mean of its sub-relevance scores: definitely useful if it is >=0.75, probably useful if it is between 0.5 and 0.75 and useless if it is <0.5.

7 Results and discussion

Table 3 lists scores tallied for each of the five sets with the following threshold values: 1 for cluster relevance, 0.5 for location relevance and 0.33 for affiliation relevance; and the percentage of returned situational events that were rated either ‘definitely useful’ and ‘definitely useful or probably useful’. At first sight, it appears in both percentages that the difference between the Location set and the other four sets is very significant. Furthermore, the outcomes show that affiliation is the context dimension that scores the best results and returns the most useful situational events to decision makers without information overload of useless situational events.

Several conclusions can be drawn from this experiment. First, it shows that the proposed information filtering method, that relies on three contexts dimensions (All-features set) to construct a complete contextual profile, produces and returns the most useful situational events to decision makers. Indeed, 76.67% of returned situational events are evaluated as definitely useful and 23.33% as probably useful. Add to this, the All-features filtering method does not return useless situational events comparing to the rest of methods resumed in Table 3. These are promising results that attest the effectiveness of the proposed system in returning useful events during actual use.

Second, it is obvious that the location at where the event is happening and its cluster are not as useful as affiliation of its Producer. Indeed, in all five conducted experiments, the percentage of the Location set does not exceed 8% of returned definitely useful situational events, which is a very low rate. One detected cause for the locations poor performance is that Event Producers, which are multiple team members/leaders with different response roles engaged in various response activities, are more likely brought to operate in the same area (the affected zone). Thus, returning all shared situational events by these different Producers based on their location only is clearly not the best filtering feature if we aim to avoid information overload of useless situational events.

Third, affiliation seems to be an acceptable filtering feature returning 52.5% of definitely useful situational events for this experiment. This is likely due to the fact that most useful situational events for a particular decision maker are produced by members and leaders belonging to its same team/organisation.

Figure 7 summarises the definitely useful rates tallied for each of the five experiments of our context-aware filtering evaluation and demonstrates that the All-features strategy clearly outperform the rest of strategies. The affiliation strategy scores the second best results. The difference between these two last strategies is that the All-features one is more efficient and does not overload Event Consumers with useless information.

In order to evaluate the scalability and time performance of the proposed framework, two sets of experiments were carried out. The first set aims to measure the time in milliseconds taken by a Client to discover and to subscribe to increasing number of Event Producers from 5 to 50. The second set aims

Table 3 Scores for each set

Set	*Returned*	*Definitely useful*	*Probably useful*	*Useless*	*Percentage score ‘Definitely useful’*	*Percentage score ‘Definitely useful’ ‘Probably useful’*
Cluster	88	23	15	50	26.13	43.18
Affiliation	40	21	7	12	52.5	70
Location	408	23	11	374	5.63	8.33
All-Features	30	23	7	0	76.67	100
Control	59	23	13	23	38.98	61.02

to calculate the execution time needed for an Event Producer to retrieve contextual profile and to deliver situational event to its subscribers. 20 runs were performed. The results, described in Figures 8 and 9, show the stability of the framework with a complete SA process time, as in Figure 6 scenario, kept under 1.4 s.

Figure 7 Definitely useful rates for each experiment (see online version for colours)

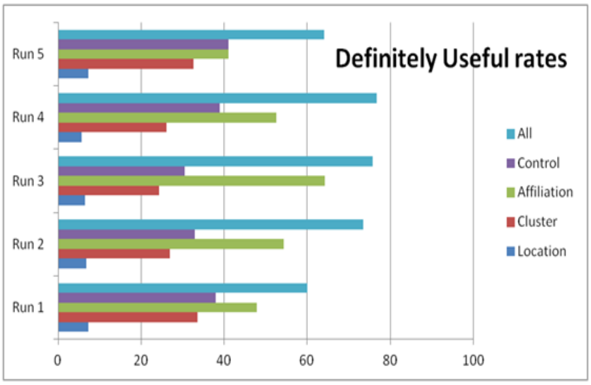


Figure 8 Event producers discovery and subscription time in millisecond (see online version for colours)

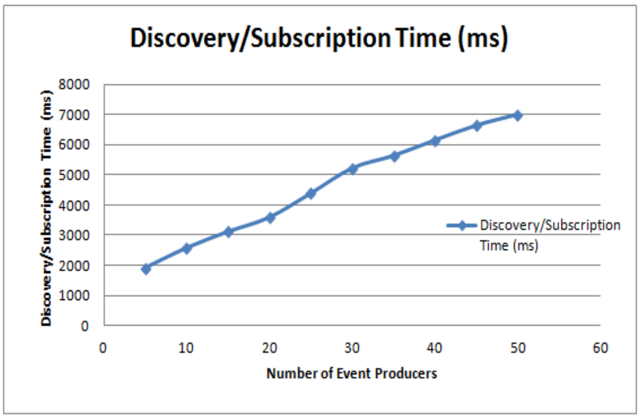
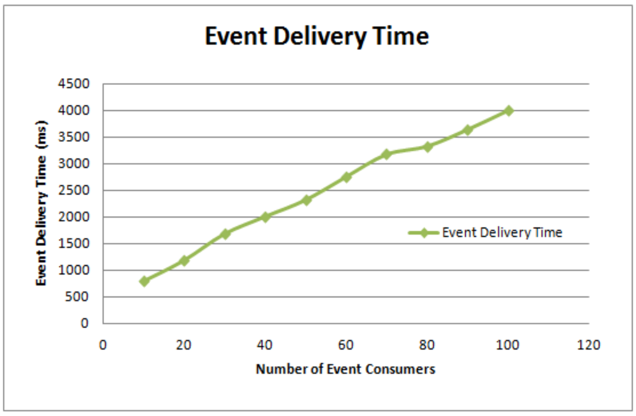


Figure 9 Event delivery. Interaction and notification time in millisecond representing the contextual profile retrieval and the event delivery process (see online version for colours)



8 Conclusion

Every year, the world knows a number of natural and technological disasters, killing a hundreds of people and causing significant economic losses to the region they hit. Rebuilding quickly societies and minimising the impacts after these disruptions are the prior tasks of any decision maker. Information and communication technologies create opportunities for new paradigms in disaster management. In this contribution, we have presented a context-aware framework to support personalised SA in crisis event. Citizens, decision makers, and responders form a pervasive environment, combining mobiles, sensors and ubiquitous devices to send and receive situational information relevant to their current needs. The framework exploits NLP techniques to extract situational events from the produced information stream and deliver in real time only preferred events to a given decision maker's contextual profile. Indeed, a contextual profile is constructed for each decision maker relying on three context dimensions: location, team/organisation affiliation and professional activity sector. Then, it is used by available data sources to filter and deliver their data intelligently. As future work, we aim to study the possibility to add other context dimensions to this profile and evaluate their effectiveness in improving the filtering process. For instance, if the decision maker is already engaged in a given response task, it would be interesting to adapt the event delivery to match specifically with this task. This task dimension is supported by the W4H context model, however, an appropriate response-tasks ontology has to be developed. Also, we aim to provide the Filtering Layer with a decision maker relevance feedback mechanism that keeps forwarding similar events to decision makers. Finally, we aim to extend our framework with an event augmentation module. We identify two types of augmentation. The first will regroup similar events into a complete 'situation', and the second will augment events with external information using Linked Open Data and ontologies.

References

Abel, F., Hauff, C., Houben, G-J., Stronkman, R. and Tao, K. (2012) 'Semantics+ filtering+ search= twitcident. exploring information in social web streams', *Proceedings of the 23rd ACM Conference on Hypertext and Social Media*, ACM, pp.285–294.

Abowd, G.D., Dey, A.K., Brown, P.J., Davies, N., Smith, M. and Steggles, P. (1999) 'Towards a better understanding of context and context-awareness', *Handheld and Ubiquitous Computing*, Springer, pp.304–307.

Ashish, N., Eguchi, R., Hegde, R., Huyck, C., Kalashnikov, D., Mehrotra, S., Smyth, P. and Venkatasubramanian, N. (2008) 'Situational awareness technologies for disaster response', *Terrorism Informatics*, Springer, pp.517–544.

Baldauf, M., Dustdar, S. and Rosenberg, F. (2007) 'A survey on context-aware systems', *International Journal of Ad Hoc and Ubiquitous Computing*, Vol. 2, No. 4, pp.263–277.

Bharosa, N., Lee, J. and Janssen, M. (2010) 'Challenges and obstacles in sharing and coordinating information during multi-agency disaster response: propositions from field exercises', *Information Systems Frontiers*, Vol. 12, No. 1, pp.49–65.

Bizer, C., Lehmann, J., Kobilarov, G., Auer, S., Becker, C., Cyganiak, R. and Hellmann, S. (2009) 'DBpedia-A crystallization point for the web of data', *Web Semantics: Science, Services and Agents on the World Wide Web*, Vol. 7, No. 3, pp.154–165.

Brown, P.J. and Jones, G.J. (2001) 'Context-aware retrieval: Exploring a new environment for information retrieval and information filtering', *Personal and Ubiquitous Computing*, Vol. 5, No. 4, pp.253–263.

Chan, S., Kaler, C., Kuehnel, T., Regnier, A., Roe, B., Sather, D., Schlimmer, J., Sekine, H., Walter, D., Weast, J., Whitehead, D., Wright, D. and Yarmosh, Y. (2005) *Devices Profile for Web Services*, http://specs.xmlsoap.org/ws/2005/05/devprof/devices profile.pdf

de Freitas Bulcão Neto, R. and da Graça Campos Pimentel, M. (2005) 'Toward a domain-independent semantic model for context-aware computing', *Web Congress, 2005. LA-WEB 2005. Third Latin American*, IEEE, p.10.

DeBusk, W.M. (2010) 'Unmanned aerial vehicle systems for disaster relief: Tornado alley', *AIAA Infotech@ Aerospace Conference*, AIAA-2010-3506, Atlanta, GA.

Endsley, M.R. (1995) 'Toward a theory of situation awareness in dynamic systems', *Human Factors: The Journal of the Human Factors and Ergonomics Society*, Vol. 37, No. 1, pp.32–64.

Franklin, M., Halevy, A. and Maier, D. (2005) 'From databases to dataspaces: a new abstraction for information management', *ACM Sigmod Record*, Vol. 34, No. 4, pp.27–33.

Goentzel, J., Van de Walle, B. and Gralla, E. (2012) *Humanitarian decision makers taxonomy*, http://digitalhumanitarians.com/content/decision-makers-needs

Gripay, Y., Laforest, F. and Petit, J-M. (2009) 'Managing Pervasive environments through database principles: a survey', *Advances in Data Management*, Springer, pp.277–298.

Gu, T., Pung, H.K. and Zhang, D.Q. (2005) 'A serviceoriented middleware for building contextaware services', *Journal of Network and computer applications*, Vol. 28, No. 1, pp.1–18.

Henricksen, K., Indulska, J. and Rakotonirainy, A. (2002) 'Modeling context information in pervasive computing systems', *Pervasive Computing*, Springer, pp.167–180.

Hristidis, V., Chen, S-C., Li, T., Luis, S. and Deng, Y. (2010) 'Survey of data management and analysis in disaster situations', *Journal of Systems and Software*, Vol. 83, No. 10, pp.1701–1714.

Iannella, R. and Henricksen, K. (2007) 'Managing information in the disaster coordination centre: Lessons and opportunities', in Van de Walle, B., Burghardt, P. and Nieuwenhuis, C. (Eds.): *Proceedings of the 4th International ISCRAM Conference*, pp.1–11.

Jammes, F., Mensch, A. and Smit, H. (2005) 'Service-oriented device communications using the devices profile for web services', *Proceedings of the 3rd International Workshop on Middleware for Pervasive and Ad-Hoc Computing*, ACM, pp.1–8.

JMEDS, J. (2008) *Stack: WS4D-JMEDS for Java*, http://ws4d.e-technik.uni-rostock.de/jmeds/

Limbu, M. (2012) *Management of a Crisis MOAC Vocabulary Specification*, http://observedchange.com/moac/ns/

Luqman, F.B. and Griss, M.L. (2010) 'Overseer: a mobile context-aware collaboration and task management system for disaster response', *The Eighth International Conference on Creating, Connecting and Collaborating through Computing*, UC San Diego, La Jolla CA, USA.

Mecella, M., Angelaccio, M., Krek, A., Catarci, T., Buttarazzi, B. and Dustdar, S. (2006) 'Workpad: an adaptive peer-to-peer software infrastructure for supporting collaborative work of human operators in emergency/disaster scenarios', *Collaborative Technologies and Systems, 2006. CTS 2006. International Symposium on, IEEE*, pp.173–180.

Mehrotra, S., Butts, C., Kalashnikov, D., Venkatasubramanian, N., Rao, R.R., Chockalingam, G., Eguchi, R., Adams, B. and Huyck, C. (2003) 'Project RESCUE: challenges in responding to the unexpected', *Electronic Imaging 2004*, International Society for Optics and Photonics, pp.179–192.

Monares, Ã'., Ochoa, S.F., Pino, J.A., Herskovic, V., Rodriguez-Covili, J. and Neyem, A. (2011) 'Mobile computing in urban emergency situations: improving the support to firefighters in the field', *Expert Systems with Applications*, Vol. 38, No. 2, pp.1255–1267.

Mountain, D. and Macfarlane, A. (2007) 'Geographic information retrieval in a mobile environment: evaluating the needs of mobile individuals', *Journal of Information Science*, Vol. 33, No. 5, pp.515–530.

Nobrega, R., Sabino, A., Rodrigues, A. and Correia, N. (2008) 'Flood emergency interaction and visualization system', *Visual Information Systems. Web-Based Visual Information Search and Management*, Springer, pp.68–79.

Okolloh, O. (2009) 'Ushahidi, or'testimony': Web 2.0 tools for crowdsourcing crisis information', *Participatory Learning and Action*, Vol. 59, No. 1, pp.65–70.

Quarantelli, E.L. and Dynes, R.R. (1977) 'Response to social crisis and disaster', *Annual Review of Sociology*, Vol. 3, No. 1, pp.23–49.

Rada, R., Mili, H., Bicknell, E. and Blettner, M. (1989) 'Development and application of a metric on semantic nets', *Systems, Man and Cybernetics, IEEE Transactions*, Vol. 19, No. 1, pp.17–30.

Rhodes, B. (2003) 'Using physical context for just-in-time information retrieval', *Computers, IEEE Transactions*, Vol. 52, No. 8, pp.1011–1014.

Schuler, K.K. (2005) *VerbNet: A Broad-Coverage, Comprehensive Verb Lexicon*, Doctoral Dissertation, University of Pennsylvania, Philadelphia, USA.

Seaborne, A., Dollin, C., Warren, C., Steer, D., Reynolds, D., Dickinson, I., Castagna, P., Vesse, R. and Allen, S. (2010) *Apache Jena – The core RDF API*, https://jena.apache.org/documentation/rdf/

Steets, J., Grünewald, F., Binder, A., De Geoffroy, V., Kauffmann, D., Krüger, S., Meier, C. and Sokpoh, B. (2010) *Cluster Approach Evaluation 2*, Synthesis Report, Global Public Policy Institute, Berlin, Germany, https://www.humanitarianresponse.info/system/files/documents/files/Cluster/20Approach%20Evaluation%202.pdf

Toutanova, K., Klein, D., Manning, C.D. and Singer, Y. (2003) 'Feature-rich part-of-speech tagging with a cyclic dependency network', *Proceedings of the 2003 Conference of the North American Chapter of the Association for Computational Linguistics on Human Language Technology*, Association for Computational Linguistics, pp.173–180.

Truong, H-L., Juszczyk, L., Manzoor, A. and Dustdar, S. (2007) 'ESCAPE-an adaptive framework for managing and providing context information in emergency situations', *Smart Sensing and Context*, Springer, pp.207–222.

Turoff, M. and Chumer, M. (2004) 'The design of a dynamic emergency response management information system (DERMIS)', *Journal of Information Technology Theory and Application*, Vol. 5, No. 4, pp.1–35.

Vatant, B. and Wick, M. (2012) *Geonames ontology*, http://www.geonames.org/ontology/documentation.html

Vieweg, S., Hughes, A.L., Starbird, K. and Palen, L. (2010) 'Microblogging during two natural hazards events: what twitter may contribute to situational awareness', *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM, pp.1079–1088.

Vieweg, S. (2012) *Situational Awareness in Mass Emergency: A Behavioral and Linguistic Analysis of Microblogged Communications*, Doctoral dissertation, University of Colorado at Boulder.

Weiser, M. (1991) 'The computer for the 21st century', *Scientific American*, Vol. 265, No. 3, pp.94–104.

Zibuschka, J., Laufs, U. and Roßnagel, H. (2011) 'Towards ubiquitous emergency management systems', *Proceedings of the 1st International Workshop on Model-based Interactive Ubiquitous Systems*, Pisa, Italy, pp.21–26.