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Delay-Aware Accident Detection and Response System Using Fog Computing

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ABSTRACT Emergencies, by definition, are unpredictable and rapid response is a key requirement in emergency management. Globally, a significant number of deaths occur each year, caused by excessive delays in rescue activities. Vehicles embedded with sophisticated technologies, along with roads equipped with advanced infrastructure, can play a vital role in the timely identification and notification of roadside incidents. However, such infrastructure and technologically-rich vehicles are rarely available in less developed countries. Hence, in such countries, low-cost solutions are required to address the issue. Systems based on the Internet of Things (IoT) have begun to be used to detect and report roadside incidents. The majority of the systems designed for this purpose involve the use of the cloud to compute, manage, and store information. However, the centralization and remoteness of cloud resources can result in an increased delay that raises serious concerns about its feasibility in emergency situations; in life-threatening situations, all delays should be minimized where feasible. To address the problem of latency, fog computing has emerged as a middleware paradigm that brings the cloud-like resources closer to end devices. In light of this, the research proposed here leverages the advantages of sophisticated features of smartphones and fog computing to propose and develop a low-cost and delay-aware accident detection and response system, which we term Emergency Response and Disaster Management System (ERDMS). An Android application is developed that utilizes smartphone sensors for the detection of incidents. When an accident is detected, a plan of action is devised. Initially, a nearby hospital is located using the Global Positioning System (GPS). The emergency department of the hospital is notified about the accident that directs an ambulance to the accident site. In addition, the family contacts of the victim are also informed about the accident. All the required computation is performed on the nearby available fog nodes. Moreover, the proposed scheme is simulated using iFogSim to evaluate and compare the performance using fog nodes and cloud data centers.

INDEX TERMS Accident detection, fog computing, mobile edge computing, cloud computing, Internet of Things, emergency alerts, disaster management system.

I. INTRODUCTION

Preventing death and serious injury from road traffic accidents is becoming an increasingly important goal for governments around the world. The United Nations General Assembly, on 18 April 2018, stated that "road traffic deaths and injuries remained a major public health and development problem with broad social and economic consequences", adopting a draft resolution entitled "Improving global road safety". The supporting document recommends Member States "address road safety holistically; implement a good road safety management system" among other initiatives. The provision of timely aid to victims involved in accidents is a key requirement to help minimizing the impact of vehicular accidents. To this end, devising appropriate notification and response is crucial to saving human life. Numerous statistics

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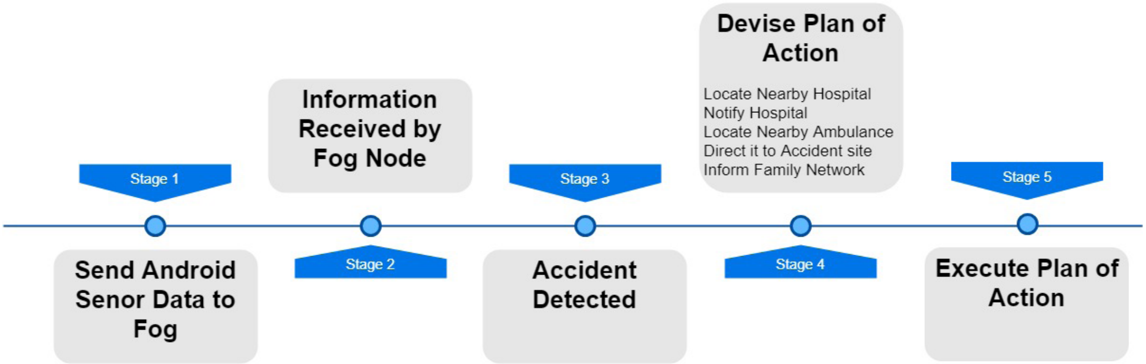

FIGURE 1. ERDMS system flow.

indicate that the number of traffic accidents is increasing every year. According to the World Health Organization (WHO) Road Traffic Facts, 1.24 million road accidents occur around the world. According to the statistics, 50% of the accidents globally result in fatalities, and 80% of the world traffic deaths occur in middle-income countries [2]. In Pakistan, for example, 15 people lose their life each day to such accidents, on average. Recent information released by the Pakistan Bureau of Statistics shows that of 9,582 accidents over a year (2016-2017), 4,036 (or 55% of the total) have resulted in death [4]. With such fatality rates, it is paramount that road safety is improved, and appropriate strategies and systems are developed, particularly in developing countries. The Internet of Things (IoT) offers promise to address these issues through the development of emerging low-cost intelligent traffic management systems [28].

In a significant number of vehicular accident scenarios, the victims are unable to call for assistance. In such situations, a plan of action is required which includes informing relevant authorities and rapid provision of medical assistance to the victims. Traditionally, such decisions are made by the human which causes unnecessary delays. The delay in communicating emergency information to the emergency services can increase the possibility of fatalities following a road traffic accident. This requirement has led to many modern vehicles being equipped with built-in emergency response systems to detect accidents and create appropriate notifications. Such technology has not only become a real option around the world, but from April 2018, the automatic emergency call system, eCall, is a legally required to be installed in all new cars receiving type approval in the European Union (EU) - regardless of manufacturer, model or price category. Whilst such regulatory advances will help address fatalities from accidents involving new vehicles, these will form a small proportion of vehicles involved in accidents globally, especially, accidents in developing countries. A challenge remains how to address the rapid response to accidents involving older vehicles, and in those countries where the installation of such systems is not mandated. Moreover, it is also very complicated to install advanced systems in older vehicles [5].

In this context, technology, especially, that delivered through advances in the IoT can play a significant role. Effective emergency detection and response systems can play a critical role in reducing the loss of life following a road traffic accident. For this reason, there is a growing body of research proposing solutions to challenges arising in emergency situations. Cloud-based accident detection systems are being proposed which utilize cloud resources for the processing, storage, and transmission of data. However, latency remains a major issue of many of the proposed solutions [6], [33]. Some researchers have proposed the use of external sensors, for instance, temperature and humidity sensors, to detect any abnormality and infer information regarding accidents [7]. While many of the systems are extremely useful, the cost of installing such systems can be very high due to the use of these expensive sensors, thereby, making the system inaccessible to low-income users [8].

To address the above-mentioned problems, we propose a fog-based delay-aware accident management system (we call it ERDMS). The proposed system aims to decrease response and rescue time. The architecture of the system is based on that presented in [9]. The overall system cost is reduced by using the built-in sensors of a smartphone to detect an accident. A smartphone application is developed that gathers the required data using smartphone sensors. The location information is collected using GPS. The acquired data is sent to the nearest fog nodes for further processing as necessary. If an accident is identified, then a nearby hospital is located, and a plan of the accident is devised to provide immediate assistance to the victims of the accident. The system flow of the ERDMS is shown in Figure 1.

The remainder of this research paper is organized as follows: Section II describes existing work concerning the design and development of smartphone-based accident detection and prevention system. Existing approaches are compared and critically analyzed. Section III presents the proposed solution, explaining how it addresses the problem under consideration and the benefits offered by the ERDMS. The performance evaluation of the proposed system is presented in Section IV. Section V concludes the paper and provides future research directions.

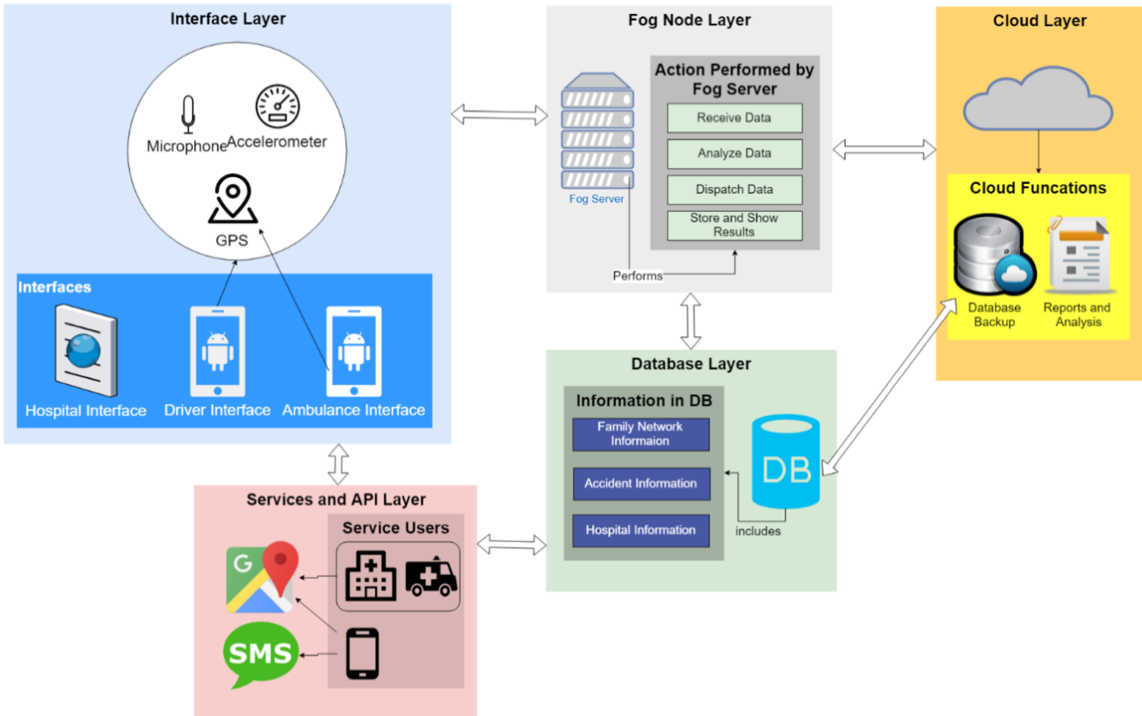

FIGURE 2. System architecture of ERDMS.

II. LITERATURE REVIEW

Disasters can be either natural or manmade, and in both cases, one of the most important factors in reducing loss of life is the time taken for response. There is a plethora of research devoted to addressing this problem, given the severity of the issue, including developments in emergency predictive systems [10] and road safety systems [11]. Recent research in the area includes smartphone-based disaster management system [8], [12]–[25], cloud-based accident detection and disaster management system [1], [7], [25]–[27] and also fog based disaster management systems [6], [10], [26], [29]–[32].

Cloud-based accident detection and disaster management system can face challenges concerning latency and bandwidth given the centralized nature of the service. An emerging concept that can help address these issues is fog computing, which offers the promise of lower latency, mobility support, increased resilience and scalability. Furthermore, by utilizing smartphone sensors, emergency detection and management systems can be more affordable and easy to deploy in legacy vehicles. A comparison of the research advances in smartphone-based accident detection and response systems is provided in Table 1 that presents brief details of the proposed solutions, along with limitations of the system. The papers are sorted by year of publication, in descending order.

III. PROPOSED METHODOLOGY

This section presents the methodology of the proposed system (ERDMS). It is a fog-based system which leverages the advantages of fog computing to reduce the overall system latency. To minimize the cost of the solution, it utilizes the sensors readily available in a modern smartphone to detect an accident and process data, thereby replacing the need for an on-board processing unit and external sensors and reducing system cost. The data gathered from the smartphone sensors is sent to the fog servers.

A. ARCHITECTURE OF THE PROPOSED SYSTEM

The proposed system is composed of five different layers as presented in Figure 2. The first layer contains the interface and devices. The second layer consists of fog nodes. The next layer holds the database, while the fourth layer is dedicated to the services; finally, the cloud resources are made available at the last layer. The data is collected through the use of smartphones, and an Android interface is provided for drivers of vehicles and ambulances; a web interface is developed for the hospital.

B. SYSTEM IMPLEMENTATION

The proposed system is divided into two major phases - accident detection and emergency response and notification. The details of both phases are as follows:

1) ACCIDENT DETECTION PHASE

The detection phase concerns identifying the occurrence of an accident. For this purpose, three built-in sensors the smartphone are utilized. These are accelerometer, GPS sensor, and microphone. To identify an accident, thresholds are defined for each sensor to determine whether an accident has occurred or not. Using accelerometer and GPS,

TABLE 1. State-of-the-art smartphone-based disaster management systems.

Title	Year	Problem Solution	Limitation
Trauma Accident Detection and Reporting System [25]	2018	An accident detection mechanism is introduced to reduce the rate of fall-related deaths.	The task proposed methodology only handles falling scenarios. Also, they do not handle any traffic accident related scenarios.
Safe Driving: A Mobile Application for Detecting Traffic Accidents [20]	2018	The authors proposed an accident detection technique that utilizes vibration and acoustic waves. Moreover, it uses an analytical model to detect an accident.	External sensors increase the overall cost of the system.
Accident Detection and Smart Rescue System using Android Smartphone with Real-Time Location Tracking [3]	2018	A smartphone application is developed which uses the Android sensors to detect an accident and provide real-time tracking of the accident location.	The system lacks rescue services.
Intelligent Traffic Accident Detection System Based on Mobile Edge Computing [18]	2017	An intelligent traffic system which utilizes edge computing to detect accidents using smartphones.	The smartphone utilizes existing datasets and is prone to errors.
S-CarCrash: Real-time Crash Detection Analysis and Emergency Alert using Smartphone [22]	2016	A smartphone-based application to detect crashes which also notifies family and friends about the accident.	The system is based on visual information which can lead to false positive and false negative results.
A Method for Collision Detection Using Mobile Devices [13]	2016	A smartphone application which not only detects accidents but also informs families and appropriate authorities.	Image processing and video processing is used to identify accidents and this increases the overall processing time of the system.
Smartphone-based Vehicle Tracking and Accident Prevention System [23]	2015	An Android-based smartphone application which allows the user to track the vehicle in real time.	The system has no emergency rescue system.
Automatic Accident Detection and Alarm System [15]	2015	An automatic accident detection and alarm system which uses user profiling to identify that either user is distracted or not and then takes appropriate action.	There is no emergency response system. Limited to distracted walkers.
Smart Vehicle Accident Detection and Alarming System Using a Smartphone [21]	2015	The team have developed a smartphone application which not only utilizes the Android sensors, but also an external pressure sensor in an effort to decrease false positives.	The external sensors increase the overall cost of the system.
iBump: Smartphone Application to Detect Car Accidents [16]	2015	A smartphone application which detects an accident and provides timely notification to the medical assistance providers.	The application does not provide information to family and friends.
Poster: A Robust Vehicular Accident Detection System using Inexpensive Portable Devices [8]	2014	An inexpensive and robust system to detect an accident and provide assistance.	The device is needed to be installed by an expert thereby making it less accessible.
Context-Aware Wireless Sensor System Integrated with Participatory Sensing for Real-Time Road Accident Detection [17]	2013	A context and behavior based accident detection technique is proposed that decreases the false alarm rate.	High cost due to sensors requiring data sets to operate.
Providing Accident Detection in Vehicular Networks Through OBD-II Devices and Android-based Smartphones [35]	2011	Smartphones are used in an existing application to detect accidents.	The on-board devices are expensive. Also, it uses a cloud which has led to latency issues.

the Gravitational force (a G-Force value) is calculated. Using previous research [34] an accident can be identified if this value is greater than 4. However, using this value in isolation gives a high false positive rate. The speed of the vehicle is also considered to measure the accident. As mentioned in [34], if the speed period variation of a vehicle is more than

2.06, the vehicle is considered in an accident state. To further enhance the reliability of ERDMS, the microphone is also used to identify an anomalous acoustic event. A value exceeding 14dB is considered as the threshold of the sound. While a microphone itself cannot be considered as the primary sensor in accident detection, it can be used as a secondary filter to enhance the reliability of the overall process. The calculations used to determine the identification of an accident scenario are demonstrated in Eq. 1.

$$\begin{cases} 1 \quad if \left(\frac{AC}{4G}+\frac{Noise}{140db}\right) \geq Accident\ Threshold \\ \qquad AND \left(Speed > \frac{24km}{h}\right) \\ 1 \quad if \left(\frac{AC}{4G}+\frac{Noise}{140db}+\frac{SVP}{2.06}\right) \geq Low\ Speed\ Threshold \\ 1 \quad if \left(\frac{AC}{4G}+\frac{Noise}{140db}\right) \geq Accident\ Threshold \\ 0 \quad Otherwise \end{cases} \tag{1}$$

where

- AC: Smartphone Acceleration
- Noise: Sound value in dB determined by smartphone
- SVP: Speed variation period
- Speed: Speed value calculated through G-Force
- Low-speed threshold: threshold to detect accident at low speed which is 1

The process of the detection phase is as follows: The vehicle user starts the application before commencing a journey. Every vehicle is identified through a unique identification (ID) number. The application continuously monitors the sensor data as acquired. If the value of the accident detection value given in the above equation is greater than or equal to 1, then an accident is deemed to have occurred, and a notification is generated and presented to the user that is displayed for 10 seconds. If the notification is canceled, a false alarm is recorded and stored in the database. If the alarm is not canceled then the notification phase is initiated.

2) EMERGENCY RESPONSE AND NOTIFICATION PHASE

Once an accident has been detected, the next step is to devise an appropriate plan of action. This involves obtaining the location of the accident and determining the nearest hospital using the Google Maps Application Program Interface (API). Once the location is identified, a nearby ambulance is informed through a notification sent from the Android device of the victim along with necessary information. Moreover, when a user installs the application, they are requested to provide information about at least two family members or friends which will also be notified in case of an accident event. Hence, when an accident occurs, a Short Message Service (SMS) is generated and information about the affected person and hospital is shared with the two contacts. Once the whole plan of action is executed, the information is saved in a central database. The entity relationship diagram of the system presented in Figure 3.

TABLE 2. Benefits of ERDMS.

	OBU based solutions	ERDMS
Accident Detection System	Yes	Yes
False Alarm and Rectification System	Sometimes	Yes
Pre Hardware deployment	Required	Not Required
Cost of Deployment	Expensive	Free
Availability	Only inexpensive cars	Available for all cars

C. ANDROID APPLICATION

The Android application is developed using Android studio and it is compatible with Android Oreo API level 26. When the application is launched, the vehicle user is requested to provide their ID and password. Once the user is logged in, he can start tracking as shown in Figure 4. During the tracking, the values are gathered from the Android sensors and sent to the fog server, as shown in Figure 5.

Once an accident is detected, a 10-second warning is shown to the user, to identify the case in which this was a false alarm, as presented in Figure 6. If the alarm is not cancelled it is determined that an accident has been detected, and the plan of action is executed which includes sending information to the nearest hospital, close contacts and notifying the ambulance. The ambulance notification is shown in Figure 7.

The list of activities of the ERDMS application are listed below:

- Launch Activity
- User Activity
- Accident Detection Start and Stop Activity
- Choose Emergency Contact Activity
- Settings Activity

D. WEBSITE AND SERVER-SIDE IMPLEMENTATION

The server side has been implemented using ASP.NET Model-View-Controller (MVC) 4 Razor 5. The website provides an interface for hospitals to check whether there is an emergency or not. If an accident is detected, the hospitals receive a notification on the web-based portal as shown in Figure 8. Each hospital has a unique user ID and password which is used to login to the portal. A dashboard provides details about the accident. Microsoft Structured Query Language (SQL) database is used to store all the information. The website uses Hypertext Markup Language (HTML), Cascading Style Sheets (CSS), and Razor 5 for the development of pages. Google Maps API is used to show the maps on the web pages. HTML 5 server events API is used to request the data from the server, automatically. Table 2 presents a brief comparison between On Board Unit (OBU) based solutions and ERDMS.

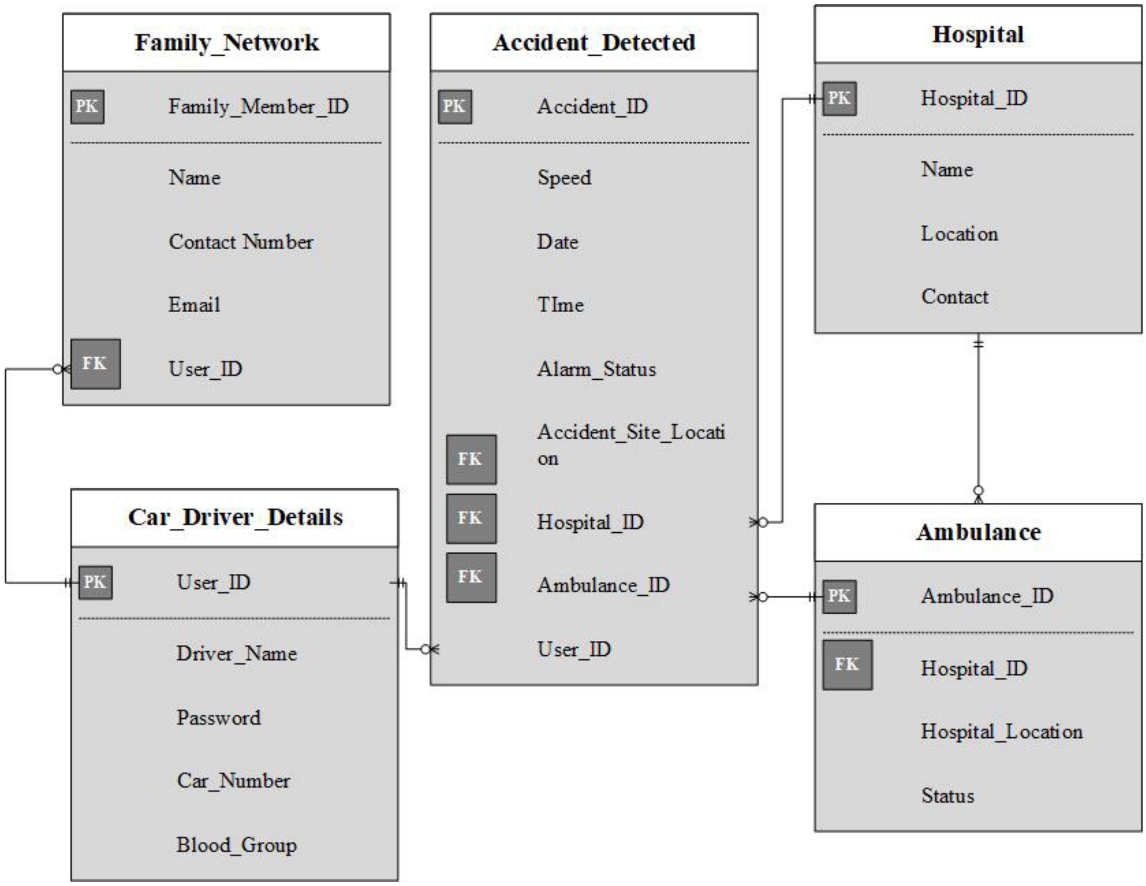

FIGURE 3. System architecture of ERDMS.

FIGURE 4. System before tracking.

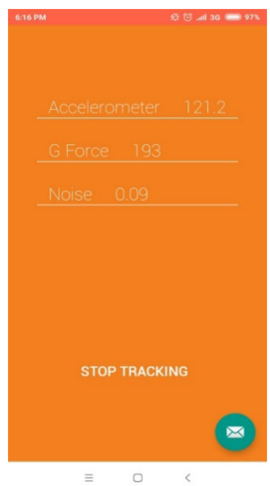

FIGURE 5. System after tracking.

IV. EVALUATION SETUP AND RESULTS

This section describes the evaluation of the ERDMS. The main purpose of the system is to achieve low cost and decrease the latency when compared to similar solutions utilizing cloud-based environments. To verify the claim, we have performed simulation using iFogSim that provides a discrete event simulation to simulate the IoT, fog and cloud environments. It enables the functionalities of IoT devices, traffic generation, network management, scheduling policies, fog nodes and cloud data center configurations [36]. Moreover, different performance metrics can also be calculated based on the simulations.

A. CLOUD-BASED SCENARIO

The proposed system is initially tested in a cloud-based scenario in which the smartphone sends the data to the cloud for

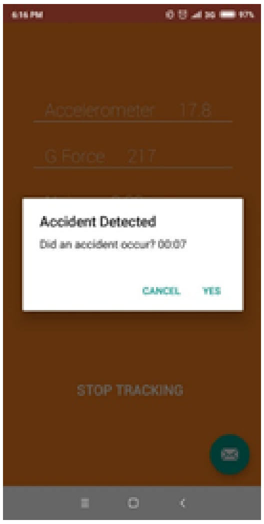

FIGURE 6. Accident detected.

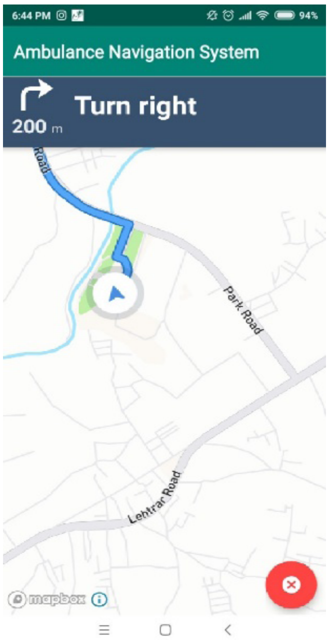

FIGURE 7. Ambulance interface.

computation. The topology for the cloud scenario is shown in Figure 9. The layer zero contains the actuators and the sensors and the data is sent to the cloud via routers. The configuration of the router, smartphone, and the cloud is shown in Table 3 and the latency between the links at each level is shown in Table 4.

B. FOG-BASED SCENARIO

The fog-based scenario for the ERDMS consists of two fog nodes which are connected to the cloud via a proxy server. Again, the actuators and the sensors are at level zero. The fog-based topology is shown in Figure 10. The configuration of all devices is shown in Table 5; whereas, Table 6 presents the latency between the links.

TABLE 3. Configuration of devices in cloud-based scenario.

Configuration Table			
Name	**Cloud**	**Router**	**Smartphone**
Processing Capability (MIPs-million instructions per second)	10000	2500	1000
RAM (MB)	10000	4000	1000
Uplink Bandwidth (MB)	100	1000	1000
Downlink Bandwidth (MB)	1000	1000	270
Hierarchy level of devices	0	1	2
Cost/MIPs (cost per million instructions processing)	0.01	0	0
Busy Power (W)	16*110	110	87
Idle Power (W)	16*85	85	82

TABLE 4. Latency at each level.

Latency between Links (ms)	
Cloud - Router	200
Router - Smartphone	30
Smartphone - Sensor	1
Smartphone - Actuator	1

TABLE 5. Configuration of devices for fog-based scenario.

Name	Cloud	Proxy Server	Fog Node	Smartphone
MIPS	10000	2500	2500	1000
RAM	10000	4000	4000	1000
Uplink Bandwidth	100	1000	1000	1000
Downlink Bandwidth	1000	1000	1000	270
Hierarchy level of device	0	1	2	3
Rate/MIPS	0.01	0	0	0
Busy Power (W)	16*110	110	110	87
Idle Power (W)	16*85	85	85	82

1) CONFIGURATIONS OF PHYSICAL TOPOLOGY

For both scenarios, five different configurations are used. Each configuration varies in the number of smartphones and users. Then all configurations are evaluated to calculate latency and network usage. The details of the configurations are shown in Table 7.

C. RESULTS

1) NETWORK THROUGHPUT

The network usage is calculated in megabytes for each scenario. Table 8 shows the bandwidth usage of both cloud and

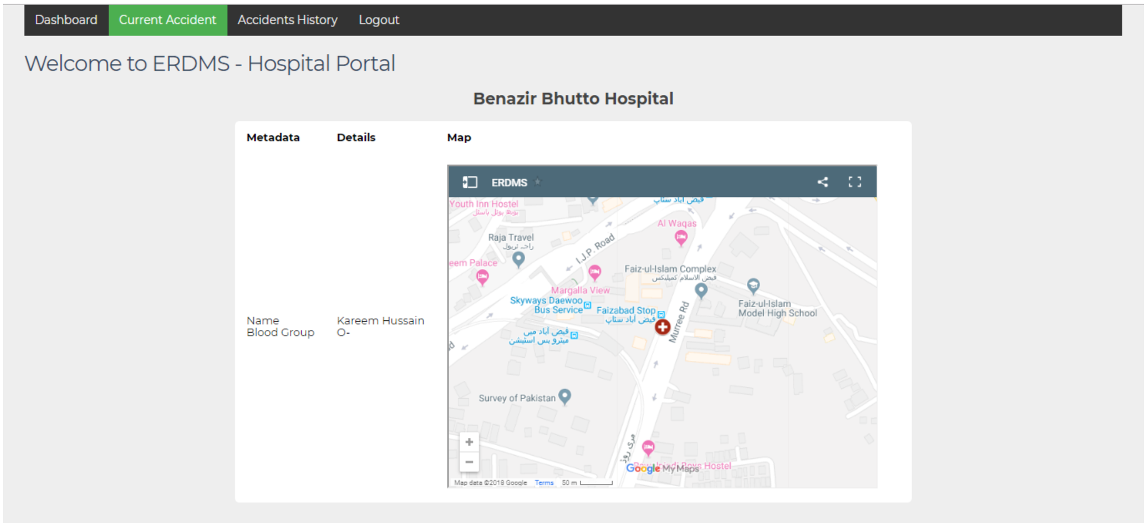

FIGURE 8. Accident notification information page.

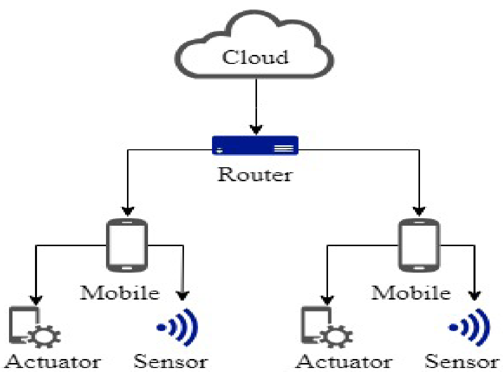

FIGURE 9. Topology for cloud-based scenario.

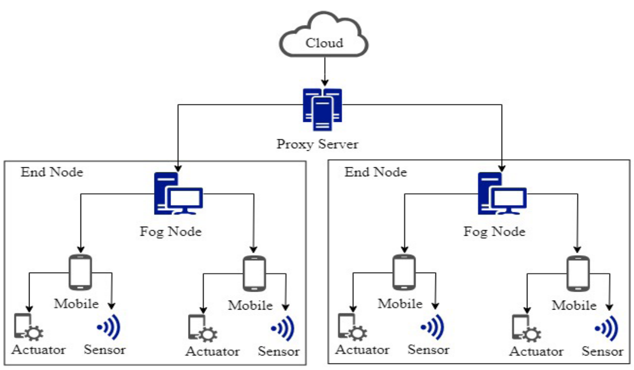

FIGURE 10. Topology of fog-based scenario.

fog scenarios. The comparison of the fog and cloud network usage is shown in Figure 11. It is evident that the fog computing saves bandwidth where cloud utilizes more network data while transmitting the data. In case of using cloud for computing and storage, all the jobs are sent to the cloud data centers. These jobs traverse the whole network from source to destination. In this case, the Internet backbone is used. Hence, it results in increased utilization of core network resources as shown in Figure 11.

TABLE 6. Latency at each level in fog-based scenario.

Latency between Links	
Cloud - Proxy Server	150
Proxy Server - Fog Node	6
Fog Node - Smartphone	4
Smartphone - Sensor	1
Smartphone - Actuator	1

TABLE 7. Configuration details.

	Number of Smart-phones	Number of Users
Conf 1	4	8
Conf 2	8	12
Conf 3	12	16
Conf 4	16	20
Conf 5	20	24

TABLE 8. Network usage in kilobytes.

	Config 1	Config 2	Config 3	Config 4	Config 5
Fog	332793	347205.7	359627.5	365388.3	368234.1
Cloud	527970.2	542358.2	554813.5	560500.7	563353.9

TABLE 9. Execution delay in control loop (in Milliseconds).

	Config 1	Config 2	Config 3	Config 4	Config 5
Fog	4333.991	4961.963	5075.444	5120.126	5121.974
Cloud	4451.691	5063.111	5174.226	5215.522	5227.116

TABLE 10. Execution time (in Milliseconds).

	Config 1	Config 2	Config 3	Config 4	Config 5
Fog	3476	4763	6439	7684	12944
Cloud	4287	5915	7839	11498	17208

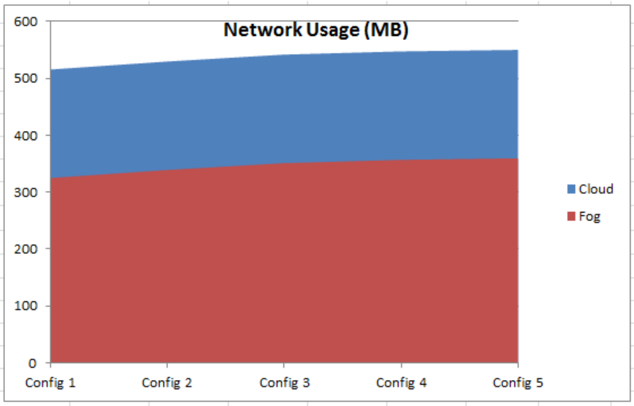

FIGURE 11. Comparison of fog and cloud network usage.

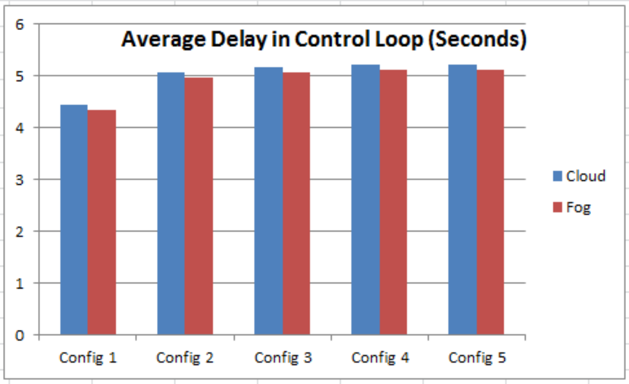

FIGURE 12. Comparison of fog and cloud latency.

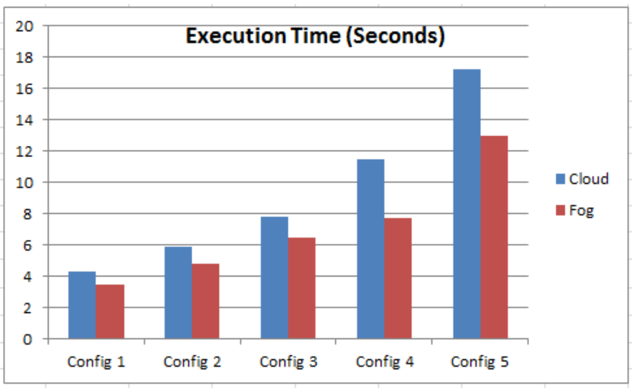

FIGURE 13. Comparison of fog and cloud execution time.

2) LATENCY AND EXECUTION TIME

Latency is a critical parameter in analyzing the performance of emergency management systems, since small delays can lead to increased likelihood of fatality. Table 9 shows the delay for complete execution of the application i.e. delay in control loop (the time is calculated in seconds). It is evident that fog computation provides lower latency than cloud computing, due to the geographical proximity of fog resources. Hence, in emergency systems, fog computing can play a vital role. Figure 12 shows the delay comparison of the control loop between fog and cloud. Table 10 shows the execution time of the operation which is again less than the cloud-based system as shown in Figure 13. It provides a comparison of the execution time taken by fog node and a cloud server. It can be noted as the number of devices increases, the benefits of the fog-based ERDMS are more visible as computation is performed with lower overall latency and bandwidth usage.

V. CONCLUSION

Fog computing enables efficient, localized processing of data which can be of particular use in time-sensitive applications. It provides benefits of low latency, geographical distribution, and mobility support. Lower response times are considered a particularly important requirement in accident detection and emergency notification systems since delay can result in loss of life. The proposed system overcomes challenges faced by cloud-based systems through utilizing fog computing. The system developed in this work makes use of smartphone capabilities to decrease the cost when compared to similar OBU-based solutions. The system also reduces cost and minimizes overall response time by minimizing human intervention through automated emergency management. To demonstrate the work, an Android application has been developed as a proof of concept. The evaluation results confirm that the fog-based ERDMS has lower latency, network usage, and execution time in comparison to cloud-based systems. The limitations of our study include the evaluation of the proposed scheme in a simulated environment. We used a state-of-the-art simulation environment, however it cannot exactly replicate all real-world scenarios. As a consequence the generalization of the overall solution is limited.

In the future, we intend to evaluate a complete ERDMS in a real environment to observe its performance in real time. Moreover, we will also work on enhancing the accuracy of accident detection. Also, we aim to integrate smart traffic signaling for the ambulance to decrease the overall rescue time [37] to enable smart transportation [38]. We also intend to address potential privacy and security concerns that require consideration before any real-world implementation can be built on our system

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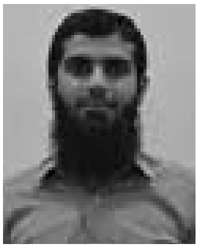

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