Asian Journal of Information Technology 14 (1): 28-36, 2015
ISSN: 1682-3915

A Distributed Disaster Monitoring and Information Dissemination Service Model for On-Road Safety

Muhammad Sohail Khan and Dohyeun Kim
Jeju National Univeristy, 102 JejuDeahakyo, 690-756 Jeju-do, South Korea

Abstract: Human history is full with natural and man-made disasters which have caused millions of deaths since. Even in the modern era of science and technology disasters do not cease to exist and human population is still vulnerable to the damages in the form of human deaths, economic and structural losses caused by various types of disasters like flooding, typhoons, earthquakes, etc. There are smaller versions of disasters such as heat waves, icy roads, land sliding, etc. which may not affect geographically vast regions simultaneously but still cause deaths and damages. This study presents a scheme for region specific disaster monitoring with a focus towards on-road safety. The proposed scheme is aimed at monitoring environmental factors using road-intersection gateways, analyzing the data and sharing of information regarding the local situation with on-road vehicles. We present two different communication models for the information dissemination and provide a detailed work domain analysis model for the implementation of the gateway for the proposed scheme.

Key words: Human, man-made, typhoons, earthquakes, disaster

INTRODUCTION

The term disaster is used to represent an event, natural or man-made such as blast, building structure collapse, wild fire, floods, plane crash or highway accidents and landslides, etc. Disaster monitoring and management has been an ever-present challenge to authorities and organizations responsible for the public safety and security. According modern studies and theories, a disaster is a considerable disruption of the functionality of a community or a society involving serious impact on human, material, financial and environmental states which are beyond the capabilities of the affected community to cope with using their own resources. Disasters are envisioned and considered as the absence or lack of appropriate risk management while risks are the product of a combination of hazards and vulnerability (Quarantelli, 1998).

Disasters have occurred since the beginning of life on earth and at various stages of human evolution these disasters have been studied by humans. There is a long history of researchers who studied and analyzed different aspects of disasters such as the causes, probability of re-occurrence of disasters, risk analysis and disaster management. In the modern ages, all these aspects were studied from the perspective of sciences such as physics, geology, geography, etc. For instance, the early studies of understanding the physical processes responsible for the onset of disastrous events (Goldthwait, 1928), the application of geographic knowledge, techniques and skills towards the understanding of natural hazards causing disasters (Platt, 1986) and to manage real world disasters with the help of conceptual models and integrative frameworks (Cutter, 1993; Tobin and Montz, 1997) developed as a result of these studies.

With the advancements of science and technology, new techniques are being introduced for monitoring the causes of disasters and to use such data for the safeguard of resources or at least proper management plans once a disaster strikes. Meissner *et al.* (2002) presented a detailed description of the design challenges for an integrated management, communication and information system from the perspective of disasters. Meissner *et al.* (2002) considered a scenario of the collaboration among emergency response authorities in case of a disaster caused by fire and presented a communication design based on Wide Area Networks (WAN) and personal Area Networks (PAN) for effective communication among headquarters and among on-field personnel, respectively. Oliveira and Rodrigues (2011) presented a comprehensive survey regarding the utilization of Wireless Sensor Networks (WSN) for environmental monitoring which in

Corresponding Author: Muhammad Sohail Khan, Jeju National Univeristy, 102 JejuDeahakyo, 690-756 Jeju-do, South Korea

turn can be used for disaster risk assessments and management purposes. A comprehensive description of technologies such as Geographic Information System (GIS), remote sensing and spatial analytical techniques which have greatly improved the research related to natural hazards has been presented by Tobin and Montz (2004).

According to researcher of natural hazards and disasters (Hyndman and Hyndman, 2010), disaster are normally associated with dramatic event such as large earthquakes, volcanic eruptions, flood, hurricanes, etc. while there are natural hazards (e.g., heat waves, wildfire, landslide, lightning, Winter waves and tornados, etc.) which take place rather infrequently and affects a relatively smaller areas. From year 1997-2008, the major natural hazards which caused the most human deaths were heat waves, cold waves, hyperthermia and accidents because of icy roads (Hyndman and Hyndman, 2010). This study, based on the statistics given above, considers that if dedicated monitoring and guidance systems are deployed in areas prone to such infrequent and limited disastrous events, more human lives can be saved and more safety can be provided to assets as well. According to our thinking, such infrequent and dramatic events can affect mostly those people who are unaware of the area or the occurrence of such events in an area. This category of people is mostly tourists or people in transit on the roads. Disasters like landslides, wildfire, heat waves, cold waves, etc. can affect people on the roads more often than others. This study proposes a scheme for disaster monitoring and information dissemination from the perspective of on-road safety. The idea is to monitor environmental and traffic flow parameters at local level using some pre-existing infrastructure and using the prevalent technologies, enable a distributed provision of the location based information to people in transit to suggest safer routes or to automatically assign travel routes to them in order to avoid the regions under the influence of the disaster.

CONCEPTUAL AND ARCHITECTURAL DESIGN

Figure 1 shows the disaster detection system for on-road safety. This on-road safety scenario is based on the installation of interchange gateways at the junctions or other major points on the roads. An interchange gateway has the functionality to collect data from environmental sensing devices in its range and can perform some basic analysis of the data in order to predict/detect the environmental state at that region towards the buildup of a disastrous situation. Once an interchange gateway detects a pattern of data which implicates disaster such as typhoon, heat wave or wild fire, etc., the interchange gateway sends a specific disaster alert to the neighboring interchange gateways. The disaster message is intended for the gateways to either re-route traffic to avoid the hazardous region and/or inform the drivers in the respective vicinities of the gateways regarding the location and hazard.

The interchange gateways are also connected to the Central Disaster Analysis and Safety Agency (CDASA). The CDASA provides a data repository for storing important data regarding the contextual patterns and may also provide centralized control point for all the connected gateways. The CDASA performs timely analysis on the data in its repository and based on inferred situation may issue control commands to interchange gateways to adjust their behavior for controlling and routing the traffic flow.

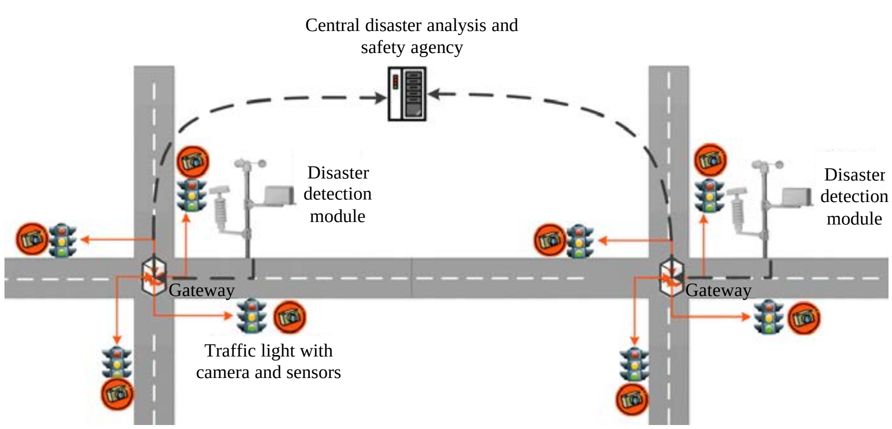

Fig. 1: General scenario

Figure 2 shows the conceptual architecture for the disaster monitoring system for on-road safety. The major components are the data acquisition, analysis and control/decision dissemination components which are components of generic Cyber-Physical System. Figure 2 illustrates the general operational cycle of the cyber-physical disaster monitoring and on-road safety system. In this scenario, the environmental data is sensed by the sensing equipment associated with a region along the road (interchange gateway). The gateway is capable of performing basic analysis on the acquired data. In a normal situation, the gateway analyses the acquired data and if no disastrous condition is detected, the data is locally stored and a summary data is uploaded to the central analysis agent at a pre-defined time interval for storage in the central repository. If the local analysis reveals/detects a disastrous situation in the area, the situation is directly notified to a central analysis agent or directly distributed to the neighboring gateways in the area which may perform further detailed analysis of the situation based on the received data as well as the stored data from the central repository. This information is then disseminated and provided to the vehicle clients on the road to avoid safety risks for the on-road vehicles.

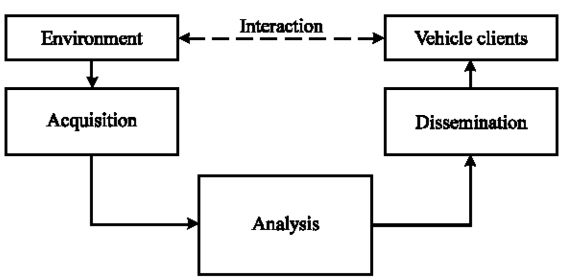

Fig. 2: Conceptual architecture

SAFETY INFORMATION DISSEMINATION

The information regarding the disaster detected by the system may be distributed/disseminated to the neighboring gateways in two different ways. The safety information dissemination is performed using the following two methods.

Centralized information dissemination: Figure 3 shows the first approach to safety information dissemination for the disaster detection and on-road safety system. The gateways collect environmental monitoring data from the associated sensing modules as shown in the figure. The gateways are capable of performing basic analysis of the collected environmental data for any patterns which may indicate or detect a disaster such as typhoon or wildfire, etc. In a normal scenario when the gateway does not find any disaster pattern in the collected data, the data is processed and the summary data is locally saved. Such instances of summary data are then uploaded for storage to the Central Disaster Analysis and Safety Agency (CDASA) at a predefined interval of time unless a hazard event occurs. The disaster event occurs when a gateway detects a disaster pattern in the sensed data. At that time, all the summary data up to that point in time and the data patterns are immediately forwarded to CDASA which may perform further analysis of the provided data in conjunction with previous records from its internal repository. The CDASA then distributes an alert message containing information about the disaster, gateway and interchange number, etc. to the gateways which can route traffic to the disaster site. The gateways when receives the alert message start to broadcast the message to vehicle client in their respective range until otherwise is directed by the CDASA. The CDASA may also be used

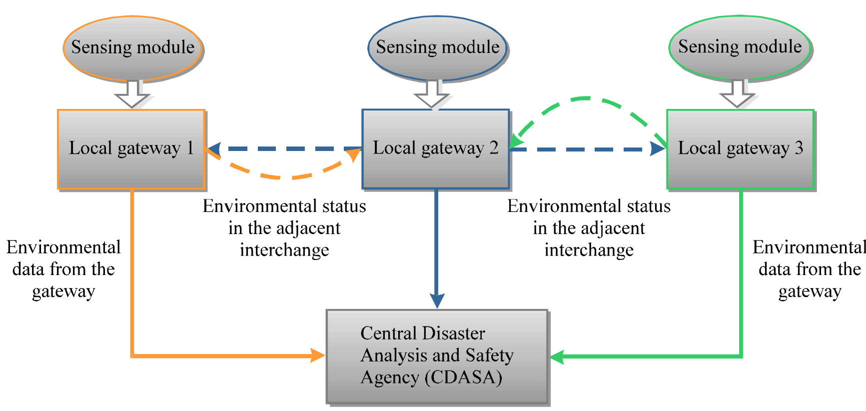

Fig. 3: Communication scenario 1

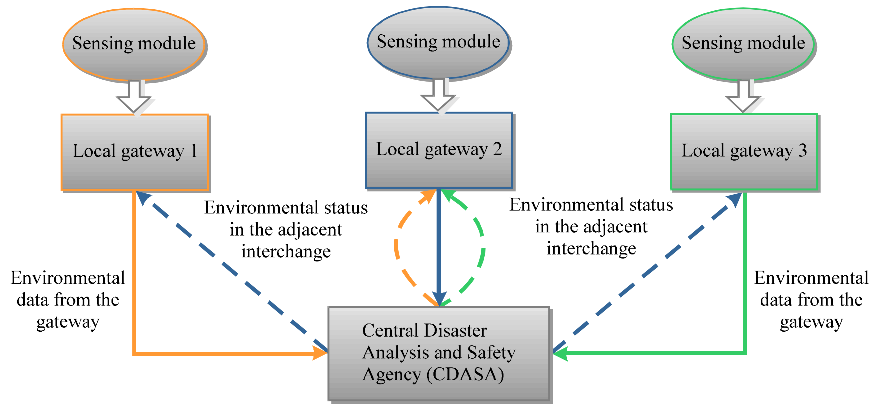

Fig. 4: Communication scenario 2

to generate centralized control messages to the concerned gateways to change their traffic routing scheme in order to avoid safety risks to the drivers and other people in the vehicles which may pass through the disaster region.

Distributed information dissemination: Figure 4 shows the second approach towards information dissemination of the disaster detection and on-road safety system. The distributed information dissemination is based on the direct communication between the interchange gateways. The CDASA is still a part of the system and may be used for detailed analysis of the stored data from the gateways that is uploaded at regular intervals. The CDASA may use this stored data to perform some inferences and may forecast/predict disaster arising at specific locations during specific seasons and other factors. Such a forecast may be used to generate and broadcast centralized warnings to all the gateways which may route traffic to the specific region for which the prediction has been made.

The distributed information dissemination process involves the direct communication between the interchange gateways. Once a gateway detects disaster patterns in the data collected from its associated environmental sensing modules, no immediate upload to the CDASA is performed. Instead, a local alert message is generated and is sent directly to the immediate neighboring interchange gateways. The message is then broadcasted by the receiving gateways to the vehicle clients in their respective areas.

INTERACTION MODEL

Figure 5 shows the sequence diagram for the centralized information dissemination approach. The entities shown in the diagram are the vehicle client for displaying information to the driver, environmental sensing module, gateway 1 as the source gateway, CDASA is the centralized disaster analysis and safety agency, other gateways are the representation of adjacent interchanges or from which the traffic may arrive at gateway 1. As discussed earlier, the gateways collect disaster monitoring data from the associated sensing modules as shown in Fig. 5. The gateways are capable of performing basic analysis of the collected environmental data for any patterns which may indicate or detect a disaster such as typhoon or wildfire, etc. In a normal scenario when the gateway does not find any disaster pattern in the collected data, the data is processed and the summary data is locally saved. Such instances of summary data are then uploaded for storage to the CDASA at a predefined interval of time unless a hazard event occurs. The hazard event occurs when a gateway detects a disaster pattern in the sensed data. At that time, all the summary data up to that point in time and the disaster pattern data are immediately forwarded to CDASA which may perform further analysis of the provided data in conjunction with previous records from its internal repository. The CDASA then distributes an alert message containing information about the disaster, gateway and interchange number etc. to the gateways which can route traffic to the disaster site. The gateways when receives the alert message start to broadcast the message to vehicle client in their respective range until otherwise is directed by the CDASA. The CDASA may also be used to generate centralized control messages to the concerned gateways to change their traffic routing scheme in order to avoid safety risks to the drivers and other people in the vehicles which may pass through the disaster region.

Figure 6 shows the sequence diagram for the centralized information dissemination approach. The entities shown in the diagram are the vehicle client for displaying information to the driver, environmental

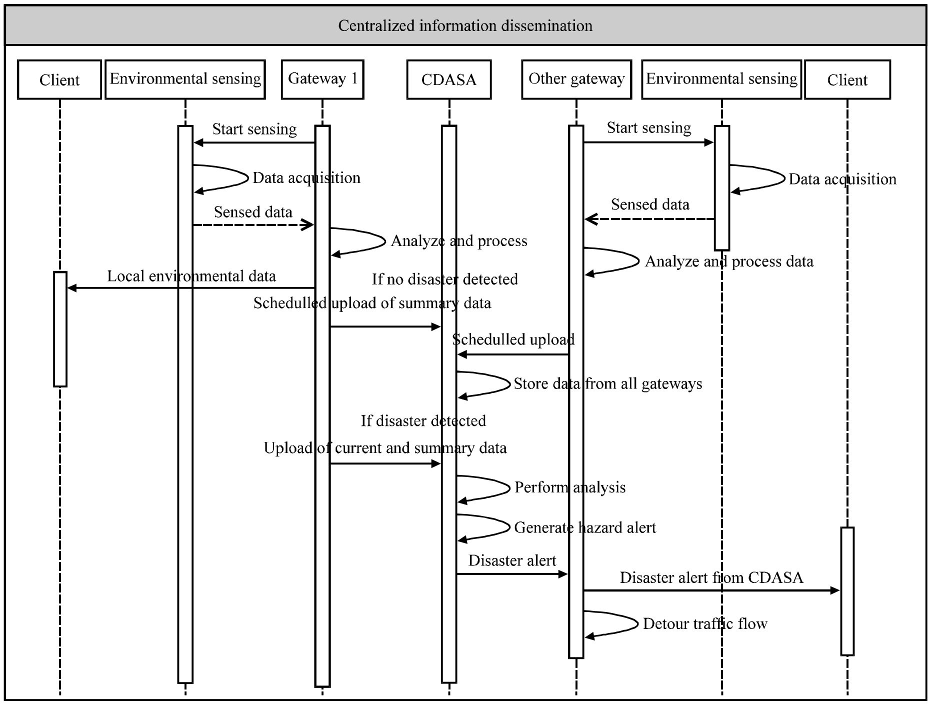

Fig. 5: Sequence diagram for centralized information dissemination

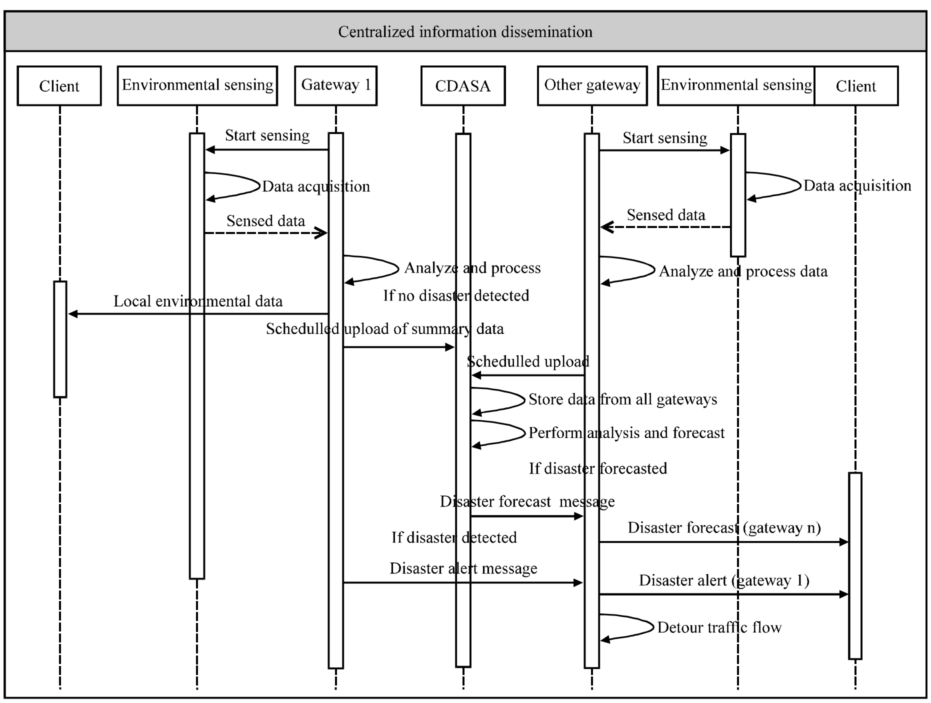

Fig. 6: Sequence diagram for distributed information dissemination

sensing module, gateway 1 as the source gateway, CDASA is the centralized disaster analysis and safety agency, other gateways are the representation of adjacent interchanges or from which the traffic may arrive at gateway 1. As discussed earlier, distributed information dissemination is based on the direct communication between the interchange gateways. The CDASA is still a part of the system and may be used for detailed analysis of the stored data from the gateways that is uploaded at regular intervals. The CDASA may use this stored data to perform some inferences and may forecast/predict disaster arising at specific locations during specific seasons and other factors. Such a forecast may be used to generate and broadcast centralized warnings to all the gateways which may route traffic to the specific region for which the prediction has been made.

The distributed information dissemination process involves the direct communication between the interchange gateways. Once a gateway detects disaster patterns in the data collected from its associated environmental sensing data, no immediate upload to the CDASA is performed. Instead a local alert message is generated and is sent directly to the immediate neighboring interchange gateways. The message is then broadcasted by the receiving gateways to the vehicle clients in their respective areas.

Figure 7 shows the business process model for the centralized information dissemination in disaster monitoring for on-road safety system. The process pools specify the sub-tasks performed by each entity. The model shows that the process starts when the gateway collects environmental monitoring data from the associated sensing module. The gateways are capable of performing basic analysis of the collected environmental data for any patterns which may indicate or detect a disastrous situation such as wildfire or typhoon, etc. In a normal scenario when the gateway does not find any disaster pattern in the collected data, the data is processed and the summary data is locally saved. Such instances of summary data are then uploaded for storage to the CDASA at a predefined interval of time unless a hazard event occurs. The hazard event occurs when a gateway detects an environmental hazard pattern in the sensed data. At that time, all the summary data up to that point in time and the disaster pattern data are immediately forwarded to CDASA which may perform further analysis of the provided data in conjunction with previous records from its internal repository. The CDASA then distributes an alert message containing information about the disaster, gateway and interchange number etc. to the gateways which can route traffic to the disaster site. The gateways when receives the alert message start to broadcast the message to vehicle client in their respective range until otherwise is directed by the CDASA. The

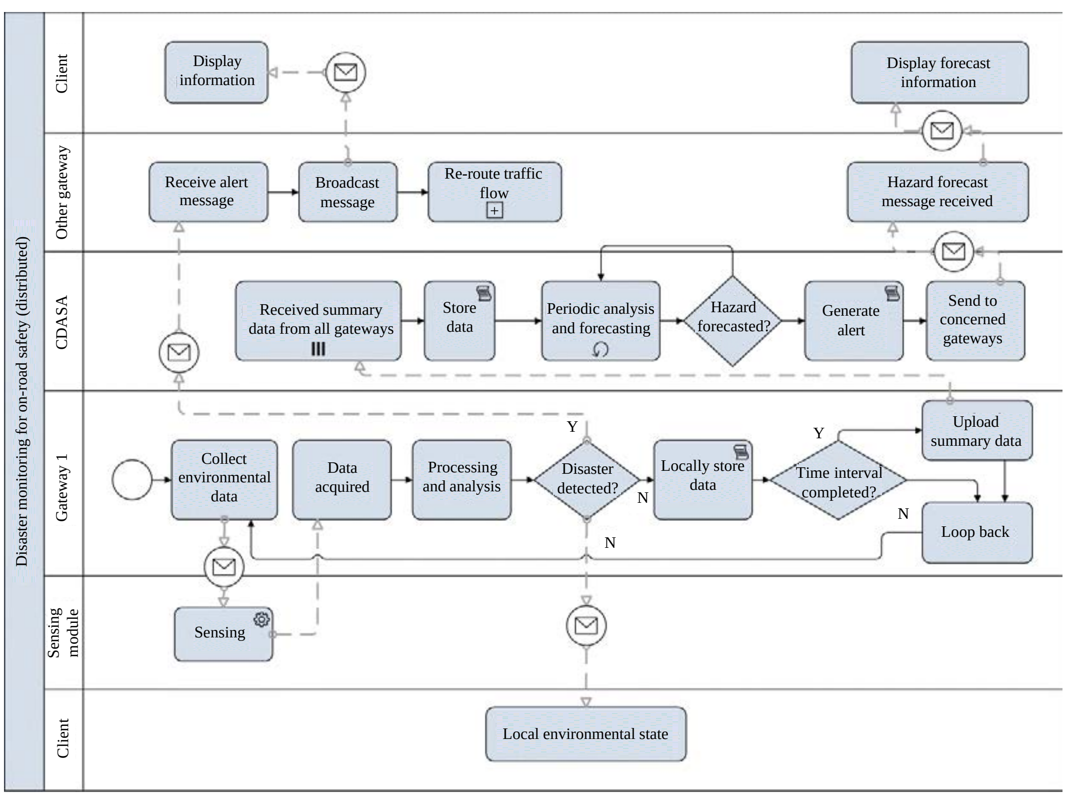

Fig. 7: Business process model for centralized information dissemination

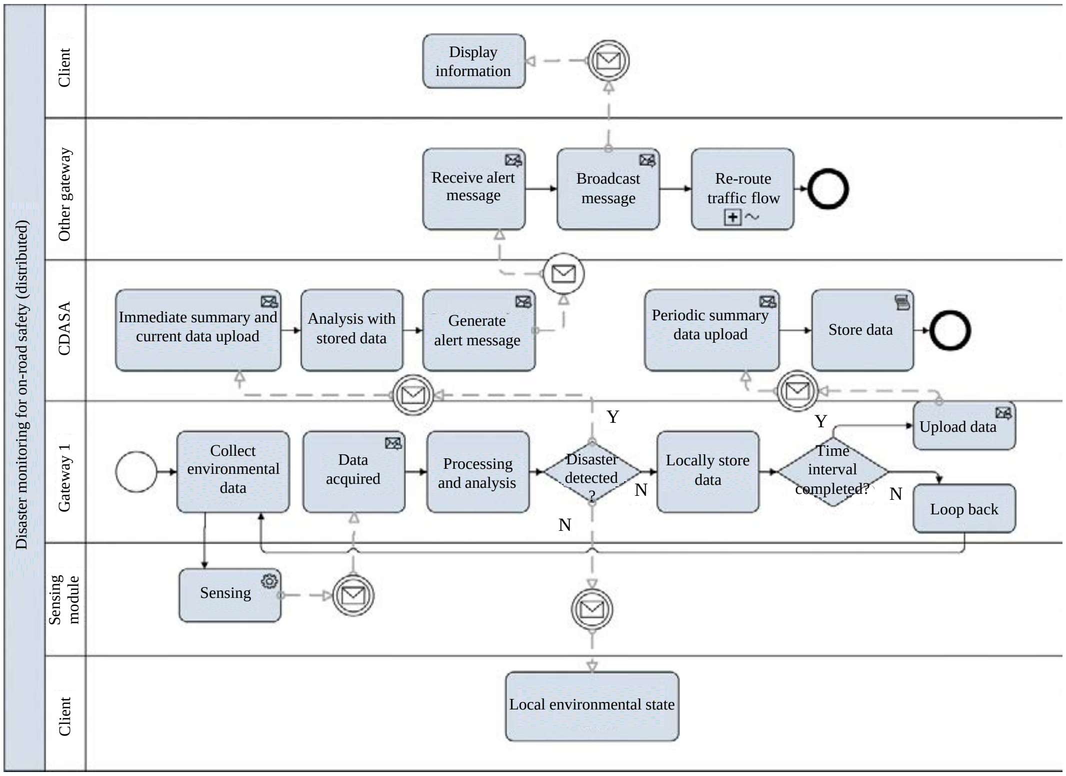

Fig. 8: Business process model for distributed information dissemination

CDASA may also be used to generate centralized control messages to the concerned gateways to change their traffic routing scheme in order to avoid safety risks to the drivers and other people in the vehicles which may pass through the hazardous region.

Figure 8 shows the business process model for the centralized information dissemination in disaster monitoring for on-road safety system. The process pools specify the sub-tasks performed by each entity. The model shows that the process starts when the gateway collects environmental data from the associated sensing module. The model illustrates that the distributed information dissemination is based on the direct communication between the interchange gateways. The CDASA is still a part of the system and may be used for detailed analysis of the stored data from the gateways that is uploaded at regular intervals. The CDASA may use this stored data to perform some inferences and may forecast/predict hazards arising at specific locations during specific seasons and other factors. Such a forecast may be used to generate and broadcast centralized warnings to all the gateways which may route traffic to the specific region for which the prediction has been made. The distributed information dissemination process involves the direct communication between the interchange gateways. Once a gateway detects h disaster patterns in the data collected from its associated environmental sensing data, no immediate upload to the CDASA is performed. Instead, a local alert message is generated and is sent directly to the immediate neighboring interchange gateways. The message is then broadcasted by the receiving gateways to the vehicle clients in their respective areas.

WORK DOMAIN ANALYSIS MODEL FOR THE GATEWAY

This study presents a comprehensive analysis of the functionalities that should be part of the gateway module proposed for the intersection gateway based disaster monitoring for on-road safety scenario in the form of a Work Domain Analysis (WDA) Model. The basic and important functionality of the gateway module is presented in the form of categorical and hierarchical distribution by the WDA Model. According to our work, domain analysis of the gateway the gateway functional purpose has been divided into four major groups. Data acquisition from all the connected devices. Processing functionality to make the acquired data usable for decision making. Communication functionality to enable

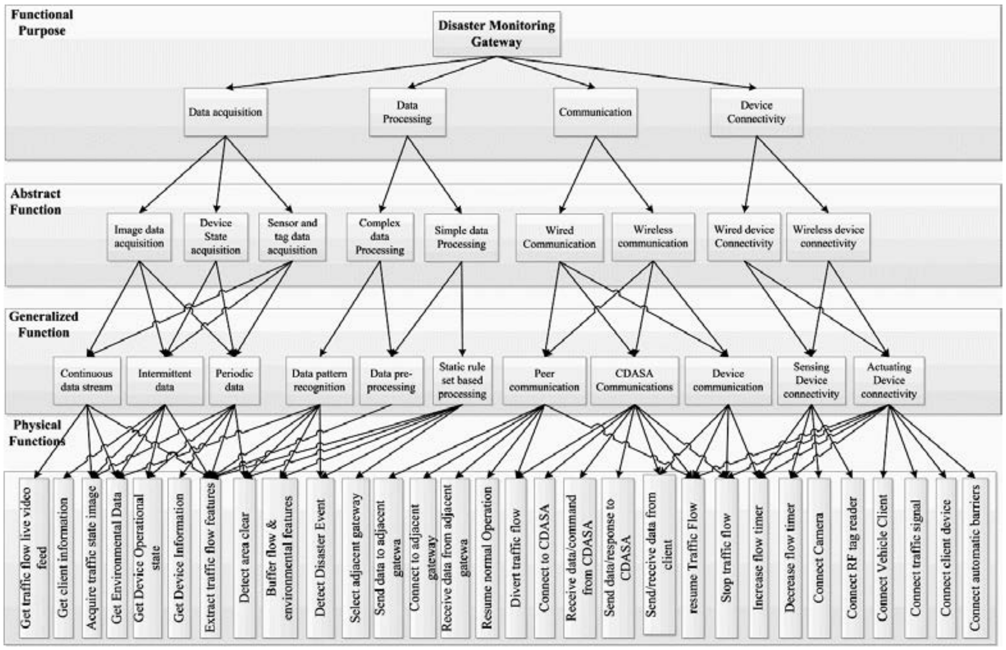

Fig. 9: Work domain analysis model for the gateway

the gateway to communicate with adjacent gateways (distributed scenario) or with the CDASA for centralized analysis and control scenario. Control interfaces for connecting sensing and actuating equipment (Fig. 9).

From the data acquisition perspective, two different approaches can be followed. The gateway may either be designed in such a way to utilize the existing infrastructure for traffic monitoring which is mostly based on cameras and video analysis devices or if the system is to implemented from the ground up then other internet of things based solutions may also be considered for traffic and environmental monitoring data acquisition.

WDA further divides these functional purposes into abstract functions, generalized functions and finally the physical functions which must be implemented as part of the gateway module in order to be used for the disaster detection and post-accident traffic management scheme proposed in this study.

CONCLUSION

This study proposed an intersection level disaster monitoring and information dissemination scheme with focus towards on-road safety. The main idea of the proposed scheme is to locally acquire data regarding environmental factors, monitor it for disaster events and using intersection level connected traffic infrastructure to communicate this information with people in transit. The intersection gateway and control infrastructure can be used to disseminate the information to vehicle clients as well as to re-direct traffic flow away from the affected areas. The same information from multiple gateways can be utilized to navigate traffic out of a region affected by the disaster. We proposed a detail design of the scheme and provided a work domain analysis model for the environmental hazard monitoring gateway. In future, we intend to implement the gateway based on some sample disaster in the past and test the efficacy of its proposed functionality.

REFERENCES

Cutter, S.L., 1993. Living with Risk: The Geography of Technological Hazards. Edward Arnold, London, Pages: 214.

Goldthwait, J.W., 1928. The gathering of floods in the connecticut river system. Geographical Rev., 18: 428-445.

Hyndman, D. and D. Hyndman, 2010. Natural Hazards and Disasters. Cengage Learning, USA.

Meissner, A., T. Luckenbach, T. Risse, T. Kirste and H. Kirchner, 2002. Design challenges for an integrated disaster management communication and information system. Proceeding of 1st IEEE Workshop on Disaster Recovery Networks (DIREN), June 24, 2002, New York, USA., pp: 1-7.

Oliveira, L.M. and J.J. Rodrigues, 2011. Wireless sensor networks: A survey on environmental monitoring. J. Communic., 6: 143-151.

Platt, R., 1986. Floods and Man: A Geographer's Agenda. In: Geography Resources and Environment: Themes from the Work of Gilbert F. White, Vol. 2, Kates, R. and I. Burton (Eds.). University of Chicago Press, Chicago, pp: 28-68.

Quarantelli, E.L., 1998. Where We Have Been and Where We Might Go. In: What is a Disaster? Perspectives on the Question, Quarantelli, E.L. (Ed.). Routledge, London, UK., pp: 234-273.

Tobin, G.A. and B.E. Montz, 1997. Natural Hazards: Integration and Explanation. Guilford Press, New York.

Tobin, G.A. and B.E. Montz, 2004. Natural Hazards and Technology: Vulnerability, Risk and Community Response in Hazardous Environments. In: Geography and Technology, Brunn, S.D., S.L. Cutter and J.W. Harrington Jr. (Eds.). Springer, The Netherlands, pp: 547-570.