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Towards Event-centric Cyber-Physical-Social System for Disaster Management

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Abstract. Disasters may be due to meteorological events, geo- logical events or man-made. Approximately 700 disasters occur each year with annual world-wide impact of over 100B/year. Cyber-Physical Systems (CPS), which are smart networked systems with embedded sensors, processors and actuators designed to sense and interact with the physical world (including the human users) in real-time, provide safety-critical applications where the proverbial "blue screen of death" can have catastrophic consequences, can dramatically increase the situational awareness of emergency responders and enable an optimized response through all phases of disaster events, i.e., prevention, preparation, response, and recovery. However, significant energy-efficiency-related research challenges arise because of disaster management requirements for the quality of service and information. Energy-efficient communication, computing and control are desirable for CPS for disaster management. In the paper, we propose a Cyber-Physical- Social System (CPSS) framework for disaster management by combing CPS and the society of human beings. We adopt an Event- Linked Network (ELN) model to achieve green communication and computing in CPSS for disaster management and apply the model to disaster management of earthquakes as a case study. We believe the CPSS mechanism with the included disaster resilience will promote the disaster management which includes the disaster resilience.

Keywords: Cyber-Physical Systems, Disaster Management, Cyber-Physical-Social System, Event-Linked Network

Kibernetski sistem za ukrepanje ob naravnih nesrečah

Vsako leto se zgodi več sto naravnih nesreč, katerih škoda presega več 100 milijard evrov. Za učinkovito ukrepanje ob naravnih nesrečah se uporabljajo kibernetsko-fizični sistemi (CPS, Cyber-Physical Systems). Sistemi CPS so pametni omrežni sistemi z vgrajenimi senzorji, procesorji in aktuatorji, ki spremljajo dogajanje v okolju in podpirajo prenos podatkov v resničnem času. Ti sistemi lahko zelo povečajo ozaveščenost enot odziva v sili in omogočajo optimiziran odziv v vseh fazah nesreče, to so preprečevanje, priprava, odzivanje in okrevanje. Poleg zahtev po zanesljivi in varni komunikaciji je pomembna tudi njihova energijska učinkovitost. V prispevku predstavljamo sistem CPSS (Cyber-Physical-Social System) z dogodkovno povezanim omrežnim modelom za ukrepanje ob nesrečah in aplikacijo modela na primeru potresa.

1 Introduction

Various disasters occur in the world frequently. A disaster is defined as an event that requires resources beyond the capability of a community and requires a multiple-agency response [1]. According to the different causes, disasters could be classified into the following categories [2]:

- Disasters due to *meteorological* events, such as avalanches, floods, fires, heat waves, hurricanes, thunderstorms, tornadoes, and winter storms.
- Disasters due to *geological* events, such as earthquakes, landslides, tsunamis, and volcanoes.
- Disasters due to *man-made* events, such as building, bridge, or tunnel collapses, chemical or radiological waste spills, dam failures, nuclear power plant accidents, and train wrecks.

Disasters have caused great loss widely in the world. From 2000 to 2009, over $7,000$ disasters resulted in over 1 million people casualties world-wide, affected another 2.5 million directly, and yielded a loss of just under $\$1$ Trillion. During the past two decades, China has occured many earthquake disasters, which have led to the loss and suffering of people. In the COVID-19 disaster, many human lives have affected and even lost. Besides, the COVID disaster management will considerably affect China hotel industry [3].

After a disaster happens, disaster resilience is necessary and Ref. [4] defines disaster resilience. In the paper,

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we discuss the topic which is a little wider than disaster resilience — *Disaster management*, also called *disaster response* or *emergency response*. Disaster management typically involves four phases: *prevention*, *preparation*, *response* and *recovery* [5]. Disaster resilience mainly focus on the phases after the disaster happens, that is, *response* and *recovery*; However, the *prevention* and *preparation* play an or even more important role than the *response* and *recovery*. The success of response and recovery depends on the data collected during the preparation and prevention phase. Data are traditionally collected by people after the disaster happens. However, sensors and wireless communication technologies have made it possible to collect data automatically without the participation of people in the scences of disasters, especially in dangerous places. Cheap sensors and wireless devices make enable building a monitoring system without too much investments.

Sensors, wireless and mobile communication networks, mobile devices and computers for information storage and computing formulate novel unified systems i.e. Cyber-Physical System (CPS). They are built from, and depend upon a seamless integration of computational algorithms and physical components. In CPS, all the elements are connected and interactive. Disaster management can benefit from the CPS application in the disaster response for avoiding the difficulty to data collection from a dangerous environment. CPS technologies, including the next generation public safety communications, sensor networks, and response robotics, can dramatically increase the situational awareness of emergency responders and enable an optimized response through all phases of disaster events such as earthquakes, hurricanes, tsunamis, tornadoes, fires, and bombing attacks [6]. However, significant energy-efficiency-related research challenges arise because of disaster management requirements for the quality of service and the quality of information. Energy efficient communication, computing and control are desirable for CPS for disaster management. Because the eletrocity supply is usually broken when disasters occur, the energy saving and energy efficiency are an important issue.

For disaster management, there are two important applications. One is to organize the information of a disater, i.e. historical archives, the other is to search historical archives for the prediction and decision-making in disaters. The historical archives can be used as training information resources and as a reference for managing the disasters. When a disaster occurs, a series of events related to the kind of the disater may occur. How to avoid or reduce the loss or suffering is the key issue in disaster management. Therefore, an event-focused information organization and prediction will play an important role in disaster management, compared to the isolated and distributed data about diasters. An event contains a set of objects, and the event occurrence is acommpanied with changed attributes.

Event-focused information organization and event-triggered decision making mechanism are an interesting topic of disaster management. In the paper, we explore the information organization and decision-making optimization from the event perspective. Our contributions are as follows: (1) we propose an Event-linked Network (ELN) model for Cyber-Physical-Social System (CPSS) to combine the CPS systems with the human participants in the disaster resilience. (2) we study the disaster management scenarios based on the ELN model to verify the feasibility and effectiveness of the ELN model. Research results show that decision-making based on the data collected by CPS, the CPS maintenance and the executions of actions including prevention, preparation, response and recovery all need human participants to formulate the social side. To fulfill the disaster managment tasks, the seamless CPSS plays important role.

The rest of the paper is organized as follows. In Section 2, the related work are discussed and mainly focus on the information organization models of disaster management. In Section 3, we present CPS for disaster management and discuss the green communication and computing in CPS for disaster management. By combining CPS and society, we propose a Cyber-physical-Social System (CPSS) framework for disaster management. The ELN model for green communication and computing in CPSS and its application in the disaster management of an earthquake as a case study are presented in Sections 4. Section 5 concludes the paper.

2 Related Work

Information is crucial for disaster management, while information technologies have greatly changed the collection of situational information of disasters [7]. Information technologies are involved in all the process of disaster management including disaster reduction, preparedness, response and recovery. Sensors have been used to monitor the environment of disasters, while the social media applications are also important information providers. Information records and their exchanging help to reduce disaster prior to its occurrence, while information collection, processing and exchange are important for decision-making in disaster relief operations.

Big data analytics and Internet of Things technologies create a huge opportunity for the disaster management information systems to acquire in-time information and make an accurate and timely decision-making [8]. The authors point out that open research challenges include disaster data quality, metadata extraction, multi-sourced data integration, quick big data analytics, time constraint for quick response, architecture, fault tolerance, privacy and security and standardization. A systematic literature review analyzes the role of big data in natural disaster management and highlights the status of the technology in providing meaningful and effective solutions in natural disaster management [9]. The authors point out that big data collection, analytics and cyber-infrastructure are big data challenge for disaster management.

Effective disaster management relies on complex interrelated knowledge intensive and time-sensitive activities, while the information system enhances the use of technologies to support disaster management [10] in terms of readiness assessment, social media content mining and stakeholder analysis.

Some existing frameworks and methods have been reviewed to understand their applications in a disaster context and to highlight key challenges and future directions for developing a robust social resilience assessment framework [11].

Disasters create extreme scales and complexity for communications and computing [5]. The challenges for disaster management are:

1) Dealing with extreme scales in four aspects: *time*, *space*, *stakeholders* and *data*. Events can be discrete and short lived, or long-term. Damage can be highly localized, or spread over areas. Citizens, governments, industry, and non-governmental organizations all have roles to play. The data is heterogeneous, takes many forms and contents, comes from different sources, arrives in different volumes at different times, and exhibits different priorities for different phases of the disaster.
2) Dealing with extreme complexity. Sources of a computational complexity include nonlinear behavior, large interdependency between variables; algorithmic and data complexity; modelling under uncertainty; the need for maintaining privacy and security of the data; the politics, sociology, and native language issues; and resilience of the infrastructure.
3) Decision-making of emergency under extreme conditions. Human capabilities in decision-making are affected by extreme events that challenge comprehension under extreme situations during which decision makers are tired, dirty, and hungry. Decision makers may be working remotely and under dangerous, uncomfortable, demanding conditions that are physiologically and cognitively disrupting.

3 Cyber-Physical-Social System for Disaster Management

Disaster management heavily depends on the data analysis on disasters. Prevention, preparation, response and recovery in the disaster management are all based on the analytics of the real-time data, and data collection of disasters is the basis of data analysis. Data collection and analysis of disasters can be supported by CPSS, which are smart networked systems with embedded sensors, processors and actuators that are designed to sense and interact with the physical world (including the human users), and support real-time, guaranteed performance in safety-critical applications where the proverbial "blue screen of death" can have catastrophic consequences [6], [12]. In the CPS systems, the joint behavior of the "cyber" and "physical" elements of the system is critical — computing, control, sensing and networking are deeply integrated into every component, and the actions of components and systems must be carefully orchestrated. The "convergence of the global industrial system with the power of advanced computing, analytics, low-cost sensing and new levels of connectivity permitted by the Internet" is called the Industrial Internet [6].

It is important to detect the data and information of places in disasters for the disaster resilience after a disaster happens. Sensors can be used to collect the weather, temperature and other environmental information. Therefore, CPS plays a critical role in disaster management: unmanned ground/aerial/marine vehicles perform search and rescues during disasters, especially in hazard conditions that are dangerous to humans; intelligent transportation systems, which connect individual automobiles to the cyber and physical infrastructure, provide transportation means for evacuation and emergency response; the health monitoring and tele-medicine infrastructure provide prompt remote medical treatments to critical patients at disaster locations [2]. However, CPS for disaster management integrates humans in the loop because they are decision makers and practitioners. The combined system of CPS and humans is a Cyber-Physical-Social System (CPSS). In the CPSS, a patient at a disaster location undergoes a telesurgery by a medical CPS. The positions of people, equipment, cars and planes can be reported according to the GPS systems, which can be known by decision makers in time for making the next decisions.

CPS for disaster management operate in challenging environments in which power may be intermittent and communication bandwidth is limited, and must address the above challenges posed by disasters. Communication and computing are essential for data collecting, transmitting and transforming into actionable information tailored for disaster professionals, citizens and their information devices, while hiding complexities of superfluous information. In this way, this provides an accurate situation awareness across all echelons of decision makers.

Green communications and computing are desirable for the energy-efficient transmission and transformation of data. Data centers cost hundreds of millions per year [13]. Increasing the efficiency of these facilities even by a small amount can lead to significant economic and environmental benefits, especiailly in the increasing

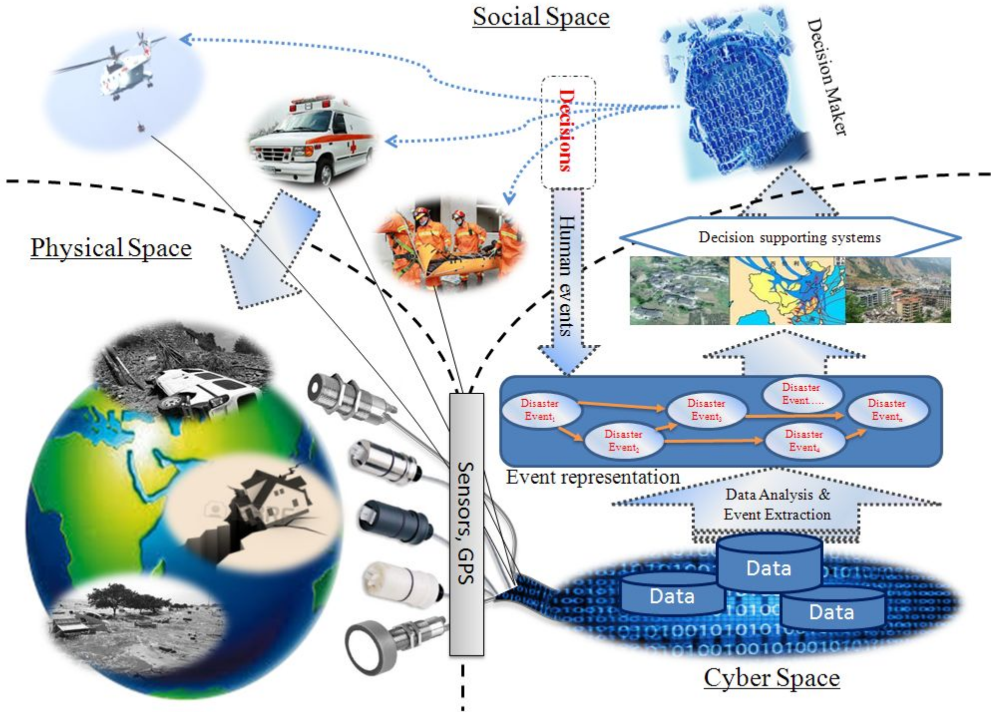

Figure 1. Cyber-physical-social system for disaster management

Internet of Things. Intelligent algorithms to optimize energy consumption like heat monitoring, adaptively spinning down disks, elastic resource allocation etc., are interesting to investigate.

In the CPSS, there is a large number of smart devices which link the physical, cyber, and social space into an integrated system. Figure 1 shows an integrated CPSS system that includes three spaces: physical, cyber, and social.

- In the physical space, especially after a disaster happens, the monitored objects are changing continually and an generating variety of heterogeneous and complex volumes of data, i.e. big data about a disaster [14]. These data can be captured by sensing devices, such as thermal, optical, humidity, and other sensors, and then transmitted to cyber systems. Besides, GPS can help to rescue teams by reporting their positions to the cyber systems.
- In the cyber space, a disaster management information system can feel the environment changes in the physical world through these sensing devices. Big sensing data are generated by continuous monitoring by a large number of the sensors. The data would be processed and analyzed in the cyber space and then users or decision systems can hold the situation of the changes in the physical space. Then, they make a decision about how to respond to the physical world according to the analysis results.
- In the social space, some actions would be executed and replied to the physical space. When there are some new changes then a new circle would be inspired.

4 Event-linked Network Model for Information Organization and Processing in CPSS

There is a very large scale of data sensored, transported and computed during the disaster management. It is impossible for humans to look into the detailed data manually for problem-solving in a limited time because of the emergency. Many data analytic tools and mining techniques have been emerging to provide a useful information from the big sensing data space. However, with the rapid increase of the data, it is becoming more and more difficult to process the big data in a reasonable time using traditional approaches, even in the cloud computing based systems. Therefore, information classification and filtering are necessary. It would be more helpful to organize the big sensing data in an efficient and normal-formed model while the data is continuously generated. One possible way is to classify the data into different event for different decision making in the disaster management. The occurrence of events acts as a trigger of decision making.

In the physical world, in most cases, the the environmental status changes steadily, and most of the data captured by sensing devices seems trivial and ordinary.

However, while events occur, the status changes dramatically and then the sensing data change significantly, too. The event data plays a pivotal role for human decisions. It would be more efficient if the sensing data can be organized based on events.

There are many kinds of events in the CPS [15]. A spatio-temporal event model for cyber-physical systems [16]. A concept of lattice-based event model for Cyber-Physical Systems [17]. We do not consider only the event management, but also the management of data implying the events. A model event-linked network (ELN) has been proposed to manage the data generated in the Internet of Things [18]–[20]. Here, we introduce the related conceptions of an event-linked network and extend the theory to make it more suitable for the disaster management in a green pervasive computing environment.

4.1 Event-Linked Network Model

We use an event-linked network (ELN) model which has the potential to achieve energy-efficiency in CPS for disaster management. As an information organization model, ELN works under the CPSS framework for disaster management. Differently from the current practice of sending all the data at the highest resolution to everyone, the right information gets to the right person at the right time, so it is valuable for disaster management. Historical disasters and management records can be used as a training data to learn the effective methods for prevention, preparation, rescue and recovery. The knowledge is of disasters can be maintained including updating, insertion and deletion according to the historical disaster information.

An Event-Linked Network ELN is represented by a triple of $(E, L, rules)$, where E is a set of events, denoted as $\{e_1, e_2, \cdots, e_n\}$, $e_i(1 \leqslant i \leqslant n)$ is an event; L is a set of events-links between events in *E*; and *rules* is a set of reasoning rules among events-links.

4.1.1 Event: For an event, in the physical world, the primary information include *What*, *When* and *Where*. In the cyber space, the two primary tasks include: (1) find the event and extract the related information from the big sensing data; (2) establish the semantic links among the events. The sensing data and event data include: (1) the time and the location that an event occurred, the list of involved objects, and the data to describe the status changes of the involved objects; (2) the links among different events if possible.

An event is represented by a 4-tuple $e(timeDescription$, $locationDescription$, $objectsList$, $dataList)$, where

- $timeDescription$ records the time when the event occurs, the starting and ending time or duration;
- $locationDescription$ represents where the event occurs;
- $objectsList(oid_1, oid_2, \cdots, oid_n)$ is a list of objects involved in the event;
- $dataList$ is a list of the data describing the event-related status or interrelations of the objects in $objectsList$.

In the physical world, events can be easily classified into different types according to their common properties. In the cyber space, correspondingly, event types should be defined as a model of two components: (1) preconditions of the event which belong to the type; and (2) the description to formulate the data of the event instances of the type.

Event types are used to regularize the events extracted from the massive and heterogeneous data. An event type is a 2-tuple $et(Precondition, eventDescription)$, where $Precondition$ is a logic expression for requirements of the et type event; $eventDescription$ is a data record. The $eventDescription$ is used to define the $dataList$ which represents the status of the objects listed in $objectsList$.

If an event $e(t, oList, dList)$ is of the type $et(P, eDes)$, it is denoted as $e \in et$. Event type $et(P, eDes)$ is called a subtype of another $et'(P', eDes')$, denoted as $et \subseteq et'$, if $e \in et'$ for all $e \in et$. It is easy to see that P is sufficient condition of P', and $eDes$ contains $eDes'$.The event set $\{e|e \in et'$ and $e \notin et\}$ are denoted as $et' - et$.

4.1.2 Event Link: Semantic relations between events are primary semantic information for smart reasoning and decision making. The links among events weave events into a connected network with enriched semantics [21], [22].

An event link between two events is a 3-tuple $L(startEvent$, $endEvent$, $\alpha)$, denoted as $startEvent \xrightarrow{\alpha} endEvent$, where $startEvent$, $endEvent$ are two events, and α is a semantic relation from $startEvent$ to $endEvent$. For example, $(hasAFever, seeDoctor, causeOf)$ means that an event $hasAFever$ (someone has a fever) causes another event $seeDoctor$ (someone goes to see a doctor). Indeed, there are various kinds of link types with different factors. The link types can be determined by a pair of event types, that is, between a pair of event types there are some certain link types with certain factors.

Link type lt between event types can be represented as $lt(startEventType$, $endEventType$, $factor)$, which means there is a link type from event type $startEventType$ to event type $endEventType$; and the link factor between two events can be defined by some certain inherent properties of the events.

For the convenience, we use $[et_i, et_j]$ to denote all possible event link types from an event type et_i to another et_j. It is obvious that $[et_i, et_j] \subseteq [et_i', et_j]$ if $et \subseteq et'$. Link types can be used to formalize the links among two events.

Connected networks with semantic links are featured by semantic reasoning [21]. Rule-based reasoning is one of the most important and most widely-used reasonings. It can be implemented among events due to the links with semantic factors. More useful and valuable evolving patterns can be reached with rule-based reasonings on events and their links. For example, we can find the inherent reasons of some illness event by the transitivity of the $causeOf$ links among a series of events.

4.1.3 Event Link Reasoning Rules: An implication reasoning rule is in the form of $\alpha \Rightarrow \beta$, which means that if there is event-link $E \xrightarrow{\alpha} E'$, there should be a link $E \xrightarrow{\beta} E'$. For example, the rule $causeOf \Rightarrow sequence$, i.e., $causeOf$ relation between two events implies the $sequence$ relation. That means event E is the cause of another E' implies that E occurs earlier than E'.

A reasoning rule is a product one with a form of $\alpha \circ \beta \Rightarrow \gamma$, which means that if there are two event-links $E \xrightarrow{\alpha} E'$ and $E' \xrightarrow{\beta} E''$, there should be an events-link $E \xrightarrow{\gamma} E''$. Product reasoning rules reflect the internal relevant relationships among event links.

Two event link types α_1, α_2 are called semantic direct relevant (d-Relevant) if they occur in the same reasoning rules, denoted as $\alpha_1 \bowtie \alpha_2$. Obviously, from reasoning rule $\alpha \circ \beta \Rightarrow \gamma$, we can get that α, β, γ are semantic d-relevant. α_i and α_j are called semantic relevant, denoted as $\alpha_i \asymp \alpha_j$, if there is a list of event link types $\beta_1, \beta_2, \cdots, \beta_k$ which satisfy that $\alpha_i \bowtie \beta_1 \bowtie \beta_2 \bowtie \cdots \bowtie \beta_k \bowtie \alpha_j$.

4.1.4 Event-linked Network Scheme: A scheme of Events-Linked Network $\hat{S}$ is a triple (*ET,ELT,rules*), where ET is a set of event types $\{et_1, et_2, \cdots, et_m\}$, and each et_i is an event type; *ELT* is a set of link types $lt_1, lt_2, \cdots, lt_m$ where each lt_k is defined between a pair of (et_i, et_j); and $rules$ is a set of reasoning rules $(r_1, r_2, \cdots, r_l)$ and each r is in the form of $lt_i \circ lt_j \Rightarrow lt_k$.

ELN schemes may vary for different application scenarios and play the most important role in organizing data. Traditionally, the event scheme is defined by the domain experts or mined from large volumes of the history information.

Once an ELN scheme is defined, we can extract the events and links from the big data by creating an agent which can filter the useful information.

4.1.5 Advantages: A set of link types can be defined according to the domain or the application. For two certain events, the semantic links between them can be determined by their inherent properties. Experts would work out a set of useful event types for a given application, and a set of link types as well as a set of reasoning rules based on the link types. These well-defined event types, link types and the reasoning rules construct a domain- or application-dependent event scheme. Indeed, an event scheme is a domain-dependent knowledge base to differentiate the critical and sensitive information from the massive and heterogeneous data.

The advantages of the ELN model are as follows:

1) ELN provides extracted information which makes it easier and more useful for people to find solutions and to make decisions intuitively.
2) ELN provides an efficient and green way to save storage for it neglects most trivial data.
3) ELN provides the relations among events which is quite useful for decision making.
4) ELN is more efficient to analyze for mining on an event-linked network then on a detailed sensing data.

4.2 Case Study: Disaster Management of an Earthquake

In this section, we present an application of an ELN model for disaster management of an earthquake as a case study.

4.2.1 Scenario: An earthquake is caused by a sudden slip on a fault. The tectonic plates are always slowly moving, but they get stuck at their edges due to friction. When the stress on the edge overcomes the friction. When the stress on the edge overcomes the friction, there is an earthquake that releases energy in waves that travel through the earth crust and cause the shaking that we feel.

Generally, disaster management involves four phases: *prevention*, *preparation*, *response* and *recovery*. We cannot prevent earthquakes from happening (or stop them once they have started). However, we can significantly mitigate their effects by characterizing the hazard (e.g., identifying earthquake faults, unconsolidated sediment likely to amplify earthquake waves, and unstable land prone to sliding or liquefying during strong shaking), building safer structures, and preparing in advance by taking preventative measures and knowing how to respond. Therefore, disaster management of an earthquake focuses on preparation, response and recovery.

During the rescue of the disaster, it is necessary to monitor the development of various events. The possible monitoring objects include damages led by the earthquake disaster, accompanied disasters after the earthquake, transportation of supplies and devices, transportation information of roads, temperature, wind and humidity, and so on.

Various information needs more monitoring staffs, however, it is impossible for a monitoring environment without automatic sensors and communication technologies. So it provides great opportunity for the application of the IoT technologies including sensors and wireless communications. Because the environment after an earthquake often lacks the power, so the green communication and power-saving sensors are urgently needed during the monitoring and command of rescue after an earthquake disaster happens.

4.2.2 Event Types: Different events happen at different stages of an earthquake such as *prevention*, *preparation*, *response* and *recovery*. At the individual level, preparation consists of four events; response consists of two events and recovery consists of one event [23]. The event types in the earth disaster are as follows.

- In the *prevention* stage, various sensors and detection devices are used to monitor the changes in the environment including temperature, humidity, wind and other relevant attributes. The reflections of animals are also monitored by monitoring staff and residents. The changes of attributes or irregular environmental phenomena will be used to predict the earthquakes with different probabilities. The prediction results can be used to prevent the health and financial damage.
- In the *preparation* stage, the rescuing of people, devices and supplies should be prepared for the response for the earthquake rescue. After the earthquake disaster is predicted, the actions will be prepared including the preventing of the earthquake hurt, the medical care, food and water supply, and so on, the collection of work staff for working in the earthquake place. The IoT technologies can help to monitor the development of preparation, especially for monitoring transportation of devices and supplies prepared for the rescue.
- In the *response* stage, the earthquake has happened. The location and the earthquake level can be definite, and then the level of rescue can be arranged. The damages include the health damage of people and their financial damage. The preparations including the humans and supplies will be transferred to the earthquake place. As the earthquake will lead to the damage of roads, water pollution, power outages and other natural disasters such as gale, storm, tsunami and landslides. These will delay or prevent the rescue in time. Sensors distributed in the earthquake places and their neighbor regions can help to monitor the development of response and the changes in the environment. The logistic of food, medicine and rescue staff can be reported by using GPS-like location position systems. The images captured by satellites can be used to monitor the status of the environment in the earthquake place.
- In the *recovery* stage, the buildings should be reconstructed for residents of the earth place. The building materials should be transported to the earthquake place. The images of satellites can be used to monitor the development of the recovery.

The focus of the paper is on the events monitoring after an earthquake happens for supporting the response stage, especially for the rescue of the victims of the earthquake and reducing the financial damages. There are many possible effects of an earthquake which can be denoted as the event types in the ELN model as follows:

- *Shaking and ground rupture*: Shaking and ground rupture are the main effects created by earthquakes, principally resulting in more or less severe damage to buildings and other rigid structures.
- *Landslides and avalanches*: Earthquakes, along with severe storms, volcanic activity, coastal wave attack, and wildfires, can produce slope instability leading to landslides, a major geological hazard.
- *Fires*: Earthquakes can cause fires by damaging electrical power or gas lines.
- *Soil liquefaction*: Soil liquefaction occurs when, because of the shaking, water-saturated granular material (such as sand) temporarily loses its strength and transforms from a solid to a liquid.
- *Tsunami*: Tsunamis are long-wavelength, long-period sea waves produced by a sudden or abrupt movement of large volumes of water.
- *Floods*: Floods may be secondary effects of earthquakes, if dams are damaged. Earthquakes may cause landslips to dam rivers, which collapse and cause floods.
- *Human impacts*: An earthquake may cause injury and loss of life, road and bridge damage, general property damage, and collapse or destabilization (potentially leading to a future collapse) of buildings. The aftermath may bring disease, lack of basic necessities, and higher insurance premiums.

4.2.3 Event-Link Types: Semantic relations exist in different events relevant to the earthquake disasters, which are shown as event links in the event linked network model. Semantic relations can be discovered according to different aspects such as time, location, sequence and components. The types of event links are as follows:

- According to the time description of events, the semantic relations between two events include *Before*, *After*, *Meets*, *Met-By*, *Overlaps*, *Overlapped-By*, *During*, *Includes*, *Starts*, *Started-By*, *Finishes*, *Finished* and *Equals* [24]. As shown in Figure 2, Mani et al. simplify the 13 types of relations into 6 types: *Before*, *IBefore*, *Begins*, *Ends*, *Includes* and *Simultaneous* [25]. Here, we simplify five types: *Before*, *Begins*, *Ends*, *Includes* and *Simultaneous*. Table 1 shows the mappings between 5 temporal relations and 13 temporal relations.
- According to the location description of events, the semantic relations between two events include *neighbor* and *sameRegion*. If the locations of two events are neighbors, the two event also have the semantic relation *neighbor*. Earthquake disaster and the rescue management are closely related to the location-based relations.
- Besides of the semantic relations based on tempo-

rary description and location description, *causeOf* and *partOf* are also semantic relations between events. According to the scope of events, *involveIn* shows the semantic relations based on granularities.

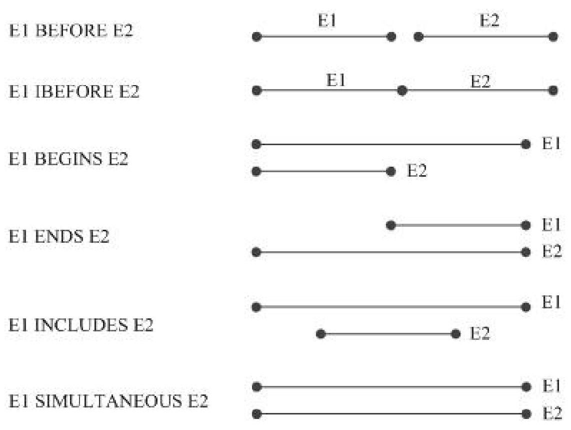

Figure 2. Six types of temporal relations between events(See Ref. [25])

4.2.4 Scheme of an Earthquake Event-Link Network : Events in the earthquake and their semantic relations together formulate the scheme of earthquake event link network. The scheme covers the most possible events during the rescue of earthquake disasters.

Table 2 shows semantic relations between events in earthquake disasters.

Figure 3 shows a scheme for an event linked network of earthquake disaster.

The possible semantic reasoning rules are as follows:

- *Before* $\circ$ *Before* $\Rightarrow$ *Before*
- *Begins* $\circ$ *Begins* $\Rightarrow$ *Begins*
- *Ends* $\circ$ *Ends* $\Rightarrow$ *Ends*
- *Includes* $\circ$ *Includes* $\Rightarrow$ *Includes*
- *causeOf* $\circ$ *causeOf* $\Rightarrow$ *causeOf*
- *involveIn* $\circ$ *involveIn* $\Rightarrow$ *involveIn*
- *Simultaneous* $\circ$ *Simultaneous* $\Rightarrow$ *Simultaneous*

4.2.5 Benefit of ELN for Disaster Management: An Event-linked Network of an earthquake disaster can be used to describe the different stages of disaster management including prevention, preparation, response and recovery. When an earthquake happens, the processes can be recorded and formulate an ELN. Different ELNs of earthquake disasters can be merged into a general ELN that could cover all the possible events that happen in an earthquake.

ELN of an earthquake disaster can be used to monitor the rescue process in time. Sensors in IoT can help to monitor the changes in the environment. The detected data can be transferred into the rescue commander center. The detected data can be used to predict the events likely to happen. Experts can then design manage the rescue according to the predictions.

Comparing the traditional earthquake disaster management system, the ELN data management approach has the following characteristics:

- *Less data transmission saves energy*. Event will be monitored and transferred as information unit through physical, human and cyber space. In the whole CPSS system, events are as the messages transferred and large scaled sensing data are processed and predicted for events. This will save the energy in the whole system.
- *Event Linked Network of the earthquake disaster is easy-to-use and fit for visualization*. After an event happens in a physical world, corresponding events can be predicted, and then possible actions taken to reduce damages in following rescue.
- *Reduced data storage.* Massive sensing data are usually used to judge what is happening at an event. However, continuously sensors are not valuable before the event occurance. If the event monitoring rules are set, the duplicate or nonsense sensing data could be compressed or deleted, and only the event triggered data are stored. Furthermore, after some events happens, the historic sensing data could be compressed for archive. The sensor work ability is thus stronger.
- *Reduced analytic data.* The massive sensing data are covered by the events in larger granularities. The support systems can analyze their decisions on smaller number of events. The management systems can make quick decisions based on a smaller events. Response in time is especially important for the rescue of earthquake disaster.

Although the case study takes an earthquake disaster to show the event management, the ELN model chould be used in more senarios which could use SPSS for the platform of diasaster management that covers disater resilience.

5 CONCLUSION

Disasters may be due to meteorological, geological or man-made events. Approximately 700 disasters occur each year with annual worldwide impact of over \$100B/year. Cyber-Physical Systems (CPS), which are smart networked systems with embedded sensors, processors and actuators that are designed to sense and interact with the physical world (including the human users), and support real-time, guarantee performance in safety-critical applications where the proverbial “blue screen of death” can have catastrophic consequences, can dramatically increase the situational awareness of emergency responders and enable an optimized response through all phases of disaster events, i.e., prevention, preparation, response, and recovery. However, significant energy efficiency related research challenges arise

Table 1. The mapping between 5 temporal relations and the 13 temporal relations

Temporal Relations from 5 types	Temporal Relations from 13 types
Before	Before, After, IBefore, IAfter
Begins	Begins, Begun_By
Ends	Ends, Ended_By
Includes	Includes, Is_Includeed, During
Simultaneous	Simultaneous, Indentity

Table 2. Semantic relations between events in earthquake disaster and rescue

startEvent	Semantic Relation	endEvent
earthquake	causeOf	shaking
earthquake	causeOf	ground rupture
earthquake	causeOf	house collapse
storm	before	flood
earthquake	before	plague
house collapse	causeOf	casualties
earthquake	causeOf	storm
shaking/ground rupture	causeOf	landslides
landslides	causeOf	houses collapsed
landslides	causeOf	debris flow
shaking	causeOf	volcano
shaking	causeOf	tsunami
ground rupture	causeOf	volcano
ground rupture	causeOf	tsunami
volcano	causeOf	fire
tsunami	causeOf	casualties
tsunami	causeOf	financial loss
fire	causeOf	casualties
plague	causeOf	casualties
fire	causeOf	financial loss
casualties	before	confirm
casualties	before	treatment
confirm	before	bury
shaking/ground rupture	causeOf	road block
ground rupture	causeOf	road block
casualties	before	rescue
financial loss	before	rescue
road block	influence	transport
road block	influence	treatment
rescue	broadThan	treatment

because of disaster management requirements for quality of service and quality of information. Energy efficient communication, computing and control are desirable for CPS for disaster management. Society of human being plays important role in disaster management including the decision making and the executions. The paper proposes a Cyber-Physical-Social System (CPSS) framework for disater management by combing CPS and the society of the human beings. An Event-Linked Network (ELN) model is set up to provide green communication and computing in the CPSS for disaster management. The model efficiency is demonstrated on an earthquake disaster management as a case study. The CPSS mechanism which includes the disaster resilience, will support the disaster management.

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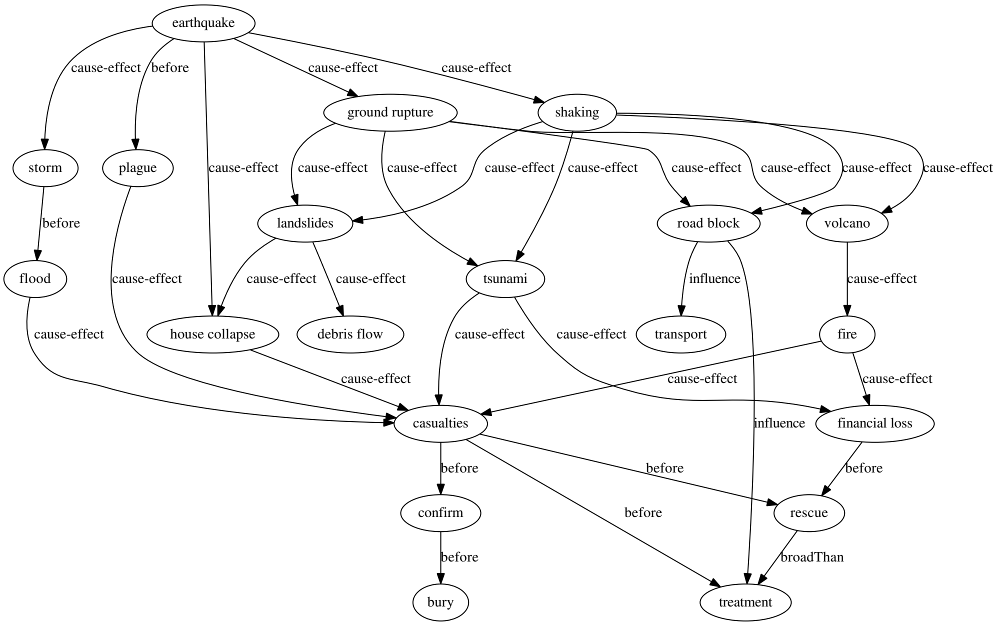

Figure 3. Schema for event linked network of earthquake disaster

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