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Internet of Things for Disaster Management: State-of-the-Art and Prospects

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ABSTRACT Disastrous events are cordially involved with the momentum of nature. As such mishaps have been showing off own mastery, situations have gone beyond the control of human resistive mechanisms far ago. Fortunately, several technologies are in service to gain affirmative knowledge and analysis of a disaster's occurrence. Recently, Internet of Things (IoT) paradigm has opened a promising door toward catering of multitude problems related to agriculture, industry, security, and medicine due to its attractive features, such as heterogeneity, interoperability, light-weight, and flexibility. This paper surveys existing approaches to encounter the relevant issues with disasters, such as early warning, notification, data analytics, knowledge aggregation, remote monitoring, real-time analytics, and victim localization. Simultaneous interventions with IoT are also given utmost importance while presenting these facts. A comprehensive discussion on the state-of-the-art scenarios to handle disastrous events is presented. Furthermore, IoT-supported protocols and market-ready deployable products are summarized to address these issues. Finally, this survey highlights open challenges and research trends in IoT-enabled disaster management systems.

INDEX TERMS Internet of Things, disaster management, cloud-assisted services.

I. BACKGROUND AND MOTIVATION

Disasters often take place in the vicinity of human livelihood. Most of the time, it is either natural (e.g., landslide, earthquake, tsunami, flood, forest-fire, and lightning) or man-made (e.g., industrial explosion, leakage in an oil pipeline, leakage in gas production, and terrorist attacks). Regardless the cause of incident, disaster leads to huge destruction in terms of economic and human lives. Some of the dangerous disasters in the history of mankind are Bhopal (India) gas accident (1984), Chansala (India) mining disaster (1975), 9/11 terrorist attack (USA), Chernobyl (Russia) nuclear accident (1986), Indian Ocean tsunami (2004), Nepal earthquake (2015), and Fort McMurray (Canada) forest-fire (2016). Around 11 million people have directly or indirectly got affected during last decade [1], [2]. In most of the cases, people have acted just like an observer. The main reason behind is the lack of knowledge and distribution of the latest technological advancement that could at least alert the citizen of the happening of possible disaster in respective location.

Fortunately, the world has recently witnessed the origination of IoT that has already created a huge buzz in social, technological, political, and economic domains. Although IoT was coined in earlier 2000, IoT has recently grabbed huge attention in almost all areas of scientific and industrial fields such as smart-home, agriculture, industry, health care, entertainment, robotics, and transportation. IoT is formulated to establish seamless communication, monitoring, and management of smart embedded devices with its counterpart, i.e., analog objects or 'things'. The IoT leverages heterogeneity, interoperability, distributed processing, and real-time analytics in parallel.

Although Wireless Sensor Networks (WSNs) are widely deployed in disaster management, they lack in a multitude of socio-techno-economic perspectives. The WSN is fundamentally orientated to cater the *vertical silos* toward solving a problem. However, the following objectives are not properly discussed such as (i) managing heterogeneous embedded devices, e.g., different processor, memory space, operating system such as embedded Linux, iOS, and Android,

(ii) managing heterogeneous protocols (e.g., discovery, data, infrastructure, semantics, communication, and security), (iii) providing efficient data analytics services, (iv) established middleware support, (v) user integration, (vi) real-time access, (vii) energy efficient algorithms, (viii) interoperability among associated enabled technologies, and (ix) cost. On the other hand, IoT is proven to be fundamentally capable enough to provide more significant, scalable, portable, and energy efficient solutions to various problems in the disaster management. Motivated by these issues, an overall understanding of how disasters are currently being monitored and managed by IoT becomes very important.

In this study, several implementations of disaster management are found to be solely based on WSN, which is considered as a key part of IoT where geographically distributed nodes sense and act accordingly. Also, such WSN systems are normally equipped with various forms of topological structures (star, ring, tree, etc.) with smart sensor and processing units. The inter-nodal communication, as well as intra-WSN frameworks, rely upon either Transmission Control Protocol/Internet Protocol (TCP/IP) or standard Open Systems Interconnection (OSI) models. Hence, such WSN-based systems become an essential part of getting associated with IoT-supported systems by their virtue.

To achieve this goal, the article presents a detailed survey of the various aspects of IoT-empowered disaster management. The main contributions of this article are as follows:

- A systematic survey is presented on the IoT-based disaster management issues highlighting the key protocols with an aim to design efficient disaster countering approaches.
- Afterward, state-of-the-art application of IoT are discussed for disaster management systems.
- We provide a selective study on market-ready IoT-enabled off-the-shelf products (either open source or proprietary) solutions toward disaster management systems.
- Finally, the key challenges in IoT-based disaster management systems are highlighted, and possible future directions are suggested.

The rest of the article is organized as follows. Section II details on various IoT-supported protocols, appropriate for applications in disaster specific problems. Section III presents the selective study on few market-ready IoT-based products in this regard. Several natural and human-made disasters such as the earthquake, landslide, flood, forest-fire, volcanic, urban disaster, and terrorism are identified in Section IV. Existing implications of IoT on these issues have been investigated. Section V provides the challenges and future road map to counter the research related issues. Finally, Section VI concludes this survey.

II. IoT-SUPPORTED PROTOCOLS FOR DISASTER MANAGEMENT

This section presents several genres of the IoT-supported protocols that are suitable for performing different activities in the disaster management. Primarily, the implied protocols are segregated into seven types such as infrastructure, discovery, data, communication, semantic, multi-layer Framework, and Security. Disasters require special interventions in terms of the protocols because each type of disaster has its notion of occurrence, time of the mishap, damage ability. For example, landslides are often localized, whereas earthquake affects the large geographical region. In addition, these disasters have various impact on human life and infrastructure. Thus, it is necessary to consider several issues while selecting infrastructure and multi-layer framework protocols. Furthermore, the lightweight and energy-efficient IoT-based protocols are useful to discover local sensor devices and gateways for starting of communications in a secure way. As the disastrous situations always cut-off the affected region from outside employing wired communication links e.g., overhead wires, antennas, and optic fiber channels; it is crucial to consider network facilities. Fig. 1 illustrates the IoT-supported communication protocols suitable for disaster management. Table 1 summarizes the abbreviated terms and their full forms.

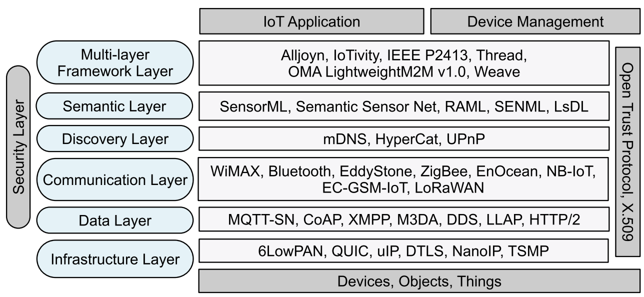

FIGURE 1. Stack-supported reference model for IoT-based disaster management.

The stack-based reference model describes how seven layers of protocols are seamlessly interconnected with each other to handle disastrous events in terms of prompt connectivity, the heterogeneous association among objects, access to secure information, and discovery of object (e.g., persons and other livelihood necessities). Although the representation of theses layers conforms to some sorts of integrity towards disastrous event management, it is not standardized at all. Its comprehensive aspect is based on the ad-hoc orientation of its layers. Most of the protocols are generally used in OSI or TCP/IP models in real-life. Few of these are recently included into this provisional and novel reference model. While designing this reference-model, coherence is constrained, i.e., from the bottom most devices layer to the top most IoT application layer. The full model is vertically secured by the security layer that holds Open Trading Protocol (OTP) and X.509 protocol suitable for the IoT-based applications. Comparison between several communication protocols is summarized in Table 2.

A. INFRASTRUCTURE LAYER

- *6LowPAN:* Since IPv6 over Low power Wireless Personal Area Networks (6LowPAN) work in 2.4 GHz

TABLE 1. List of abbreviation.

6LowPAN	IPv6 over Low power Wireless Personal Area Networks
ALARMS	Acoustic Real-time Monitoring Systems
AST	Adaptive Signal Thresholding
ATDS	Advanced Terrorist Detection System
BDC	Brinco Data Center
BLE	Bluetooth Low Energy
BSL	Berkeley Seismological Laboratory
CRB	Cramer-Rao Bound
CS-IoT	Crowd Sourced-IoT
DDS	Data Distribution Service
DIME	Data in Motion Exchange
DMR	Digital Mobile Radio
DTLS	Datagram Transport Layer
EC-GSM-IoT	Extended Coverage-GSM-IoT
EEM	Earthquake Emergency Management
EIF	Event Identification and Formulation
FH+	Fusion Hybrid
FMC	Field Management Center
FWI	Forest Weather Index
GIS	Geographic Information System
GSCL	Gate-way Service Capability Layer
GSM	Global System and Mobile Communication
ICS	Incident Command System
IIoT	Industrial IoT
IoT	Internet of Things
IoTEWS	IoT-based Early Warning System
LoT	Location of Things
LsDL	Lemonbeat smart Device Language
LTR	Long Term Reasoning Module
M2M	Machine-to-Machine
MAV	Micro Air Vehicle
MCSOS-FM	Morse Code-based SOS Message Broadcasting System
Mi-oT	Multi-function IoT
MLE	Maximum Likelihood Estimation
MTR	Medium Term Reasoning Module
NanoIP	Nano Internet Protocol
openMTC	Open Machine Type Communication
QUIC	Quick UDP Internet Connections
RFID	Radio Frequency Identification Module
SCALE	Safe Community Awareness and Alerting Network
SENML	Sensor Markup Language
SIP	Session Initiation Protocol
SSN	Earthquake Emergency Management
STR	Short Term Reasoning Module
TDM	Time Division Multiplexing
TLS	Transport Layer Security
TPM	Topology Preserving Map
TRM	Terrorist Reasoning Kernel
TSMP	Time Synchronized Mesh Protocol
TW-ToA	Two-Way Time-ofArrival
UAV	Unmanned Aerial Vehicle
UPnP	Universal Plug and Play
VANET	Vehicular Ad-hoc Area Network
VPN	Virtual Private Network
WILA	Wearable Indoor Localization Approach
WSN	Wireless Sensor Network

frequency range based on IEEE 802.15.4 standard, it can easily handle disaster related tasks.

- *QUIC:* The Quick User Datagram Protocol (UDP) Internet Connections (QUIC) protocol is suitable for disaster management and relief work due to the follows reasons: 1) supports multiplexing of connection streams between two P2P nodes over UDP, 2) provides security protection similar to TLS/SSL, 3) has low transport latency, and 4) supports bandwidth estimation to avoid congestion in both way communication.
- *uIP:* Micro IP (uIP) is an open-source TCP/IP. This protocol is designed to work with 8/16-bit microcontroller, which is one of the designing aspects of a sensor node in the disaster management scenarios.
- *DTLS:* The Datagram Transport Layer (DTLS) protocol handles the privacy in datagram communications. As it provides the security level of master/slave applications similar to Transport Layer Security (TLS), it acts as a necessary barrier for message forgery, eavesdropping, and tampering activities in the disaster management aspects.
- *NanoIP:* The Nano Internet Protocol (NanoIP) is a novel and light-weight approach to create Internet-like networking services toward sensor systems and embedded devices. The main purpose of NanoIP is to minimize the overhead of TCP/IP in local wireless networking and address the naming aspects.
- *TSMP:* Time Synchronized Mesh Protocol (TSMP) is necessary to design a time-synchronized protocol for efficient organization of wireless devices (e.g., motes). It is a special form Time-Division Multiplexing (TDM) systems to communicate in any resource-constraint situations such as disastrous events.

B. DATA LAYER

- *MQTT-SN:* Generally, in the IoT-based disaster management systems, machine and users need to interact with each other. The Message Queuing Telemetry Transport for Sensor Networks (MQTT-SN) protocol supports lightweight publish/subscribe activities particularly for Machine-to-Machine (M2M) applications.
- *CoAP:* Constrained Application Protocol (CoAP) is one of the widely used IoT protocols for the resource-constrained Internet devices, such as disaster monitoring WSN nodes. CoAP holds various functional characteristics such as (i) multicast support, (ii) very low data overhead, (iii) Uniform Resource indicator (URI) support, (iv) content-type support, (v) subscription of a resource, and (vi) surfing push notifications.
- *XMPP:* Extensible Messaging and Presence Protocol (XMPP), which is an open-source protocol, provides the following facilities as: (i) lightweight middleware, (ii) instant messaging, (iii) real-time communication, (iv) voice/video call (v) multi-party chat, and (vi) content syndication of XML data.
- *M3DA:* It acts as a mediator between machine-to-machine (M2M) server and embedded gateway designed for assisting the transportation of M2M binary data. This protocol is originated from an open source incubator project ''Mihini'' under the Eclipse technology and delivers two tasks such as device and asset management. The first task is used to ease of manipulating the IoT device's data model, on the other hand, the latter one is used to facilitate the exchange of typed data with the M2M server.

TABLE 2. Comparison between IoT-enabled disaster management solutions.

Parameters	WiMAX	Bluetooth	Eddystone	ZigBee	EnOcean	NB-IoT	EC-GSM-IoT	LoRa-WANs
Standard	IEEE 802.16	IEEE 802.15.1	IEEE 802.15.1	IEEE 802.1.5.4	ISO/IEC 14543-3-10	3GPP	ETSI GS LTN 001-003	IEEE 802.15.4
Frequency Band	2–66 GHz	2.4 GHz	2.4 GHz	2.4 GHz	315/868 MHz	180 kHz	433/868 MHz, 2.4 GHz	868/915 MHz, 2.4 GHz
Data Rate	1 Gbps (Fixed) and 30-40 Mb/s (mobile)	1–24 Mbps	1–24 Mbps	250 kbps	125 kbps	250 kbps	$<$ 300 bps	40–250 kbps
Transmission Range	50 km	8–10 m	8–10 m	10–100 m	30–300 m	10–15 km	5–40 km	10–20 m
Energy Consumption	Medium	Bluetooth: Medium, BLE: Very Low	Bluetooth: Medium, BLE: Very Low	Low	Low	Low	Very Low	Low
Cost	High	Low	Low	High	Medium	Medium	Very Low	Low

- *DDS:* Data-Distribution Service (DDS) for real-time systems is used as a middleware to help real-time publish/subscribe communications in IoT-based embedded systems.
- *LLAP:* Lightweight Local Automation Protocol (LLAP) is designed to facilitate in transmission of short messages among IoT-based intelligent and smart devices.
- *HTTP/2:* It is a recent inclusion in the IoT-based approaches. This protocol is suitable for the disaster management due to its ability to reduce the network latency. It compresses the header-field data and allows parallel data exchanges on the same network.

C. COMMUNICATION LAYER

- *WiMAX:* Worldwide Interoperability for Microwave Access (WiMAX) standard provides data rate from 1.5 Mbps to 1 Gbps. Its recent update (i.e., IEEE 802.16m standard) provides the data rate about 100 Mbps for mobile stations and 1 Gbps for fixed stations.
- *Bluetooth:* It works in 2.4 GHz frequency band. Generally, the concept of frequency hopping is used while communicating with neighbor devices. The maximum data transmission rate is about 3 Mbps and communication range is about 30 m.
- *Eddystone:* Eddystone, which is a variant of Bluetooth, uses Bluetooth low energy protocol to communicate with local beacons.
- *ZigBee:* Zigbee is one of the most popular protocols that are developed based on the IEEE 802.15.4 standard. Its normal range of frequency is 2.4 GHz and data transmission rate is 250 kbps. Moreover, it can use Advanced Encryption Standard (AES)-128 encryption while talking with its peers.
- *EnOcean:* It is particularly suitable for disastrous event management, due to its low energy harvesting feature. Usually, it works in 868MHz frequency in Europe and 315MHz frequency in America.
- *NB-IoT:* Narrow Band IoT (NB-IoT) is the most recent IoT-based communication protocol designed to work in Narrow Band (NB) frequency. It is most appropriate to the 3rd Generation Partnership Project (3GPP) standards, especially Long-Term Evolution (LTE)-Machine Type Communication. It is expected that the victims can be located and further be communicated using NB-IoT in a very efficient manner.
- *EC-GSM-IoT:* ExtendedCoverage-GSM-IoT (EC-GSM-IoT) empowers the existing cellular communication networks to get associated with LowPAN-based IoT applications, such as disaster management. It can be incorporated with the GSM footprint and further extends the current coverage area. This protocol is useful in remote locations where only GSM facility is available in the disaster.
- *LoRaWAN:* LoRa, which is one of the latest line-of-sight-based wireless communication protocols, is preferred for installation in Wide Area Network (WAN) scenario. It aims to provide long-range communication in different terrains. It works in both 868 MHz and 915 MHz frequency range with transmission speed is about 0.3-50 kbps while covering 15 km distance in free space.

D. DISOVERY LAYER

- *mDNS:* Device discovery is important when localizing a victim in disaster. The Multi-cast Domain Name System (mDNS) protocol resolves the issue of converting host names into IP addresses within a small range of the network that excludes a local name server.
- *HyperCat:* In the disastrous situation, to obtain seamless communication, a large number of devices are connected to distributed backbone using their URIs. This protocol provides a lightweight and open-source JavaScript Object Notation (JSON)-based hypermedia catalog to expose the collections of device URIs on the network.
- *UPnP:* Device discovery is essential to establish communication among devices to share data for

strengthening their social relationship. Universal Plug and Play (UPnP) protocol provide a discoverable ecosystem in the network for disaster management systems.

E. SEMANTIC LAYER

- *SensorML:* Sensor Model Language (SensorML) is a generalized approach to provide standard semantic models in terms of XML encoding to describe IoT-based sensors. It can also be used to effectively model the measurement process in IoT system.
- *Semantic Sensor Net Ontology-W3C:* This is designed by the World Wide Web Consortium (W3C). Semantic Sensor Net (SSN) describes and observes ontology of various IoT-based sensors. Upon import of W3C Web Ontology Languages (OWLs), SSN is capable of formulating the following (i) time, (ii) domain concepts, and (iii) locations of the sensors.
- *RAML:* Representational state transfer (RESTful) API Modeling Language (RAML) manages the RESTful API lifecycle. Programmers need to define the elements that are reusable in APIs life cycle.
- *SENML:* In disastrous events, various sensors such as temperature sensor and accelerometer could use Media Types for Sensor Markup Language (SENML) along with HTTP and CoAP to either transmit or configure the measured values and configuration profile of the sensor, respectively.
- *LsDL:* It is another Extensible Markup language (XML)-based smart devices encoding language that is read as Lemonbeat smart Device Language (LsDL). Generally, the IoT-based service oriented smart things (devices) are leveraged with it.

F. MULTI-LAYER

- *Alljoyn:* It is an open-source multi-layered software framework to help smart devices and APPs in discovering as well as communicating among themselves.
- *IoTivity:* This is another open-source project. Currently, it is being hosted by the Linux foundation to leverage multi-layer framework services to its peers such as a Linux-based gateway or computation intensive devices, such as Raspberry Pi.
- *IEEE P2413:* It is a recent IEEE standard. It is designed for disseminating a multitude of architectural framework support to IoT devices and applications.
- Thread: Its ordinal behavior includes the powers of open source technology, IPv6, and 6LoWPAN while providing easy to code and modify its core by leveraging the theoretically large number of device sets and low powered Personal Area Network (PAN) facilities. It is perfectly suitable for IoT-based disaster management tasks.
- *OMA Lightweight M2M v1.0:* Its motivation lies on fast lightweight, and efficient deployment of master/slave architecture among M2M services. Disaster events were distributed devices at a site need to correlate with each other for data and message passing, Open Mobile Alliance (OMA) protocol could be helpful.
- *Weave:* It is a recent inclusion in IoT-based protocols that perform the following tasks as (i) smart device setup, (ii) hybrid mode (phone-device-cloud) communication establishment, and (iii) efficient user interaction in web-based application scenario.

G. SECURITY

- *OTrP:* Trust is a crucial part of managing security configuration in IoT-based heterogeneous devices, particularly, when the system is running in a Trusted Execution Environment, OTrP helps users to configure (such as install, modify, and delete) the devices.
- *X.509:* It is one of the popular security protocols in the domain of public-key infrastructure that manages two main tasks such as (i) public-key encryption and (ii) handling digital signatures. It further integrates transportation layer for secure management of web-based packets and related messages.

III. IoT-BASED COST EFFECTIVE AVAILABLE MARKET SOLUTIONS FOR DISASTER MANAGEMENT

In this section, we present a few examples of IoT-based solutions (both hardware and cloud-based) for disaster management available in existing market (proprietary and test case). Table 3 compares these solutions regarding various design and application perspectives. This comparison presents the current scenario where smart and hand-held IoT-enabled solutions are readily available for the ordinary citizen.

A. BRINCO

It is the first IoT-enabled beacon that is designed to notify its user about possible earthquake or tsunami in personal-aware mode. The sensor system comprises of accelerometer, signal processing unit and audio alarm units. It works as follows. If it perceives a vibration of the ground, it sends this information to the Brinco Data Center (BDC), a private cloud service. This DC assimilates this information with other seismic networks information to obtain its perception. Finally, if the judgment is good enough, it makes alarming sound and sends push notifications to it users smart phone (Android or iOS) instantly. Further, this information can be shared among the local as well as global community utilizing social network sites.

B. BRCK

It is versatile IoT-enabled device meant to be used in poor infrastructures. This gives it power to connect with low connectivity areas where 2G communication still exists. It is also em-powered with its private cloud service where environment data could easily be transmitted and fetched on. It is capable to work with solar energy, hence very much suitable for disastrous sites where flawless power is a main constraint. The rugged design makes Brck the most suitable product to be deployed in disaster management scenario. Users having smart phone can easily connect with it and share the information to other WiFi-enabled local devices.

TABLE 3. Comparison between IoT-enabled disaster management solutions.

Solutions	Repository	Cloud-enabled	APP-based	Key sensors	Communications	Application
Brinco	(brinco-home.com)(Self)	Yes	Yes	Accelerometer	WiFi and BLE	Earthquake and tsunami
Brck	brck.com(Self)	Yes	No	Various	WiFi and GSM, and Ethernet	Various
Grillo	grillo.io(Self)	Yes	Yes	Accelerometer	WiFi and BLE	Earthquake and tsunami
Flood network	flood.network (Self)	Yes	No	Ultrasonic range finder	GSM	Flood
Flood Beacon	floodbeacon.com (Self)	Yes	Yes	Ultrasonic range finder	GSM and BLE	Flood and tsunami
Floating sensor network	float.berkeley.edu (Self)	Yes	Yes	Accelerometer and ultrasonic range finder	GSM, BLE	Flood and tsunami
Lightning detection	Self	Yes	No	Lightning sensor	Radio	Lightning
ALARMS [4]	Self	Yes	Yes	Accelerometer	Radio and BLE	Landslide
MyShake	Self	Yes	Yes	Accelerometer	CDMA, WiFi, and BLE	Earthquake

C. GRILLO

Grillo is an innovative solution to alert vulnerable people about the possible hit by any seismic wave, i.e., earthquake. It is purely an APP supported product that need to installed at users living or working area. It is generally connected with Grillo Sensor Network, a proprietary network of Grillo devices (currently in Maxico). Whenever, Grillo senses an abnormal vibration on ground it immediately contacts with its own sensor network to get verified about. Upon successful verification, it generates an alarming sound, push notifications to local users and sets up a timer to hit counter.

D. CITIZEN FLOOD DETECTION NETWORK

It is an open crowd-sensing IoT-enabled infrastructure that is connected to flood sensing nodes around the globe. However, presently, this facility is implemented in Oxford floodplain. The current design of the node comprises of Raspberry Pi, ultrasonic range finder, and router. The node, which is usually deployed under the river bridge, measures the water-level at every five-minute interval. The data is then transmitted to the mapper-service of the remote cloud located at http://map.flood.network for real-time monitoring of current flood contexts. If water-level exceeds the predefined safety level, the map changes colors (e.g., yellow and red). At the same time, the notifications are also sent to the local control center and connected people over the Internet.

E. FLOOD BEACON

Flood beacons are designed to broadcast the current water-level and its location with a sudden change of its behavior over the Internet. Mainly, this beacon assists in flood as well as tsunami monitoring in real-time. The floated beacons over the water body monitor the level of water. Upon the rising beyond a threshold level, the push notifications are sent to the person in danger. The overall information of water body is stored in remote IoT cloud, named Xively, for further processing and analysis.

F. FLOATING SENSOR NETWORK

A recent advancement at UC Berkley has opened a new paradigm of gathering information about flood situation of a river using their floating product. The portable and cost effective floating object carries Global Positioning System (GPS) sensor and acceleration sensor. Up-on sudden rise or gradual change in water is monitored by floating object and instantaneously sent to the nearby people through web as its alerting act.

G. LIGHTING DETECTION

Heavy lightning may kill human lives. Every year, lightning takes around 24, 000 lives of people in the world [3]. To counter this natural phenomenon, an IoT-based lightning detector is developed [3]. Raspberry Pi-assisted such lightning detector is equipped with a lightning sensor that can sense small change in gamma blast (happen in heavy lightning) from 40 km away. This system transfers the lightning data, if any to the remote server in every 15minute. At the same time, the system can minimize the false lightning/high energy signals (due to human, animal or other reasons) to accurately identify the event. The information is instantaneously sent to the local people over Internet connection for their safety.

H. ALARMS

Recently, the British Geological Survey has released an application, called as Assessment of Landslides using Acoustic Real-time Monitoring Systems (ALARMS) to provide the information about early warning for landslide in the deployed areas [4]. To obtain slope instability, an accelerometer-based sensor system is deployed over the slope region where landslide is evitable. Based on the movement and density of ground, an early warning is sent to its periphery.

I. MYSHAKE

It is an APP-based service for the detection of seismic activities. This APP has initially to be installed on users smart phone which whenever perceives a ground vibration through the phones accelerometer, performs a match operation with the vibrational profile of the quake. If matched, the information along with the present GPS coordinate (received from the smartphone) is sent for analysis to the Berkeley Seismological Laboratory (BSL) for final check. This has opened a way to develop a cost-effective, distributed and crowd sourced quake monitoring system that is obviously a demand of time [5].

Following study is based on several disaster management aspects which are concentrated on service-specific disaster management, volcanic, flood, forest-fire, landslide, earthquake, urban, and industrial. Victim localization and positioning is also investigated in this section. Finally, terrorist attack and its management related works have been discussed. Table 4 summarizes some of key works from the below into four categories such as: (i) IoT-based architecture, (ii) cloud enabled, (iii) technical novelty, and (iv) deployed applications.

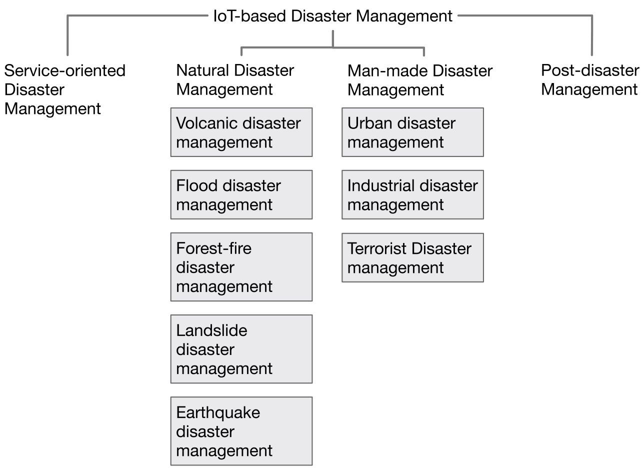

FIGURE 2. **Classification of IoT-based disaster management systems.**

IV. STATE-OF-THE-ART IoT-BASED APPLICATIONS FOR DISASTER MANAGEMENT SYSTEMS

This section provides the ongoing research works to cater the integration of IoT with the disaster to management systems. We classify the disaster management systems based on the application point of view as follows (i) service-oriented, (ii) natural, (iii) man-made, and (iv) post-disaster management systems as shown in Fig 2. The natural disaster management includes volcanic, forest-fire, flood and, earthquake, whereas the man-made disaster management systems mainly consider the urban and industrial disaster and terrorist attacks. Finally, the post disaster management systems mainly focus on victim localization and positioning.

A. SERVICE-ORIENTED DISASTER MANAGEMENT SYSTEMS

While looking at novel integration techniques for disaster management, Crowd Sourcing (CS) is the key enabler in this field which has recently been investigated to accommodate with IoT [6]. The corresponding authors have formulated into the Crowd Sourced-IoT (CS-IoT) framework to find answers to the following research questions, such as (i) what the enablers are for the CS that may guide disaster response, (ii) what the enablers are for IoT as key technology, and (iii) how CS and IoT can be integrated to leverage this issue.

Similarly, semantic integration approach is presented in [7] where researchers have paved IoT-based Early Warning System (IoTEWS) to cater the environment disaster risk and effect management in an efficient way. In this work, ''heavy weight semantics'' are put upon the top level ''W3CWeb Ontology Language''-based ontology models to augment the following: (i) descriptions of the multi-leveled knowledge-bases, (ii) semantic-driven decision support, and (iii) orchestration for the underlying workflow.

Gautam et al. [8] designed a novel master-slave architecture-based system ''Tensai Gothalo'' to control the large-scale network fault to guaranty the robustness, network stability, ensure disaster readiness, and assist the network administrator in the decision-making process. A novel algorithm for fault restoration in the network, in conjugation with IoT, has also been proposed and validated in this experiment. Post disastrous situation is key for the relief of the living ones. But, food and other necessary consumable items become very difficult to be handed over topology the victims of the disaster. Notably, three types of discrepancies do facilitate this unreachability including (i) lack of prior knowledge of demands to suppliers ratio, (ii) difficulty of sorting, packaging, and packing of relief materials, and (iii) optimal storage strategy at the delivery time. To cater this problem, a novel cost-efficient and sustainable system under *evacuee support*-mode is proposed and implemented where traceability is given priority as the crucial maker of the whole process [9].

It is always better to be aware rather than be cured after an emergency. The IoT-based Safe Community Awareness and Alerting Network (SCALE) is a similar platform with cost effective sensors, actuators, and microcontroller [10]. The main purpose of SCALE is to provide an alarm when it detects such prospective act of nature. This work proposes the Data in Motion Exchange (DIME) platform that is designed to allow heterogeneous integration of devices (and services) to publish/subscribe to any other data feed (see Fig 3).

Real-time stream processing may be helpful for providing network services to the disaster affected people. But, inefficiencies in spanning memory, scheduling algorithm, effective networking, and stream processing kernels cause high throughput in stream-processing. To solve this problem, ''NEPTUNE'' is proposed that reuses of objects that in turn performs memory swapping, page faults, and thrashing functionalities in a stabilized mode while throttling up the earlier stages in the processing pipeline [11].

Lack of well-equipped and connected infrastructure in a mass casualty scene may lead to misdirected and delayed triage of scene-wide critically injured patients, for instance, when the area is large enough where a huge volume of victims

TABLE 4. Comparison between IoT-based disaster management schemes.

Article	IoT Architecture	Cloud-Enabled?	Feature	Focus	Application
Bolton [14]	Yes	Yes	Machine Learning and AI-enabled	To incorporate IIoT platform in prediction of volcanic eruption	Volcanic
Morra [15]	Yes	Yes	WSN is enacted with IoT	To leverage Chirp Spread Specturm in long long radio communication	Volcanic
Kim et al. [39]	Yes	Yes	GIS incorporated	To provide decision support and damage prediction measures	Volcanic
Ancona et al. [39]	Yes	No	Scalable, Reliable and Efficient design	To integrate intelligent WSN with IoT in efficient, reliable and scalable way	Flood
Kumar et al. [18]	No	No	M2M and ultra-low power processing	To develop low-cost sensing platform to alert people by instant messaging, audible sound, and social network	Flood
Hernández-Nolasco et al. [19]	No	No	Netduino Plus 2-based integration	To integrate WiFi with developed system in monitoring of water level	Flood
Shalani et al. [20]	Yes	Yes	Early detection SMS service	To facilitate messaging system to warn people	Flood
Lo et al. [21]	Yes	Yes	CCTV enabled and machine learning-based visual monitoring	To automate and process real-time flood monitoring using image processing	Flood
Alkhatib [23]	Yes	No	Forest Weather Index	To decide on forest-fire event using threshold-based sleep/wave algorithm	Forest Fire
A. Herutomo et al. [24]	Yes	Yes	OpenMTC and M2M communication	To provide HTTP RESTful M2M communication among distributed sensor nodes	Forest Fire
Ramesh et al. [26]	Yes	Yes	Rainfall induced land slide management using INSAT 3A satellite	To measure, monitor and manage local data by satellite links	Landslide
Jones [27]	Yes	No	Precise detection of landslide using acoustic sensor	To measure 20-30 KHz sound frequency by lowering its attenuation	Landslide
Mali et al. [29]	Yes	No	Accelerometer and HSPDA modem	To collect, aggregate, and analyse disaster data	Landslide
Inoue et al. [30]	Yes	Yes	Bypass network-based NerveNet	To provide topology independent highly resilient data transfer facility	Earthquake
Alphonsa [31]	No	No	ZigBee and PIC microcontroller-based early warning system	To measure and warn people about the P-wave and transverse S-wave	Earthquake
Nan et al. [54]	Yes	No	Novel system model	To provide solution for scheduling unified management, tracing of resources	Earthquake
Chi et al. [33]	Yes	Yes	Session Initiation Protocol	To develop a system for providing early warning using multicast messaging in peer to ISP facilitator	Earthquake
Benson [34]	Yes	Yes	SCALE framework	To provide scalability into highly resilient multiprotocol data transceiving	Earthquake
Spalazzi et al [35]	Yes	No	SSN based Earthquake Emergency Management	To sort out scalability, heterogeneity, conflict resolution, and metadata handling in an ontology-based infrastructure	Earthquake
Zelenkauskaite et al. [53]	Yes	No	Social awareness	To predict disaster situations by dynamic categorization and recognition of objects social behavior	Urban disaster
Tan et al. [54]	Yes	Yes	Urban underground business ecosystem disaster management	To develop underground safety management and support system for business ecosystem	Urban disaster
Chatrapathi et al. [55]	Yes	No	VANET-based accident monitoring	To design aframework for prediction of accidents, avoidance of accidents, alerting medical responder team in a VANET system	Urban disaster
Gallego et al. [42]	Yes	No	Micro drone-based monitoring	To locate gas leakage by adaptive and high resolution mapping while using micro drones	Gas Industry
Juli et al. [44]	Yes	No	Fault diagnosis system model	To facilitate an architecture for efficient knowledge engineering and multiple information sharing in online fault diagnosis for process industry	Gas industry
Yu et al. [46]	Yes	No	Safety monitoring	To design a cross platform information system that counters heterogeneity, user experience and business expansion in one go	Coal mines
Soni et al. [64]	No	No	SVM classifier and FastSLAM	To transmit relayed information about a trapped victim in a disaster site toward the receiver of the rescue team using Robots	Localization
Liao et al. [66]	No	No	K-out-of-K fusion rule	To regain the unknown fade signal corrupted by Gaussian noise to recover the victims	Localization
Manaffam et al. [31]	Yes	No	RFID clustering	To communicate with nearby things using RFID in terms of unknown position of both the tag and reader	Localization
Vermula et al. [69]	Yes	No	Fusion Hybrid rule	To adopt RFID readings in situations where RSSI-based signal strength measurement technique fails	Dynamic Localization
Hooi et al. [70]	No	No	Adaptive Signal Thresholding	To select the appropriate signal source-based on ther dynamic weights when a victim moves from indoor to outdoor or in opposite direction	Localization
Jayasumana et al. [71]	Yes	No	Topology Preserving Map	To estimate Topology Preserving Map from litte and unknown virtual coordinates	Localization
Chen et al. [72]	Yes	No	FM integration	To perform cross correlation between the narrow band and distorted sound signals so as the victim could be localized	Localization

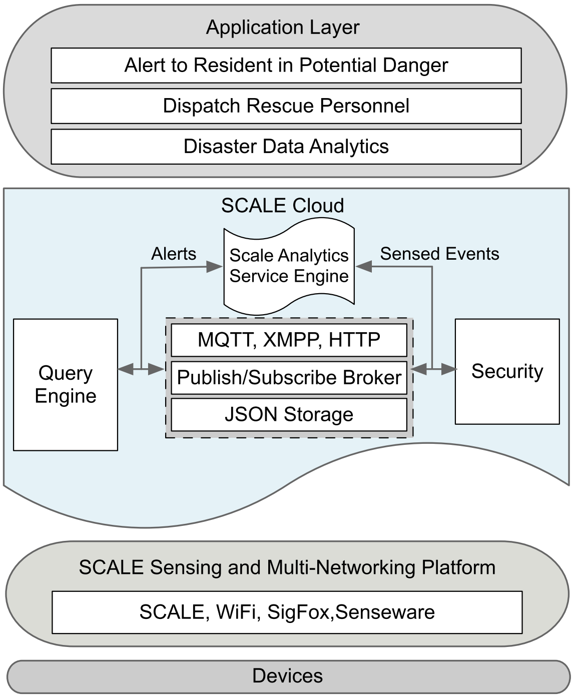

FIGURE 3. Communication between the SCALE and DIME.

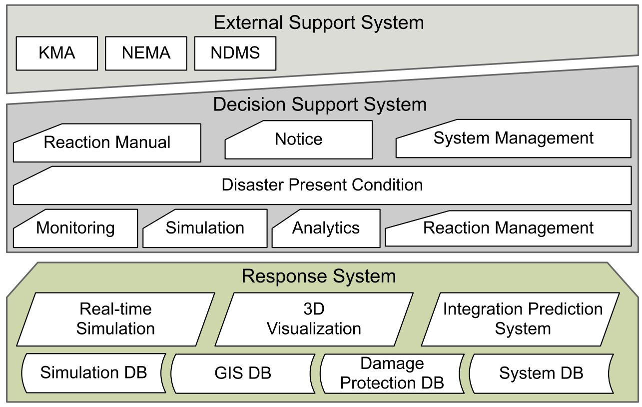

FIGURE 4. Working model of a volcanic disaster response system.

needs different medical care. Panaceas IoT-based Cloud is the appropriate solution to this problem that includes display panels, virtual beacons, and QR-code cards. This wireless mesh network is capable of coordinating and co-operating multiple affected areas at once with the help of a *responder theater*-based Incident Command System (ICS)-enabled dashboard [12], [13]. Panaceas IoT-based Cloud is built upon the principle of distributed augmented reality to facilitate the disaster communication management efficiently.

B. VOLCANIC DISASTER MANAGEMENT

Volcanic eruptions took millions of lives in last century. Industrial approaches are indeed necessary in this regard. In the latest research, a novel sensor system (based on Libelium platforms) is being built employing the Industrial IoT (IIoT), especially by General Electric, on and around the Masaya Volcano in the Nicaraguan. This research aims to design a digital early warning system to predict the volcanic eruptions. More than 80 IIoT-enabled sensors placed inside the crater and remotely located cloud services altogether give this system the capability to monitor the volcanic activity and predict the eruption of dead time. Machine learning algorithms and artificial intelligence are currently given preferences to discover the suspicious patterns in the volcanic activity. This is truly the first IoT-based volcano monitoring project being governed in the world [14].

Japan is also conducting the similar experiment to predict and monitor sudden eruption in 47 different active volcanoes utilizing gathering a vast pool of data used through deployed WSN where IoT is acting as the backbone [15]. The sensors of this systems are designed to monitor (i) several Volatile Organic Compound (VOC) emissions, (ii) topography changes in geolocations, and (iii) vibrations in the surrounding air which are caused by the spewing rocks and ashes from the volcanoes. The Korean researchers have developed a volcano disaster response system using Geographic Informatics System (GIS) with IoT. Fig. 4 illustrates the underlying working model of the volcanic disaster response system [16]. The proposed system uses a GIS DB, Spring MVC, Spring iBatis, and PostgreSQL to monitor, predict, notify, and manage response manuals in a web portal.

C. FLOOD DISASTER MANAGEMENT

Flood is one of the most common disastrous events that take place in different countries every year around the globe. IoT has been able to be applied to save the livelihood among flood affected areas in recent times. Ancona et al. accumulate IoT-based flood monitoring research in terms of efficiency, scalability, and reliability [17]. It further investigates the M2M and ultra-low power processing architecture for better dissemination with flood monitoring purpose.

An integrated weather and flood detection and notification system are also proposed where audible alarms, Short Message Service (SMS)-based notification, web portal-based visualization, and status of the flood situation is facilitated [18]. A Netduino Plus 2-based water level mentoring system is recently designed to measure the water level in a river, pond, lake, and lagoon [19]. The developed system uses water level sensor to estimate the depth of water bodies by incorporating IoT as an essential tool where the information about a level of water is sent to a local machine through the local WiFi. The received information on the local machine can be obtained by any smart phone and other digital devices. A recent experiment shows how cooperative flood monitoring and early detection service can be leveraged using IoT, Global System for Mobile communication (GSM) and SMS [20]. Designated MCU ARM7LPC2148 is employed against GSM and several water sensors that in turn notifies the local network about the possible occurrence of a flooding event.

Lo *et al.* [21] have employed a novel mechanism for dissemination of prior flood status using Closed-circuit television (CCTV) and IoT. Fig. 5 presents the idea behind the

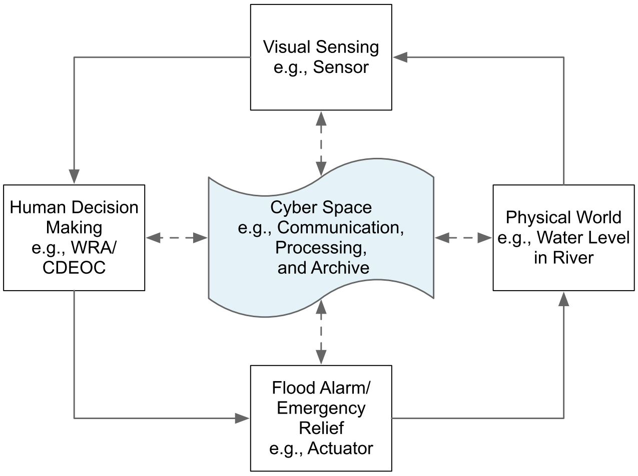

FIGURE 5. Visual flood monitoring system.

visual flood monitoring where CCTV cameras capture real-time image from the river and send the images to remote machines where machine learning algorithm decides about the flood status and water level in the river. If level crosses the threshold alert is given in form of alarm as well as push-up notifications. The flow chart of the visual flood sensing is described as follows. Initially, images are captured in the remote IP enabled CCTV cameras, later-on, real-time feed and virtual markers are added on to the images, it is followed by event-based visual sensing, that is logged as floor risk and water level estimation. Finally, the fluctuation level is recorded and seamlessly posted over the system. The event-based triggering mechanism is performed in two steps as firstly, an image parser processes all the noises from an image and ordinarily marked and set up for further feeding; secondly, an algorithm searches for the availability of water using the proposed approach.

D. FOREST FIRE DISASTER MANAGEMENT

A forest fire is one of the most ancient mishaps taking place on the earth. Recently, several destructive incidents happened, for instance, seven people died in Uttarakhand, India forest-fire where 4,048 hectares forest were burned. More incidents are also regularly taking place around the globe throughout the year [22]. This is obviously a serious concern where the IoT has already been applied. Forest Weather Index (FWI) is the key to in this involvement. A novel FWI algorithm is proposed in [23] using sensors with WSN taking the Internet as a backbone, to determine and make decisions over the occurrence of forest-fire. Moreover, camping fire, slow propagation, medium propagation, shadow detection, etc., all types of solutions have been investigated in this article.

Another research shows the advancement of this approach while utilizing the Open Machine Type Communication (OpenMTC) platform. OpenMTC is an open source and cloud-enabled platform to carry out research activities in IoT incorporated M2M communication. OpenMTC has been used to detection forest-fire [24] by allowing the sensed data into the Gate-way Service Capability Layer (GSCL) directly employing Arduino, DHT11 sensor, LM35 sensor, and MQ 7 (Carbon Monoxide gas sensor) over the Internet. The received information at GSCL is viewed in real-time and is further analyzed. Fig. 6(a) presents the OpenMTC architecture in detail whereas Fig. 6(b) presents the interface between GSCL and Network Service Control Layer (SCL) layers.

A much improved and widely formulated version of early warning cum detection of forest-fire using IoT is discussed in [25]. Motivated by the enormous number of causalities occurred in Greece and California in 2007 (more than 94 people died and about 1,170,000 acres area) an international level project 'DIMAP-FactorLink' was initiated to design environmental monitoring infrastructure, in particular for a forest-fire scenario. The project utilized 'Libelium' platforms along with several temperatures, humidity and gas sensors to automate the process of notification and visualization on a web portal.

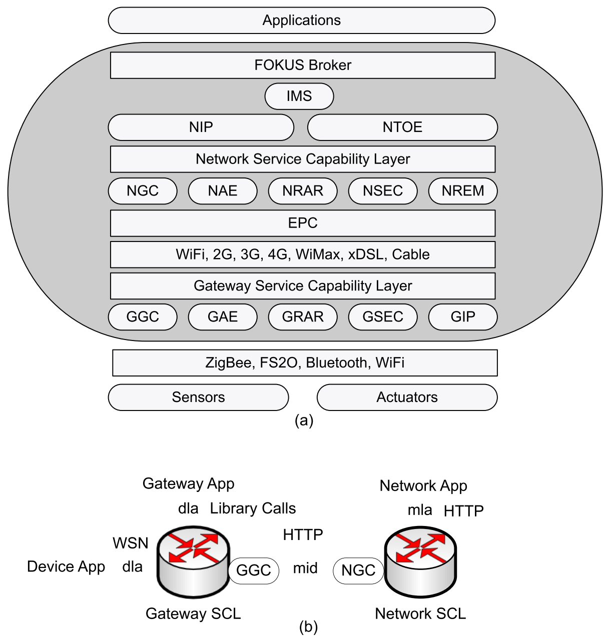

FIGURE 6. (a) Overall OpenMTC architecture. (b) Interface between GSCL and NSCL (courtesy: www.openmtc.org).

E. LANDSLIDE DISASTER MANAGEMENT

Landslide typically occurs after either rapid deforestation or earth quake followed by heavy rain in short duration of time. For instance, in recent times, few casualties have been reported due to repeated landslides in Sikkim, a hill state of India. An excellent demonstration is carried out at Bidholi, Dehradun, India, by incorporating tilt sensor, pressure sensor, moisture sensor, geophone, and strain gauge along with Arduino. The moisture level and real-time soil tilting information are sent and received by the ZigBee-based transceivers. Ramesh [26] performed a similar approach at Idukki district, Kerala, India, where rain fall induced landslide was monitored. The sensor column with pressure, tilt, geophone and strain gauge sensors were distributed over the test field. The standard consensus value after the reception at the Field Management Center (FMC) is processed and retrieved by the intervention of INSAT 3A satellite at the remote Data Management Center (DMC). The MicaZ sensor nodes were deployed over the entire zone. A report on precise land sliding is obtained at Loughborough University [27], where the acoustic sensor is embedded with the designed system. At the rate of 20–30 THz, the acoustic signals are sent into the soil, and reflected signal strength gives the high accurate reading in terms of millimeter shift per day.

Another approach uses the topographical information to cater the prior knowledge of a landslide using the geographically distributed network of web-sensors utilizing the Internet as the backbone [28]. This network shares real-time information on the landslide to trigger respective notification and messaging events. Three basic types of sensing cum communicating devices (accelerometers, High-Speed Downlink Packet Access (HSDPA) modem, and GPS module, etc.) have been incorporated in the study. Use of accelerometer in a detection of landslides is also investigated by Mali and Kumbhar [29]. The actual representation of the laid architecture behind this approach uses ZigBee-based sensor nodes to collect the information about landslides in the test area and transmit to its neighbors. The overall activity of the system is remotely accessible with the intervention of General Packet Radio Service (GPRS)-based SMS services.

F. EARTHQUAKE DISASTER MANAGEMENT

Earthquake is one of the natural events that occur almost every day in different parts on the earth. It causes millions of people die and homeless. The latest event was recorded in Nepal in April 2015. It took nearly 9,000 human lives and injured more than 22,000 people [1]. Nevertheless, researchers are consistently engaging themselves to design and develop novel forms of IoT-based systems that may help to notify the prospective remotely located victims before the incidence takes place. 'NerveNet' [30], implemented at Onagawa, Japan, is one of the most recent advancements toward the IoT integration with earthquake monitoring. It is based on the concept of *bypass network* which is proven to be disaster-resilient. This network is geographically distributed over several kilometers of a region where local and remote communications take place by involving WiFi, satellite, optical Ethernet, and Unmanned Aerial Vehicle (UAV) as shown in Fig. 7.

Nevertheless, the success of any earthquake related system depends on its prior knowledge sharing. An IoT-based early warning system is designed in [31] to cope up with this issue. The proposed system is built on top of ZigBee communication where PIC microcontroller does all the necessary computation-intensive works. A few number of accelerometers collect the raw vibration data from different places on the ground and assimilate together at the server-end. Then, if the gathered measurement is above the threshold level, the system notifies all the nearby people about the possible danger

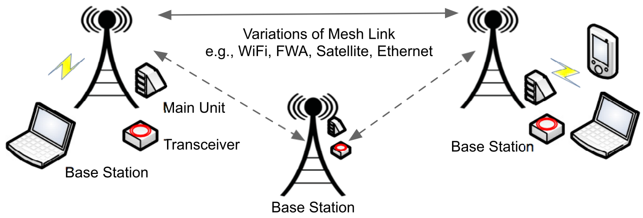

FIGURE 7. Architecture of NerveNet.

of an earthquake. Furthermore, the earthquake information needs to conveyed and analyzed for further processing and inference of knowledge. To this end, Wu et al. [32] proposed an IoT-based system model to leverage the earthquake information for the better purpose of its understating.

A novel multimedia multicast-based algorithm is proposed in [33] to notify about the earthquakes in parallel at the same time interval. This algorithm relies upon the Session Initiation Protocol (SIP), which allows high reliability at message distribution activity with the IoT-enabled devices. Moreover, resilience is another crucial factor that requires a grave concern. To pursue this objective, a novel Safe Community Awareness and Alerting Network (SCALE) architecture is proposed in [34]. It utilizes the classic *observe-analyze-adapt* loop to communicate in resilient mode, earthquake data exchange, and service execution. In addition, the IoT ontology-based Earthquake Emergency Management (EEM) has also been devised to manage the devastating scenario [35]. In this case, two types of key features such as interest and properties are used to disseminate the ontological structure. The EEM is proposed to cater the following parameters of semantic IoT such as (i) scalability, (ii) broad heterogeneity, (iii) incomplete meta-data, and (iv) conflict of resolutions.

G. INDUSTRIAL DISASTER MANAGEMENT

Industrial disasters can be massive enough to grab human lives as well as to damage the economic condition of workers, factories, and government. The risk becomes higher with gas, coal, electrical, and oil industries [36]. This section describes the involvement of IoT to handle the disasters in some of these industrial sectors.

The design for detection and monitoring of toxic gases [37], [38] is a major concern in the gas generation facilities around the globe. A simple client-server-based system model using Raspberry Pi is proposed in Korea to identifying any hazardous gas in a gas factory [39]. A similar approach is observed in [40], where AT Mega32 has been employed as sensor node. This node is equipped with a platinum micro-wire to detect dust particles in a gas leakage. This IoT-supported sensor node is connected to the remote user with ZigBee to monitor the gas leakage in its vicinity. Industrial gas repairing work takes a lot of manpower and time. However, this process can be automated with the help of IoT [41]. To send the detected gas via Internet, ZigBee and JenNet communication paradigms are exploited. A recent methodology presents the usage of micro-drones to assist in gas leakage detection in an industrial area [42]. The proposed system primarily identifies Nitrogen Oxides (NOx) and Volatile Organic Compounds (VOCs) in gases. In addition, the overall network is connected with the GSM module.

Furthermore, safety management is very crucial for the oil depot. In this case, a safety management system must ensure all the real-time monitoring facilities. A similar system has been designed in [43] based on Radio Frequency Identification (RFID) tags, Virtual Private Networks (VPN), and the Internet. A fault diagnosis model is leveraged to pursue the safety in the industries [44]. The main contributions are as follows: (i) inclusion of IoT, (ii) applicable in processing industry, multiple information collection, and (iii) knowledge sharing. Meanwhile, smoke and LPG gas detection [45] have been made easier using Texas EZ430-RF2500 wireless module.

As mishaps take place regularly in different coal mines around the world, safety in the coal mine industry becomes most essential. The disaster happens mainly due to power fluctuation, fire from organic gases, underground water intrusion, etc. As an example, Chansala mining disaster is one of the worst incidents took place in recent times in India. More than 300 people including the miners died due to flooding in the mine. Several solutions are being sought where IoT is given full consideration. Yu et al. [46] proposed a cross-platform coal mine mobile information system to navigate the internal condition using multi genres of mobile platforms. A knowledge and reasoning-based information sharing structure are further investigated where automation, intelligence, and standardization of monitoring technique are specially nurtured [47]. A closed loop intelligent and management system has been proposed based on IoT [48]. This hypothetical system monitors electro-mechanical equipment in a coal mine while employing integrated production control system with the GIS. Industrial threats may arise in multiple forms as mentioned in this section. A generalized approach is observed in [49] where a collective motion is obtained by Arduino as a key communicator between the sensors and users.

Natural disasters (like hurricane and storm) often destroy high tension voltage lines. IoT is a key tool to monitor such obligations that restrict smooth flow of electricity through these lines. Shen and Cao [50] proposed a technique to keep eye on the transmission of current in electric grid in China. This research investigates the feasibility issues with GPRS and fiber optic-based communication channels to transmit real-time data over Internet. Accordingly, IoT-supported power generation facility is another avenue of this research. A recent article presents the location-based power facility management system that uses augment reality on smart phones. The actual power transmission rate is visible on managers mobile phone by means of Internet [51].

H. URBAN DISASTER MANAGEMENT

The disastrous incidents in urban areas have recently gone up on the list of mishaps. Mainly, urban flood, massive accidents, construction accident, and unauthorized movement of air vehicles are frequently observed. The risk factor becomes higher when this kind of disaster is related to any smart cities as the maximum coverage area in the smart cities are totally equipped with digital infrastructures.

In this context, a novel technique gives a way of monitoring every sort of dangers associated with its periphery [52]. The proposed system uses WiFi as key communication enabler among the devices and citizen. When any mishap (e.g., fire, flood, and poisonous gas) occurs, the proposed scheme immediately sends the information to local people. Nevertheless, social awareness is being considered as a key tool to network among the IoT-enabled things (e.g., people and smart devices) for prospective disaster management in urban areas [53]. A generic profile of recognized and categorized objects properties (transient and dynamic nature) is exploited in urban society. The persistent and temporal relationships are formulated between the objects to aggregate its common nature in dynamic dimension.

The urban underground business ecosystem is gradually taking its speed. Researchers at China have investigated on the logical and feasibility aspects of improvement of such concept into reality. The IoT is at this moment chosen as the backbone of the whole infrastructure [54]. After solving of several identified challenges, it is hoped that IoT shall leverage the underground business city equally important to its parallel competitor smart city above the ground. Accidents in urban regions are common. A recent literature [55] expedites the design of monitoring and alerting process in this regard. A novel concept utilizing Vehicular Ad Hoc Network (VANET) is comprised of all forms IoT-enabled technologies to monitor and alert the emergency services after any accident. It includes a traffic planner and route optimization algorithm. Finally, the accelerometer and the GPS-enabled test circuit shows its efficiency in the above context.

I. TERRORIST ATTACK MANAGEMENT

Terrorism becomes one of the human-made disasters [56]. Thus, effective techniques are required to combat and rescue the victims of a terrorist attack. An IoT-based architecture is proposed in [57] (see Fig. 8) to predict terrorist attacks in urban locations. This architecture includes a Terrorist Reasoning Kernel (TRM) that consists of several reasoning modules such as Long Term Reasoning module (LTR), Medium Term Reasoning module (MTR), and Short Term Reasoning module (STR). It mainly aims at predicting possible terrorist attacks with essential requirements regarding actors and users of the system. It further considers the information that comes from Event Identification and Formulation (EIF) module in the form of sensors (where the human can also act as a sensor). These detected events are treated as input to suspicious activities that help in taking predictive measures for setting alert levels at specific locations. At the same time, lack of trustworthiness among the local officials is one of the main causes of terrorism. Guo et al. [58] proposed Trust-as-a-Service (TaaS) for IoT to provide more accurate,

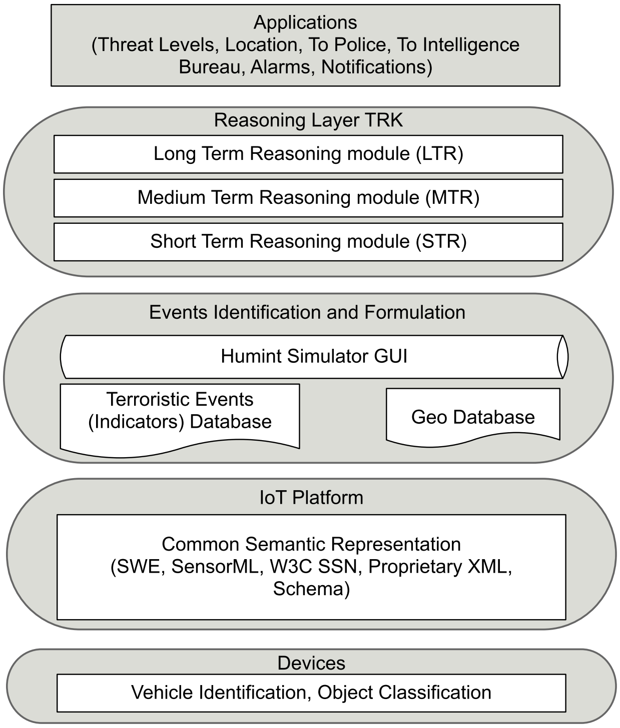

FIGURE 8. IoT architecture for prediction of terrorist attacks in urban area.

resilient and convergent way toward filtering untrustworthy elements from the sensed information. These IoT cloud-assisted services assimilate scalable and P2P-distributed trust protocols to help in its decision-making process regarding the fast and accurate response. Crawling into the terrorists web sites would be a practical approach to estimate the prospective behavior of frequent users. Advanced Terrorist Detection System (ATDS) [59] is an application that mines users data transaction-related information from the 'suspicious sites and arranges them using the respective vectors. Afterward, such cluster-specific terrorist representations are fed into the content detector that notifies local authority about predicted terrorism based on its preset threshold values.

J. VICTIM LOCALIZATION

Efficient localization and positioning system are essential for the safety of victims in a disaster [60]. To this end, Micro Air Vehicle (MAV) is one of the efficient approaches in a disastrous scenario. The MAVs can locate a victim with the help of an attached microphone. Basiri et al. [61] applied this concept to track victim. Four microphones are mounted over the MAV and perform particle-filtering on the received audio signal. Doppler shift in the sound and aerial dynamics assist the MAV to track the victim accurately. Since IoT devices are easy to get tagged, an approach for efficient localization is presented in [62]. The localization process is performed as follows: (i) two neighbor devices in Location-of-Things (LoT) tag each other by Two-Way Time-of-Arrival (TW-ToA) protocol, (ii) based on the audibility, a Maximum Likelihood Estimation (MLE) algorithm is used, and (iii) finally, the comparison is made by the Cramér-Rao Bound (CRB) method.

Furthermore, the wearable devices are used to identify victim's indoor location. A Wearable Indoor Localization Approach (WILA) is presented in [63] where hip and leg angles are used to estimate and predict the movement and location of the victim. Particularly, it estimates the walking ability of the victim. Another localization approach is discussed in [64] which has three key components as: (i) victim detector, (ii) a human-robot interaction component, and (iii) detection history component. The process is formulated by two ways as: (i) using a Histogram of Oriented Gradients (HOG) feature extraction techniques on Support Vector Machine (SVM) classifier and (ii) Deformable Part Model (DPM) body parts detector on Fast Simultaneous Localization and Mapping (FastSLAM) plan.

Digital Mobile Radio (DMR) is an another emerging approach to detect cognitive signs among human. In addition, Multi-function IoT (Mi-oT) platform is developed to manage the cognition using Ultra Wide Band (UWB) radio shields [65]. At the same time, the signal of a mobile phone can be important to track a victim in the disastrous situation. A novel fusion rule algorithm that is based on AND-fusion and OR-fusion rules is proposed to efficiently sense the energy spectrum transmitted from a victim's mobile phone [66].

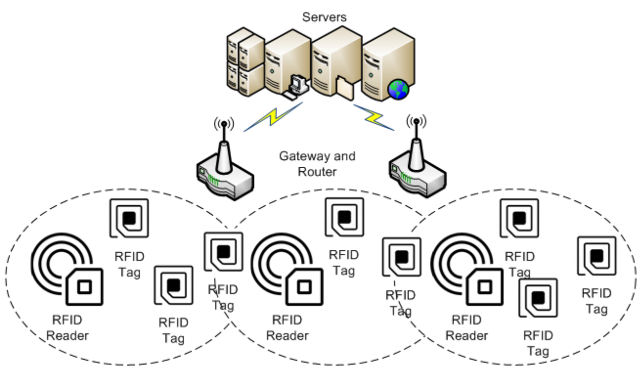

FIGURE 9. RFID-based victim localization.

Moreover, a RFID-based localization algorithm [67] is presented for IoT devices. The system declares an analytical bound on the estimated number of IoT-devices to the RFID readers. Fig. 9 presents the overlapping of RFID range with a server and tag-enabled IoT devices. A similar solution is discussed in [68] where the proposed RFID system is calibration-free and infrastructure-less. It can easily locate a victim from a distance about 20 ft. In addition, Received Signal Strength Indicator (RSSI)-based localization technique also a critical approach to find the victim [69]. When a victim is moving from indoor to outdoor or vice-versa, a new type of solution is required to handle the dynamic location of the victim. An enhanced mode of Fusion Hybrid (FH+) algorithm is proposed in [70] to detect the victim. Basically, this algorithm employs Adaptive Signal Thresholding (AST) to accurately locate the victims' position.

A topology-based approach is proposed in [71] where multiple Topology Preserving Maps (TPM) are extracted from the anchor-based Virtual Coordinates (VCs). In this case, the virtual-geography is useful to detect the victim. When the smartphone and other devices are unable to send SOS messages such as SMS, Frequency Modulation (FM) could be an alternative solution. A Morse Code-based SOS Message Broadcasting System using FM transmitter (MCSOS-FM) is discussed in [72]. Furthermore, this system is capable of getting associated with available Internet.

V. CHALLENGES AND FUTURE DIRECTION

The existing solutions mentioned in the earlier section deal with the managerial, monitoring, analysis, and predictive aspects of various disasters. Although, many efficient approaches smoothly aggregate major issues in disastrous events, further improvement and enhancement are essential in different technological and design perspectives. This section outlines main key challenges with current IoT-based solutions for the disaster management systems.

A. CHALLENGES

1) COST EFFECTIVENESS

Researchers around the world are mainly focusing on the reduction of hardware and software costs in IoT deployments while maximizing the system output. It is assumed that disaster management is a life-saving task. Hence, international farms should consider the development of cutting edge technologies in this regard, to bring down the cost further. Presented works do not involve cost effectiveness in their design part. Hence, such point is deliberately the need of time.

2) STANDARDIZATION

Current works do not conform to the standardized format of representation of data as well as the process. Although it is understood that different kind of disasters needs vertical silos of solutions, standardization may, on the other hand, be difficult to assimilate in this form. However, security standards, communication standard, and identification-standard are three key portions of this challenge that needs to be evolved with the spread of IoT technologies while designing emerging technology at a horizontal equivalence.

3) CONTEXT AWARENESS

When billions of sensor-enabled things are connected to the Internet, it may not be feasible for the user group to handle all the collected data in one go. Context-awareness based techniques need to be used in a better way to help decide what data needs to be processed. As mentioned earlier, the disaster-related tasks are void of context awareness. This seems to ascertain the negation of information validation in form of continuous disrupted process. The surrounding environmental parameters and self-assessment may transfer the localized context to others while making a well-connected self-cum-periphery-aware IoT ecosystem.

4) MIDDLEWARE

Most of the presented works follow their respective silos designed for the sole purposes. A generalized disaster management oriented middleware could hereby provide a common platform to achieve the specific goals incorporating multi-localized (i.e., geographically distributed) modules within a tenant. Middleware paves the horizontal flow of information among the devices, protocols, and disaster centric applications with respect to itself. These disaster-specific-applications can also be performed over the whole data set and query is processed on the connected devices in a distributed manner.

5) FAULT TOLERANCE

Fault tolerance is one of the most important issues that is absent in the earlier solutions. To make a flawless system, the fault tolerance level of a system should be kept very high so that despite any hardware or software issues (i.e., low battery signal, memory crunch due to dynamic paging, repetitive pooling and interrupts from sensors, sudden rise in current, etc.), the system must keep working. The hardware modules may fail due to the depleted battery or other reason. Similarly, the generation of erroneous value by a sensor, faulty calibration, and failure in communication may develop a faulty situation. Use of myriad communication protocols may increase the power consumption but always provide seamless connectivity. Power-consumption in such case may be lower down by enacting one protocol to get activated at any instance. Proper calibration needs to be done before final installation. Besides power consumption, rigid sensor design is another inclusion. The casing or fabrication of sensors shall be done in the pre-disaster mode so that hurricane, flood, or earthquake have less impact on it, resulting in effective information fetching.

6) DATA ANALYTICS

This is the bottleneck of existing disaster-oriented IoT solutions. Based on the characteristics of disastrous problems, the developed systems should analyze spatial-temporal datasets that are accumulated from various disaster sites at different point of time. This is even difficult when semantics, formats, sizes, and contexts are uneven in form and formats. Hence, a seamless data analytics platform in terms of cloud service [73], should efficiently be associated with the current scenario.

7) KNOWLEDGE DISCOVERY

Due to the involvement of a huge number of deployed sensor modules in geographical sites, final aggregation of a pile of data is very challenging. That surely may comprise into the form of big data. Here, effective data mining on this potential of big data could be used for knowledge discovery with respect to the disastrous data correlations, data contexts, and data-semantics. Despite its promising aspect, it is still a big challenge, because knowledge discovery is a complex task in dynamic situations (e.g., change in geothermal activity, soil moisture, level of water, and wind speed).

8) RUN-TIME ANALYTICS

Disaster is generally not under control of human due to its highly dynamic nature. Hence, a hard real-time analytics solution is indeed. Recently, Yin et al. [74] proposed two algorithms for the real-time fault-tolerant systems. Similar algorithms may also be applied in the decision-making process in real-time.

9) GENERIC DATA MODEL

Knowledge discovery about several disastrous events needs the usage of spatio-temporal data out of the existing IoT solutions. In this regard, a generic data model may be appropriate to handle different data, complexity, and privacy requirements.

10) SECURE AND TRUSTED MODEL DESIGN

Security issues are very important in disaster management as personal and private information are being collected in disastrous data. The collected data from devastated sites or events may not be hampered by any malicious attackers. Thus, a secure and collaborative framework may be devised under strong supervision of domain of citizen.

11) SOCIAL MEDIA WITH SYNCHRONIZED EMERGENCY COMMUNICATIONS

During Nepal earthquake, Facebook launched "safety-check"[1] service that enables trapped victims to inform their locations and status of their safety to their family and neighbors. Such solution is in its initial phase of testing. Thus, micro-blogging service providers such as Facebook and Twitter may support these synchronized services pre-incorporated with prospective disastrous sites with more effective notation

B. FUTURE DIRECTION

We summarize some of the future research directions in IoT-based disaster management systems as follows:

1) COST

Low-cost solutions are desirable for the growth and usage of IoT-based solutions in disaster management systems. Minimization of production and selling cost of these nodes is essential for the large-scale deployment of IoT-based sensor modules

2) USER CONTROL PANEL

Generally, the interface in the form of a control panel is designed for experienced users. However, in a disastrous event, the interface should be user-friendly to the victim.

3) ENERGY

There is a lack of energy sources in the disaster. Thus, IoT-enabled nodes should be designed to work in low-power. In addition, harvesting energy from renewable energy sources become another promising approach to overcome the energy-constraint issues in a network.

4) INTEROPERABILITY

Interoperability is one of the most common issues in the IoT-devices. The deployed IoT-enabled sensor nodes need to be developed in such way that they can transmit (and receive) data to (and from) other local or remote devices with a different genre.

5) ARTIFICIAL INTELLIGENCE

Machine learning and artificial intelligence techniques should be implemented together to cope up with predictive and behavioral analysis functionality using advanced decision support system and real-time assessments.

6) MAINTENANCE

Sensor elements for disaster events are normally deployed in no man's location. Since maintenance of these products is is very hard, low-maintenance devices are preferable in IoT-based disaster management system.

7) ROBUSTNESS

IoT-based architecture needs to be robust and fault-tolerant so that applications may be ensured to be sustainable at their operation in disasters.

8) REAL-TIME PROCESSING

Real-time processing is one of the fundamental requirements in IoT-enabled devices for disaster management system to handle dynamic nature of the disaster. Although, a few approach [75] considers the real-time processing, the IoT-based disaster management system must consider the real-time processing.

9) STRUCTURING OF DATA

Since the IoT-based equipment is placed in different sites to handle possible disastrous events, the data structure or format should be evenly framed. This will minimize the additional overhead in data processing facilities in IoT-based disaster management system.

10) INTERFACE BETWEEN MODULES

The interfacing among internal modules is one of the major issues in IoT-based disaster management to improve the overall workflow performance.

11) DATA MINING ALGORITHMS

Different types of data are inevitably assimilated into a disaster management system. Their context and timing are always difficult to measure due to various factors. Appropriate selection of data mining algorithms [76] will enhance the effectiveness of the IoT-based systems. For example, monitoring and analyzing data in a slide-prone hilly area may predict the behavior of soil, after that, the possible occurrence of disaster incident such as a landslide.

[1] https://www.facebook.com/safetycheck/nepalearthquake/

12) TIME-SERIES DATABASE

Natural mishaps occur suddenly without any prior knowledge. In such situations, IoT devices could be connected to time-series databases (e.g., Axibase, Riak TS, influxdata, pipelinedb, and kdb+) to obtain accurate inclusion of regular incidents which further could be analyzed by running NoSQL queries.

13) TEXTILE ANTENNA

Ultra Wide Band (UWB)-empowered textile antenna is used to provide ad-hoc communications among victims in disastrous events. To this end. A conductive sheet like Velostat and Linqstat is effective. Ramasamyraja et al. [77] proposed a conductive textile-based antenna for emergency situations. In addition, since UWB antenna work in the frequency range between 3.1–10.6 GHz, it is suitable to correlate with other popular short and long range communications [78].

14) INTERNET OF SOFT ROBOTICS

Internet of Soft Robotic Things (IoSR) [79], [80] is another promising area to facilitate the victims using soft robots. However, IoSR is in its nascent stage, developments of soft-materials, processing engines, and communication protocols are important issues to be considered in future to enable smart disaster management systems.

VI. CONCLUSION

Adoption of new techniques could reduce the chances of losing human lives as well as damage to large-scale infrastructures due to both natural and human-made disasters. IoT, which allows seamless interconnection among heterogeneous devices with diverse functionality, is a viable solution for disaster management. By applying data analytics and artificial intelligence tools, IoT-enabled disaster management systems are used for early warning about the mishap. Since the impact of any disaster is enormous, the IoT-enabled disaster management system can be applied to find the victim and possible rescue operations. This article summarizes the available IoT-based technologies for disaster management and their suitability to apply into the disastrous situations. Finally, this survey presents some of the open research challenges and fundamental design principles for IoT-based disaster management systems. In summary, the aim of this study is to provide fundamentals about IoT-based disaster management systems that help us to understand past research contributions and future research direction to solve different challenges disaster management systems.

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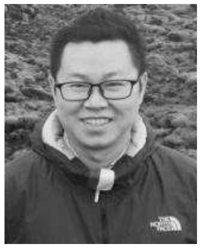

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