Intelligent Disaster Management System based on Cloud-enabled Vehicular Networks

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Abstract—The importance of emergency response systems cannot be overemphasized today due to the many manmade and natural disasters in the recent years such as September 2001 and the recent Japan earthquake and tsunami disaster. The overall cost of the Japan disaster alone is estimated to have exceeded 300 billion USD. Transportation and telecommunications play a critical role in disaster response and management in order to minimize loss of human life, economic cost and disruptions. Our research is concerned with developing emergency response systems for disasters of various scales with a focus on transportation systems which exploit ICT developments. In this paper, we leverage Intelligent Transportation Systems (ITS) including VANETs (Vehicular Ad hoc Networks), mobile and Cloud computing technologies to propose an intelligent disaster management system. The system is intelligent because it is able to gather information from multiple sources and locations, including from the point of incident, and is able to make effective strategies and decisions, and propagate the information to vehicles and other nodes in real-time. The effectiveness of our system is demonstrated through modelling the impact of a disaster on a real city transport environment and comparing it with the case where our disaster management system was in place. We report great benefits derived from the adoption of our proposed system in terms of improved and balanced traffic flow and smooth evacuation.

Keywords-Disaster Management and Resilience, Intelligent Transportation Systems, Cloud Computing, VANETs, Mobile Communications, Digital Econom

I. INTRODUCTION

The importance and scope of emergency response systems have grown tremendously over the past decade in particular after September 11, 2001. Disasters, manmade and natural, are a cause of great economic and human losses each year throughout the world. The overall cost of the recent Japan earthquake and tsunami disaster alone is estimated to have exceeded 300 billion USD. This has driven many new initiatives and programs in countries throughout the world, in particular in the US, Europe, Japan and China. See, for example, [1], [2], [3], for emergency response and evacuation initiatives in the US. A great deal of advisory and policy documents has been developed by various government authorities through surveys, consultations, experiences and other means of research: see e.g. [4], [5].

Transportation and ICT (Information and Communication Technologies) technologies play critical roles in responding to emergencies and minimising disruptions, human and socioeconomic costs. We have witnessed unprecedented advancements in information and communication technologies over the last few decades and the role of ICT technologies in Intelligent Transportation Systems is to grow tremendously. Vehicular Ad hoc Networks (VANETs), sensor networks, social networks, Car-to-Car (C2C) and Car-to-Infrastructure (C2I) technologies are enabling transformational capabilities for transportation (see e.g. [6], [7]). Our ability to monitor and manage transportation system in real-time and at high granularity has grown tremendously due to sensor and vehicular network that generate huge amount of extremely useful data. However, many challenges in realising the ITS potential remain including the interworking and integration of multiple systems and data to develop and communicate a coherent holistic picture of transportation systems. This is particularly difficult given the lack of data and systems interoperability as well as the business models to develop such an advanced infrastructure which requires coordination between many stakeholders and general public.

> *"Ensuring the success of mass evacuations—The conferees direct the Department of Transportation (DOT), in cooperation with the Department of Homeland Security (DHS), to assess mass evacuation plans for the country's most -high-threat, high-density areas and identify and prioritize deficiencies on those routes that could impede evacuations…"*
>
> Departments of Transportation & Housing & Urban Development and Related Agencies Appropriations Act, 2010 Conference Report (111-366) to Accompany HR 3288 & Public Law 111-117, FY 2010 Consolidated Appropriations Act [1]

Cloud Computing has emerged as a technology, coupled with its innovative business models, which has the potential to revolutionise the ICT and ITS landscape. It is already making a huge impact in all sectors through its low cost of entry and high interoperability. Moreover, the technology allows one to develop reliable, resilient, agile, and incrementally deployable and scalable systems with low boot-up time, and at low costs, while giving users access to large shared resources on demand, unimaginable otherwise.

In this paper, we leverage the advancements in the ICT technologies - including ITS, VANETs, social networks, mobile and Cloud computing technologies - to propose an intelligent disaster management system for an urban environment. By exploiting these latest technologies, the system is able to gather information from multiple sources and locations, including from the point of incident, and is able to make effective strategies and decisions, and propagate the information to vehicles and other nodes in real-time. The effectiveness of our system is demonstrated through modelling the impact of a disaster on a real city transport environment. We model two urban scenarios: firstly, disaster management using traditional technologies, and secondly, exploiting our intelligent, modelling and vehicular Cloud based disaster management system. The comparison of the two scenarios demonstrates the effectiveness of our system in terms of the number of people evacuated from the city, the improved traffic flow and a balanced use of transportation resources. This paper focuses on disaster management although our work is broadly applicable to emergency response systems of any scales, such as emergency vehicles warning system, and, in general to the operational and strategic management of transportation systems.

This paper is organised as follows. Section II provides introduction to Cloud computing and VANETs. Section III describes the architecture and various components of our disaster management system. Section IV provides an evaluation of our system and Section V concludes the paper with directions for future work.

II. BACKGROUND MATERIAL

A. *Cloud Computing*

Cloud computing is swiftly becoming a very attractive and foundational element in global enterprise computing. There are several companies across a wide range of industries which implement, develop and offer cloud technologies. Cloud computing can be defined as web applications and server services that users pay for in order to access, rather than software or hardware that the users buy and install themselves [8]. Cloud computing offers great advantages for organisations and businesses of all sizes. One of the main advantages of cloud computing is the fact that organisations and businesses do not need the infrastructure or the necessary information and knowledge to develop or maintain the infrastructure, as providers are taking care of all that. Moreover, Cloud computing also allows users to access a wide variety of applications, services, and hardware, which they might not be able to access otherwise. By using cloud computing organisations and businesses hugely save money and can cut the cost because they will rent the software and applications rather than buying them and have them installed on their machines. Additionally, using cloud computing could save time due to the fact that businesses will not have to install and or upgrade software and applications. Furthermore, businesses can easily gain access to applications which are specified to their needs and available only over the Internet [8], [9].

It is believed that the foundation of cloud computing was a result of a set of many pre-existing and researched concepts: distributed and grid computing, service oriented architectures, virtualisation, and Software as a Service [10], [11]. Cloud computing is an enabler of innovation and new business models in enterprise computing. The true innovation and improvement that Cloud computing brings in is seen in the way its computing services are being provided to the customers. Additionally, such services comprise the ability to offer software applications, programming platforms, data storage or computing infrastructure. There are several IT system components that are being offered as services, such as Hardware as a Service (HaaS), Software as a Service (SaaS) and Data as a Service (DaaS). These services are offered together as a Platform as a Service (PaaS) [10], [11]. It is therefore useful to look at Cloud Computing as a stack of layers, as proposed in [11]; see Fig. 1 that is adapted from [11] with slight modifications in terminology. The figure depicts that the cloud computing systems comprise five layers: applications, software environments, software infrastructure, software kernel, and hardware.

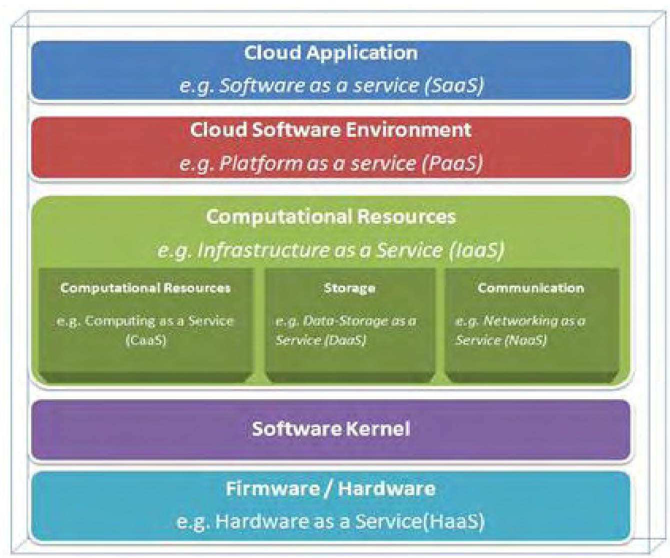

Figure 1. The layers of Cloud computing

B. *VANETs and Intelligent Transportation Systems*

The inherent human desire for change, progress, mobility, entertainment, safety and security are leading the way to the development of intelligent transportation systems (ITS). Vehicular ad hoc network (VANET) are the most prominent enabling technology for ITS. VANETs are formed on the fly by vehicles equipped with wireless communication capability. The participant nodes in VANET interact and cooperate with each other by direct communication with the nodes within range, by hoping messages through vehicles and road side masts. Traditionally, information about traffic on a road is only available through inductive loops, cameras, roadside sensors and surveys. VANETs provide new venues for collecting real-time information from onboard sensors on vehicles and for quick dissemination of information. The information collected through individual nodes participating in VANETs can be integrated together to form a real time picture of the road situation. Many new applications have been enabled through VANETs, though safety and transportation efficiency applications are the most important driver for VANETs. The various ITS stakeholders such as governments, telecommunication companies and car manufacturers are working together to make VANETs based ITS a reality. Hundreds of projects are underway in the US, Europe, Japan, China, Singapore and other countries in the world helping with research, innovation, testing and standardisation activities [12], [13].

III. THE DISASTER EMERGENCY RESPONSE SYSTEM

A. System Architecture

Fig. 2 depicts the system architecture of the Cloud-enabled vehicular emergency response system. The system consists of three main layers. The Cloud infrastructure layer provides the base platform and environment for the intelligent emergency response system. The Intelligence Layer provides the necessary computational models and algorithm in order to devise optimum emergency response strategies by processing of the data available through various sources. The System Interface acquires data from various gateways including the Internet, transport infrastructure such as roadside masts, mobile smart phones, social networks etc. As depicted in Fig. 2, vehicles interact with the gateways through car-to-car (C2C) or car-to-infrastructure (C2I) communications. For example, vehicles may communicate directly with a gateway through Internet if the Internet access is available. A vehicle may communicate with other vehicles, road masts, or other transport infrastructure through point-to-point, broadcast or multi-hop communications.

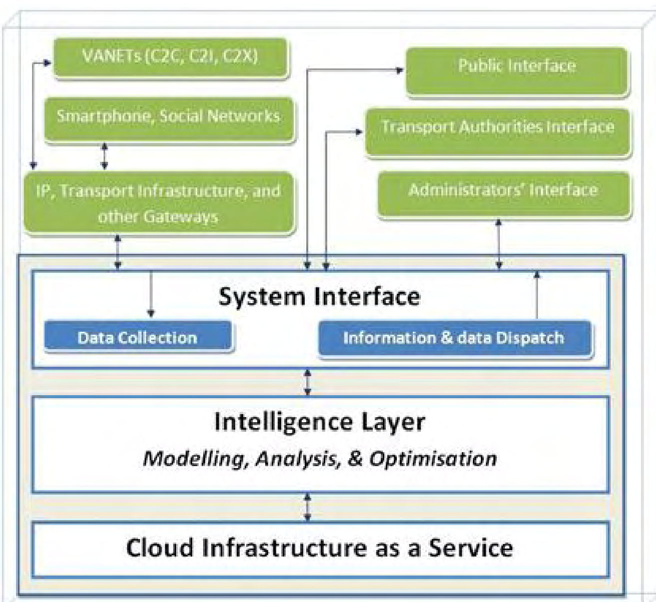

Figure 2. Emergency Response System - Architecture.

The emergency response system provides multiple portals or interfaces for users to communicate with the system. The Public Interface allows any individual to interact with the system. The purpose is to interact with the system on one-to-one or group/organisation basis with the system, either to request or provide some information. Of course, an authentication, authorization and accounting system is expected to be in place to allow and control various activities and functions. The Transport Authorities Interface provides is a high-privilege interface for the transport authorities to affectively manipulate the system for day to day operational management. The Administrators' Interface provides the highest privilege among the system users and is designed for policy makers and strategists to enable highest level system configuration.

The motivation and background for a Cloud based distributed control system can be found in our earlier work, for example in [14], where we present an architecture for distributed virtualisation using the Xen hypervisor; it allows control and management of a distributed system by posting high-level queries on the system and their validation through real-time monitoring and control of the system. Monitoring relates to the acquisition of data and control relates to despatch of commands and decisions. Also see [15], where a Pervasive Cloud is proposed using the WiMAX broadband technology for railway infrastructure.

B. The Ramadi City and its Transportation Network

The Ramadi city (Al Ramadi) is the capital of Al Anbar Governorate and is situated at the intersection of the Euphrates River and Al Warrar Channel. The Habbaniya Lake is located a short distance to the south of the City of Al Ramadi. The General Directorate of Physical Planning of the Ministry of Municipalities and Public Works (MMPW) is preparing for the Development Strategy of Al Ramadi, and it is in line with the development policies of MMPW for other Iraqi cities. The Association of the Canada-based HYDROsult Center for Engineering Planning (HCEP) and the Iraq-based Engineering Consultancy Bureau of Al Mustansiriya University has been commissioned by MMPW to carry out the tasks of this assignment and they have produced a second stage report [16] in November 2009 for the development of the Ramadi city. Iraq is now open to new developments and it is a great opportunity to develop intelligent transportation systems for Ramadi and other Iraqi cities.

Fig. 3 shows the transportation network map of the Ramadi city, the network consists of zones, nodes, and links. The city is divided into 5 traffic zones; Zone 1 and Zone 5 are in the west side of Al-Warrar River which divides the city into two parts. Zone 1 represents the location of a huge glass factory; Zone 5 represents the west part of the city. The east part of the city contains Zones 2, 3, and 4. Zone 2 represents the old city centre which attracts high number of trips in the morning peak hour.

Note also in Fig. 3 the two evacuation areas, Evacuation Area 1 and Evacuation Area 2. Their purpose is to provide an appropriate and safe location for the population in case a major disaster strikes the city and people need to be moved out of the city. The two evacuation zones are chosen in the north of the city, because there is an international roadway that joins the Iraqi borders with Syria and Jordan in the west with the capital Baghdad, and the evacuation zones are just a few minutes away from that road. In the south of the city there is the desert only and the connections of roadways in this area are very poor. If there is a need to give medical supplies or transport to injured and affected population, it will be best provided through the international roadway. The area in the east side of the city is mostly is for agriculture land use and is a private property. The west street leads to a nearby city about 30km away, this city has a good hospital but it can be best reached through the northern international roadway. We will discuss the city network and evacuation plan further in Section IV.

C. The Intelligence Layer

We have described the architecture of our proposed emergency response system in Section III.A. Here we give details of the Intelligence Layer (see Fig. 2).

As mentioned in Section III.A, our emergency response system has a System Interface that communicates with various user interfaces and communication gateways. This interface is used to gather and propagate data, information and decisions in order to carry out day to day transport management operations, policy implementations, and emergency response operations. The Intelligence layer consists of various mathematical models, algorithms and simulations, both stochastic and deterministic. These models accept transport related data received from various sensors such as inductive loops, intra-vehicular sensor networks, VANETs and C2I communications, and user interfaces. The data received from various sources goes through an internal validation layer before it is accepted by the modelling and analysis layer. The modelling or simulation algorithm is used for a particular activity based on the nature of the activity. In some cases, it is necessary and/or affordable to employ microscopic traffic models, for example in developing transport policies and procedures; this is due to the demands on higher accuracy and greater flexibility on the available time for decision, optimisation and analysis. In other cases, microscopic simulations may not be necessary, or may not be possible, due to the real-time nature of operations such as day to day transport management operations.

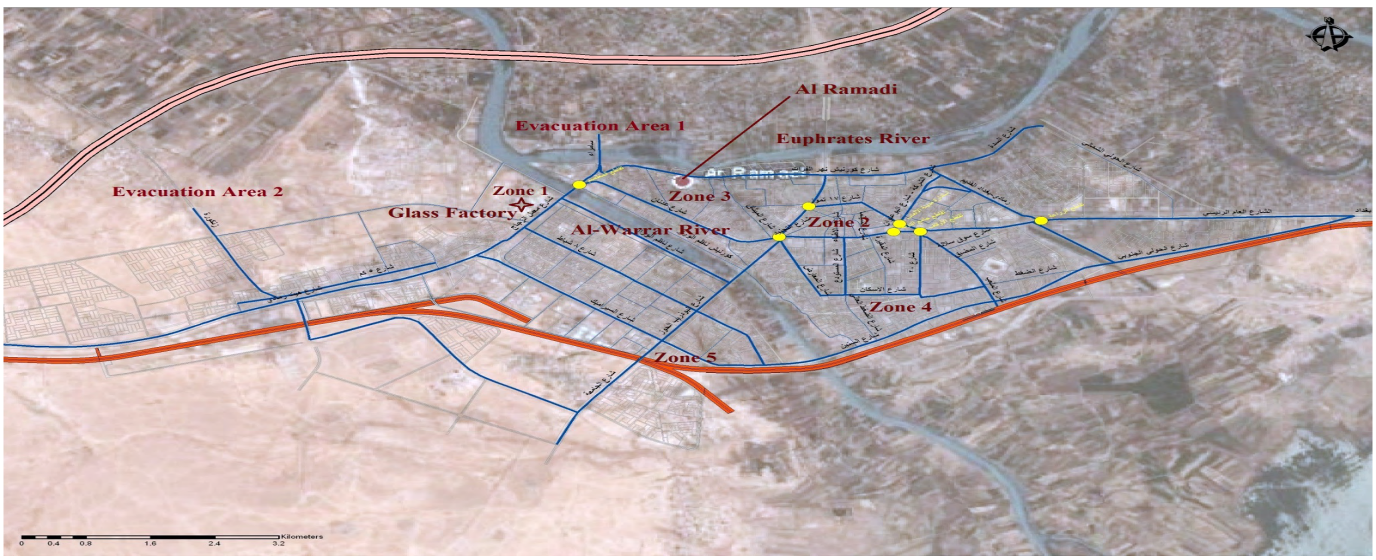

Figure 3. Transportation network of the Ramadi city.

Emergency response systems are an extreme example because, firstly, the availability of real-time data may be greatly limited due to the unavailability of many communication sources due to a disaster (e.g. broken communication links), and secondly, the time period in which the system has to act would be short. In such cases, macroscopic models which require relatively small computational time and resources may be the only option. Which models to invoke in a particular situation is an area of our ongoing investigation and we will continue to improve on our automatic model selection algorithm. We will also be looking at ways of enhancing our distributed algorithms so we could invoke the most precise models for real-time critical situation such as great disasters. It is important to note here that we envisage a Cloud infrastructure which is virtualised and flexible to exist, or moved, outside the area affected by the disaster. This is possible considering the capability of Cloud technology.

We focus on the topic of this paper, i.e. emergency disaster management, and as an example present here some details of a macroscopic model that is used for emergency situations where time to act is short and real time information is limited due to possibly broken communication links. For our work on other types of modelling, in general, see [12] for vehicular grid networks, [17], [18] and [19] for Markov modelling of large systems, and [20] for 3D virtual reality microscopic simulator.

We consider the Lighthill-Whitham-Richards (LWR) model, a macroscopic model, to represent the traffic in the city. The LWR model can be used to analyse the behaviour of traffic in road sections, and describe the dynamic traffic characteristics such as speed (u), density (ρ), and flow (q). The model is derived from the conservation law (first order hyperbolic scalar partial differential equation) by using the following equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u}{\partial x} = 0,$$

where ρ is the traffic density in vehicle/km, and u is the traffic velocity according to distance x and time t.By using

Greenshield traffic model, the relation between ρ and u could be as follows

$$u(\rho) = u_{max} = \left(1 - \frac{\rho}{\rho_{max}}\right),$$

where u_max is the maximum speed, and ρ_max is the maximum density. The fundamental relationship between flow, density, and speed is given by

$$q = \rho * u.$$

In this paper, we will use flow and volume interchangeably. Having given here the mathematical description of the macroscopic model that we employ, in the next section, we will describe our approach for city evacuation in a disaster emergency situation.

IV. System Evaluation

The transportation network of the Ramadi city consisting of zones, nodes, and links has been depicted earlier in Fig. 3. We now make use of our earlier discussions in Section III and describe the disaster scenario in Section IV.A. Subsequently, in Section IV.B, we present analysis of the system and establish its usefulness as a disaster response system.

A. The Disaster Scenario

Consider Fig. 3 which divides the Ramadi city into 5 zones. In Table I, we quantify transportation trends of the city in terms of an Origin-Destination (O-D) matrix between the five city zones. The numbers of trips in the O-D matrix shown are in the mid-week period with natural conditions. These trips are calculated using the Fratar model. Note that the highest rate of trips is toward destination Zone 2 in the city centre.

TABLE I. An O-D Matrix of the Transportation Network in Ramadi City

	zone 1	**zone 2**	**zone 3**	**zone 4**	**zone 5**
zone 1	0	0	0	0	0
zone 2	82	0	172	935	228
zone 3	172	2757	0	1171	108
zone 4	343	10026	381	0	248
zone 5	272	4835	358	1699	0

In Zone 1 lies a glass factory and beside it is Al-Warrar dam; both of these pose major risks to the city. We consider in this paper the risks related to the glass factory and Al-Warrar dam as a case study in order to describe and evaluate our emergency response system. The related potential risks for disaster events in Zone 1 are outlined below:

- ✓ Fire hazards at the main factory
- ✓ Technology failure due to shutdown of power plants that feed the city
- ✓ Explosion of hazardous materials in the glass factory
- ✓ Terrorist attack in the area of the factory
- ✓ The collapse of Al-Warrar dam adjacent to the factory

The above listed disaster events except the last one may last several hours before it will be controlled; for transportation planning purposes, special care is required to handle the emergency situation and saving peoples' lives.

We now focus on a disaster event which could happen in the glass factory. This event could be any one of the potential risks listed earlier in this section, e.g. fire or explosion of hazardous materials in the glass factory. The details of the event are as follows.

1) Timing of the Disaster Event

The traffic conditions in a city typically vary during the course of the week. We consider that the event happens during the mid-week period, say on Tuesday. Our methodology is independent of a particular day/time, although the traffic situation would vary depending on the day and time of the disaster event. Usually the most critical condition in the traffic network is in the morning peak (herein between 7:30 am to 8:30 am) and evening peak hour (2:00 pm to 3:00 pm). These peaks are for official commuters but the commercial activity in the city centre usually begins after 9:00 am, at this time the peak hour are somehow relieved. We consider that the incident happens at 9:30 am. The event causes the network to be closed in the Zone 1 and some nearby road links. An emergency response system is required, at this stage, to coordinate the city transport, communicate with the city population, and lead people out of the city to a safe location. In this case of the Ramadi city, people will be moved to the two evacuation areas (see Fig. 3; we have already discussed the justification of the two evacuation areas in Section III.B). The emergency response systems are discussed and evaluated next.

B. Results and Discussion

We consider and compare two scenarios for emergency response system. Firstly, the traditional emergency response system where people will gain awareness of the disaster situation and response procedure through media such radio, television, telephones (given that such means are still accessible), and through their physical environment (e.g. interacting with the people who are in the nearby area). Secondly, our VANET and Cloud-based intelligent emergency response system, which automatically collects data; intelligently processes the data; and, devises and propagates effective strategies and decisions based on the real-time situation, in line with appropriate policies and procedures already in place in the system. We evaluate the two systems and compare their performance.

1) A Traditional Disaster Response Scenario

A disaster usually causes most people who are in its vicinity to move away from the disaster location. The panic sets off and people start pushing each other without any effective coordination. The situation with vehicles becomes no different, as in the absence of any effective coordination, the roadway sections around a disaster area are blocked, and the incident will spill over like a shockwave over the entire network system. Such a reaction for the Ramadi city caused by a major disaster in the glass factory is depicted in Fig. 4. Note in the figure that the roads, near the factory, that connect Zone

1 with Zones 3 and 5, and with Evacuation Area 1, all are blocked (depicted by the roads coloured in black). Also note that the roads connecting Zones 2, 3 and 4 with each other, all have very low volume below 500 vehicles per hour (depicted by the roads coloured in red). We further note a couple of roads near Zone 2, nearer the outer boundaries of the city, with volumes between 500 and 1000 vehicles per hour (represented by roads coloured in blue). Furthermore, we note that the road which are located at the outer boundaries of the Ramadi city are coloured in brown and green, depicting higher volumes, between 1000 and 1500 (brown), and greater than 1500 vehicles per hour (green), respectively.

The Vehicle volumes that we have computed using our models amounts to 660 vehicles per hour (400 vehicles in the first 30 minutes) after the glass factory incident for Evacuation Area 1, and 2200 vehicle per hour (1000 vehicle in the first 30 minutes) for Evacuation Area 2. Clearly, there are many more vehicles (almost 4 times) reaching Evacuation Area 2 compared to Evacuation Area 1.

The traffic situation painted in the city network of Fig. 3 and described in the paragraph above is calculated using the macroscopic model described in Section III.C; it represents a snapshot taken at 10am, i.e. half an hour after the disaster incident has taken place. The 30 minutes period after the incident gives some opportunity to people to start heading towards, and reaching, safe places (such as evacuation areas) outside the boundaries of the city. This period also gives time for transmission of the information so most of the road users know what is happening and where they should be heading.

A final note on the evacuation process: the public transportation vehicles in Ramadi city consists of buses only. The public transportation vehicles will be involved, where possible, in the cases of emergencies, although it will need a decision from the City Council authorities. There is however a plan in place for emergency events in the Ramadi city that 50% of the public vehicles will be involved in transporting people to safe areas. Since public transportation vehicles have a high passenger capacity, these will be useful in the evacuation process. Thirty minutes after the event, when all the drivers in the event area have received the information about the event by VANET, is an appropriate period to make such a decision of incorporating these public vehicles in the evacuation process.

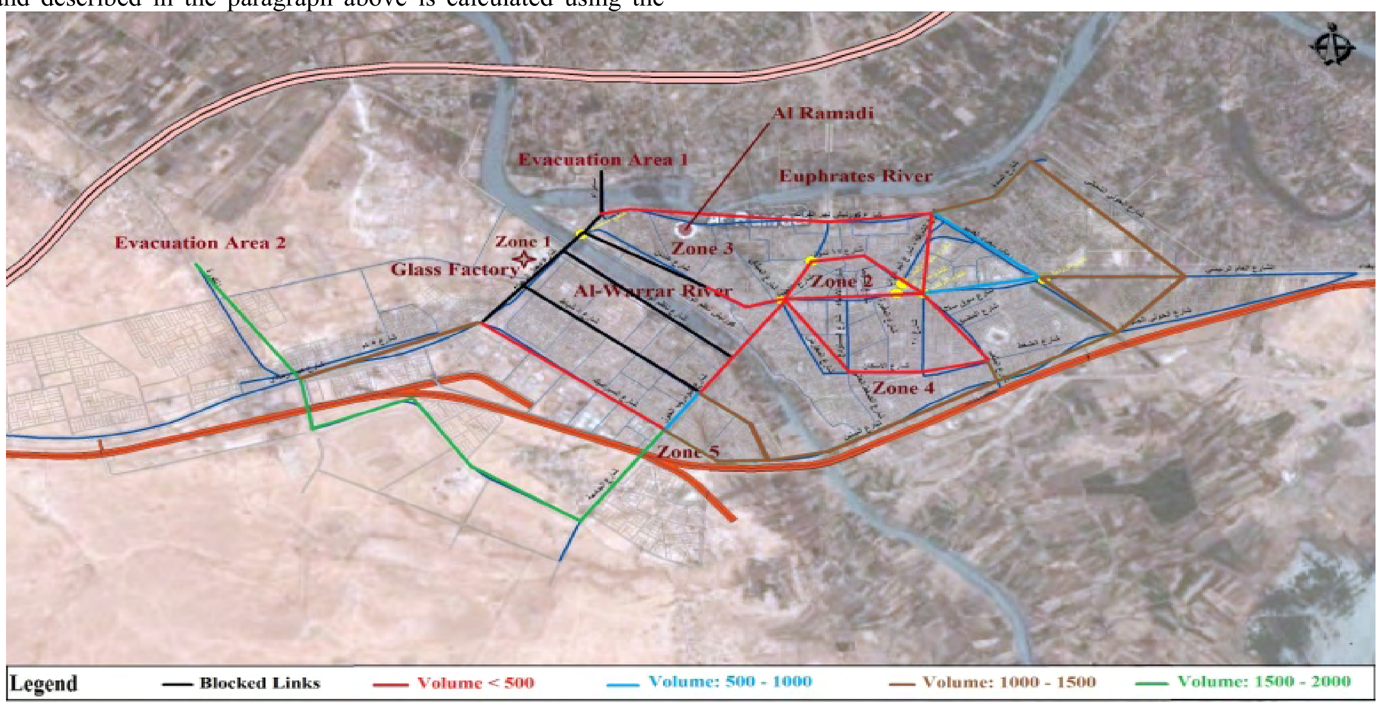

Figure 4. transportation network of the Ramadi city with traditional disaster response system.

2) Inteligent VANET Cloud Emergency Response Sysem

We now evaluate our proposed VANETs and Cloud based disaster response system. All the disaster scenario conditions are same as in the previous section including the role of public transportation in the evacuation process. The difference lies in the ability of the system to (i) acquire real-time data, and establish communication through VANETs, smartphones and social networks, (ii) process the data and devise an optimum strategy by data analysis, and (iii) coordinate and control road traffic and other efforts through dissemination of information and management of the available transport infrastructure (e.g. controlling traffic signals if possible, sending a route map to the traffic navigators and other GPS enabled devices etc). These three steps are iterative and can provide a periodic update to take any real-time changes into account. For instance, the macroscopic modelling in the Intelligence Layer could be used to periodically compute an O-D matrix depending on the type of disaster and real-time traffic conditions. The O-D matrix then can form the basis of information that is propagated to the transport infrastructure and authorities, individuals and groups. Furthermore, certain boundary conditions will be enforced on the city through traffic management systems and authorities, such as (i) there will be no entry in the city, (ii) no entry in the area of event, (iii) many routes will be changed into one way flow outside the event area etc.

The road traffic network situation after the disaster hits the Ramadi city is depicted in Fig. 5, this time though we have exploited our proposed disaster management system to curtail the disaster impact. As in Fig. 4, the network represents a snapshot taken at 10am, half an hour after the disaster incident has taken place. Take a quick look at the two figures, Fig. 4 and Fig. 5, and note the differences – do you see in Fig. 5 less black and red and more roads in green? Note also that the roads leading to both evacuation areas are now green representing clear roads and high flow (1500-2000 vehicles per hour). Moreover, Note that a greater part of the city centre has roads with free flow (i.e. in green colour) except the roads between Zone 1 and Zone 5 which are coloured in red, representing low flow at less than 500 vehicles per hour. The road next to the glass factory is coloured black and represents a broken link. Also, a few roads near Zone 2, nearer the outer boundaries of the city, with low (red), medium (blue) and medium high (brown) volumes. The low volume (less than 500), we believe, is because of the use of alternative roads available in this case towards Evacuation Area 1.

Based on the computations and our models, 2660 vehicles per hour (1260 vehicles in the first 30 minutes) are being evacuated to Evacuation Area 1, and 2860 vehicle per hour (1530 vehicle in the first 30 minutes) are evacuated to Evacuation Area 2. The evacuation volume per hour is almost similar for both evacuation areas. This is clearly a balanced use of the two evacuation areas, an improvement over the traditional disaster management approach reported earlier where the use of Evacuation Area 1 was significantly smaller.

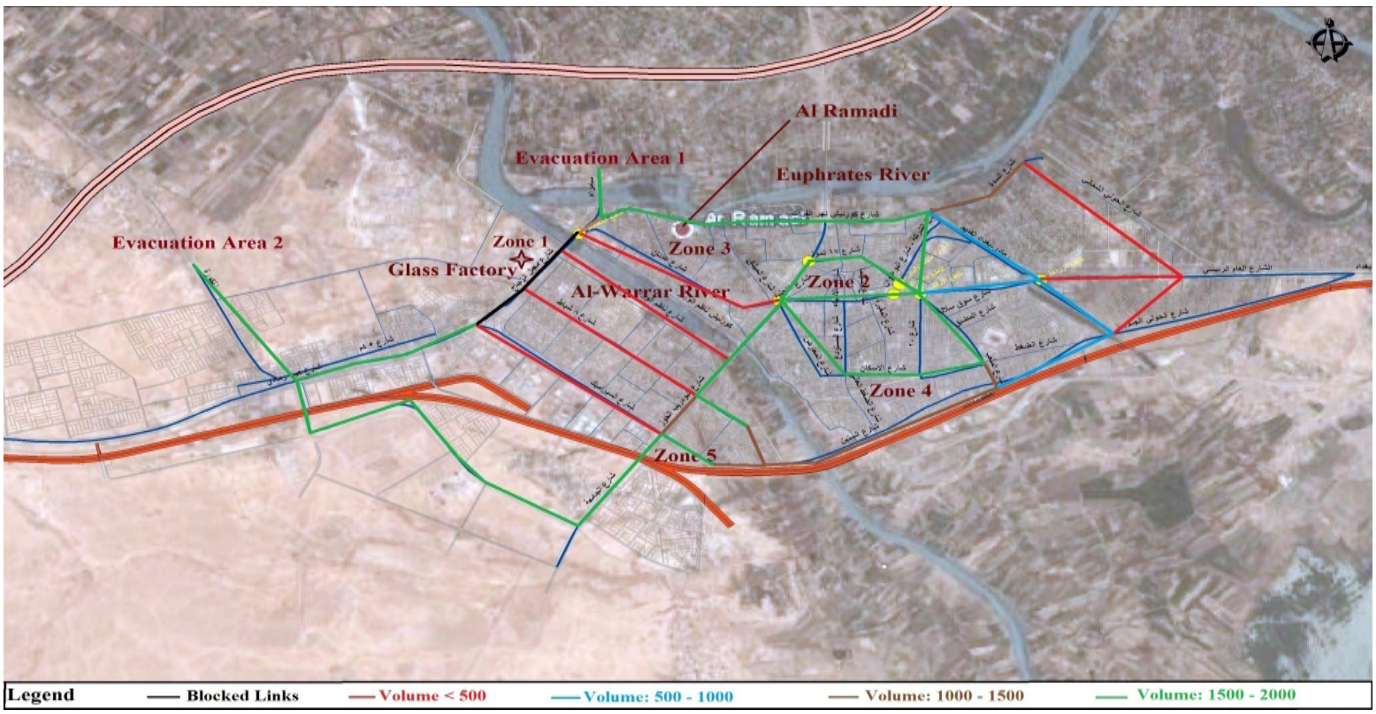

Figure 5. Transportation network of the Ramadi city with our disaster management system.

V. Conclusions And Future Work

The importance of emergency response systems cannot be overemphasized due to the many manmade and natural disasters in the recent years. A greater penetration of ICT in ITS will play a critical role in disaster response and transportation management in order to minimize loss of human life, economic costs and disruptions. In this paper, we exploited ITS, C2X, VANETS, mobile and Cloud computing technologies and proposed an intelligent disaster management system. The system architecture and components were described. The system was evaluated using modelling and simulations and its effectiveness was demonstrated in terms of improved disaster evacuation characteristics. The future work will focus on further analysis and validation of the disaster management system, and on broadening the scope of this work to real-time operational and strategic management of transport infrastructure.

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