Advanced Wireless Technology for Disaster Management System Framework Development

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***Abstract*—This paper describes the development concept of an integrated disaster management system based on advanced wireless communication technology. The aim of the system is to prepare, respond, recover and reduce the risk of a disaster comprehensively by employing the latest technology in wireless communication. The system comprises five main components; Wireless Monitoring and Alert, Resilient Wireless Mesh Network, Energy Harvesting, Mobile Healthcare and Evacuation Management System. The development of a highly reliable and comprehensive disaster management system enables first-hand information to be instantaneously analyzed and acted upon by the most significant people to facilitate the best actions to be taken and relayed to the people in charge.**

***Index Terms*—Disaster Management System; Wireless; Development Concept.**

I. INTRODUCTION

Disaster management is defined as a collective term encompassing all aspects of planning for and responding to disasters, including both pre-disaster and post-disaster activities [1]. It may refer to the management of both the risks and consequences of disaster. According to the International Federation of Red Cross and Red Crescent Societies, disaster management cycle consists of preparing, responding, recovering, and reducing risk of disaster [2].

Although disasters are rare and less severe in Malaysia compared to the neighboring countries, we are not spared from catastrophic events. In the last two decades for example, we experienced Tropical Storm "Greg" in 1996 [3] that destroyed almost 5000 residences, massive floods in the 2000s that brought losses amounting almost RM 1 billion [4] and recently tsunami that killed 74 innocent people. Malaysian government agencies have taken imperative actions in dealing with such disasters by developing forecast, monitoring and warning systems. However, the actions lack integration of all phases in the disaster management cycle, require high cost to ensure their operation are sustainable and reliable as well as lack innovative devices to operate wirelessly, etc.

In this proposal, we introduce a unified program known as Advanced Wireless Technology for Disaster Management System (AWT-DMS) that can prepare, respond, recover and reduce the risk of disaster comprehensively in a single system. This program will support the national agenda that will bring Malaysia onto the same pedestal with the developed nations, and should be regarded as one of the Entry Point Projects (EPP) for the Government Economic Transformation Program (ETP). The aim of AWT-DMS is to develop an integrated disaster management system, which comprises Wireless Monitoring and Alert, Resilient Wireless Mesh Network, Energy Harvesting, Mobile Healthcare and Evacuation Management System.

The project of Disaster Monitoring and Alert will improve the preparation and response toward the incident of disaster and will apply existing wireless communication technologies such as GPS, GSM and WiMAX. A multi-radio router/sensor with ad-hoc Resilient Wireless Mesh Network connectivity is proposed to create a robust infrastructure that can be deployed at the disaster site. These mesh networks will be used to interlink between different wireless communication technologies. As sensors and devices are normally powered by batteries or power supply, which is interrupted during disasters, Energy Harvesting from enclosed environment with exposure to vibrations, heat, force and wind flow can be exploited by converting the waste energy into useful electrical energy for powering low power miniature electronic devices. The converted energy from energy harvesting will extend the battery lifespan for a sustainable and reliable system.

At a crowded disaster scene, where injured victims far outnumber caregivers, Mobile Healthcare can be used to monitor these post-disaster patients. As it is almost impossible to use cables at the disaster site, a wireless infrastructure including body area biomedical sensor networks is desired to monitor remotely the status of the patients. Data gathered from the sensor network and communicate wirelessly can be used by the caregivers to locate the position of the patients, monitor health status through measuring body signals, and alert caregivers of significant events in an efficient way.

In dealing with disasters, evacuation is a challenging issue since evacuees have difficulties to find the best or optimal evacuation routes, especially in high-rise buildings. Getting out of the building during the emergency poses special challenges even though such building has been supported by appropriate exits, alarms, emergency lighting, communication systems, and sprinkler systems. Furthermore, with the complex man-made infrastructures and human behavior during the evacuation process, finding task process gets increasingly difficult. The process becomes critical, when an ongoing hazard is present in the building. This behavior will slow down the evacuation process, causing a collision with other evacuees and congestion at the exit. Therefore, it is crucial to prepare in advanced a safe evacuation of high-rise building with comprehensive Evacuation Management System.

The development of a highly reliable and comprehensive

disaster management system enables first-hand information to be instantaneously analyzed and acted upon by most significant people to facilitate the best actions to be taken and relayed to the people in charge. It is expected that these technologies will create a new platform for Malaysia to be a leader in disaster management

II. System Background

The Malaysian National Security Council Directive 20 [5] defines disaster as "an emergency situation of some complexity that will cause the loss of lives, damage property and the environment, and hamper local social and economic activities".

Malaysia often face the aftermath of natural disasters that cause damage to property, loss of life and displacement of the population. For example, Tropical Storm "Greg" hit the West Coast on December 26, 1996, in which more than 200 people were killed and 4925 houses destroyed. Another incident was a massive flood throughout the country in 2006 & 2007 has resulted in losses with an estimation of RM776 million to the nation [6]. Moreover, the tsunami that hit the West Coast of Peninsular Malaysia on 26 December 2004 has resulted in 74 fatalities and 8000 displaced people [7]. Recent earthquakes that happened in Indonesia caused tremors that can be felt in Bukit Tinggi, Pahang and Selangor [8].

A comparison between the developed and under-developed nations in terms of casualties during disasters shows that the damage is higher in the under-developed nation. For example, developed countries such as Japan and Korea experienced less calamities compared to Indonesia, Bangladesh and the Philippines. One of the main reasons is due to poor relay of aftermath critical information. Many decisions were made by various officers in charge, from different units and departments confusing the situation further resulting in delay on the effective responses.

In Malaysia, there are several actions that have been taken by the responsible agencies [5]. For example, *Jabatan Meteorologi Malaysia* (JMM) is the lead agency in providing forecasts and early warnings to countries in matters relating to meteorology and seismic in the country. National Tsunami Early Warning System Malaysia (SAATNM) has been developed, involving the installation of two units of tsunami buoys at Rondo Island and Pulau Layang-Layang [9]. This system will enable the country to get an early warning in the event of an earthquake and tsunami in the Indian Ocean, South China Sea and the Pacific Ocean. JMM also has developed a Disaster Fixed-Line Alert System for tsunami warning which allows people living within 3 kilometers from the coastal areas to receive alert and evacuate to safer areas. Department of Environment Malaysia has developed 51 air-quality monitoring stations throughout Peninsular Malaysia to monitor the air pollution index in the country. *Jabatan Pengaliran dan Saliran* has provided Urban Stormwater Management Manual to tackle flash flood events in urban area.

While government and private agencies have join forces in addressing disasters, there is no system at the moment that addresses the preparation, response, recovery, and risk reduction of disasters comprehensively. It is, therefore crucial to develop a unified system that integrates all four disaster phases as is being proposed here; it is referred to as Advanced Wireless Technology for Disaster Management System (AWT-DMS). Figure 1 shows the framework of the research program including the research groups involved, their position in the framework and linkages in the disaster phases.

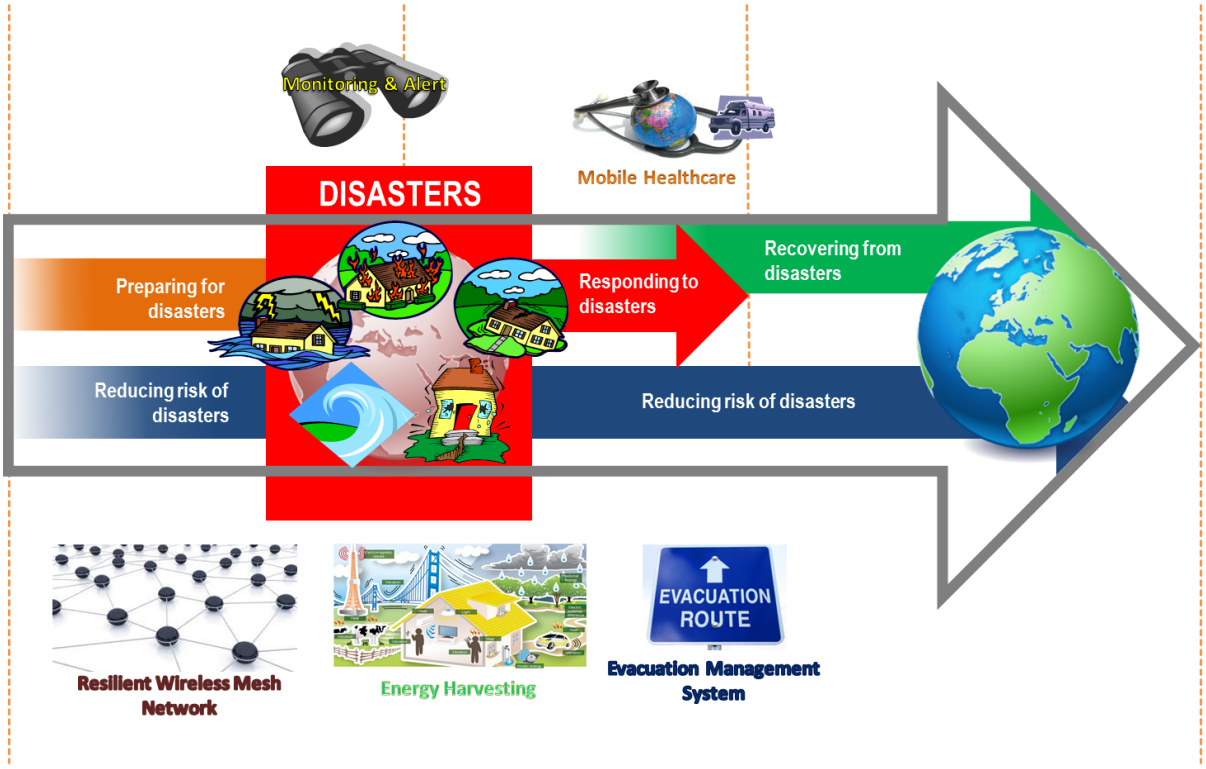

Figure 1: Overview of the Advanced Wireless Technology for Disaster Management System

III. DESCRIPTION OF THE CONCEPT

This program embarks on the following objectives:

- To model, develop and test an integrated disaster monitoring system utilizing advanced wireless technologies
- To develop and examine resilient and secure wireless infrastructure that can be deployed at disaster sites to assist in rescue missions
- To design, fabricate and measure the effectiveness of energy harvesting system for powering sensors and low-powered critical devices during disasters
- To analyze, design and assess patient monitoring system utilizing a wireless infrastructure including body area biomedical sensor networks to monitor remotely the status of the patients during disasters
- To develop and evaluate Evacuation Preparedness Algorithm for Critical Incident to assist in preparing for and reducing the risk of disasters.

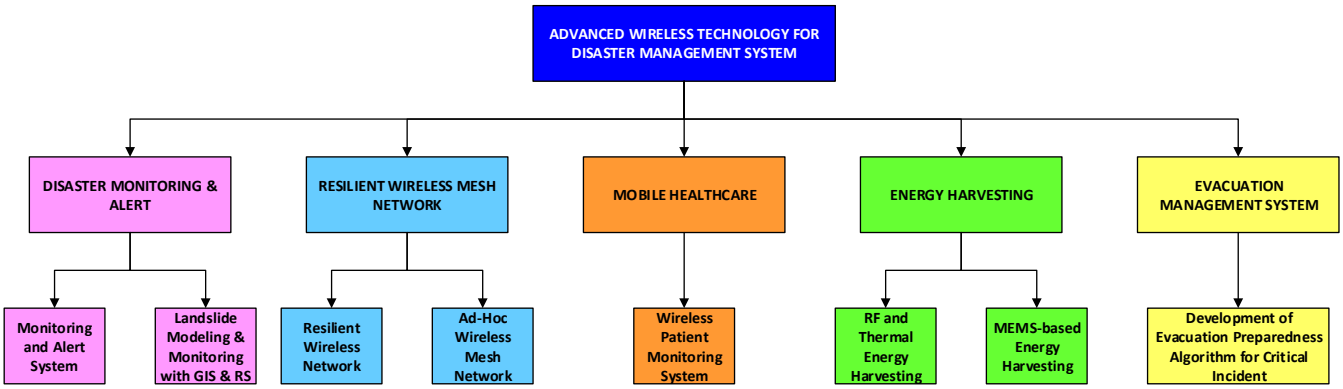

Figure 1: Overview of the Advanced Wireless Technology for Disaster Management System

IV. METHODOLOGIES

The description of the projects shown in Figure 2 are as below:

A. Monitoring and Alert System

In this project, sensor node coordinate location will be formulated with a predefined zone for optimized wireless communication. The sensor nodes will be optimized in terms of the power usage to conserve energy. A routing algorithm will also be developed for efficient data transfer between the nodes.

B. Landslide Modeling & Monitoring with Geographic Information System (GIS) & Remote Sensing (RS)

In this project, a reliable RS technology will be developed to perform accurate measurements of landslides. The RS and GIS technology will be integrated with real-time wireless technology. This will allow a proper understanding of landslides based on RS and wireless measurements.

C. Resilient Wireless Network

A literature review on resiliency and security in wireless communication and network will be conducted which include investigation and identification on resiliency components and risk analysis on security issues for wireless communication. A secured and resilient wireless communication and network architecture will then be designed and developed. The architecture consists of survivability modeling, feature extraction sub-system based on the parameter selection, flaws detection sub-system, crypto sub-system, preventive sub-system, authentication and access control module.

The system prototype will consist of module development for all sub-systems, integrating modules and prototype validation in term of functionality and accuracy of detection, recovery and proposed security solution. Advanced wireless technology such as WiMAX, LTE and UWB will be employed to provide enhance various applications such as location and positioning [10, 11, 12].

D. Ad-Hoc Wireless Mesh Network

The study in this project will be conducted based on different protocol layer:

(a) Physical layer: Propagation study for reliable communication in chaos environment (building collapse)
(b) Medium Access Control layer: Short signaling for reduce the number of handshaking.
(c) Link layer: Study of IEEE 802.11s (draft) to form resilient Wireless Mesh Network.
(d) Network layer: Solving Spatial Bias issue and network buffer management in WND.

At system level, power management of WNDs (maintain minimum number of WNDs to establish to WMN) will be studied. Based on the studies, an ad-hoc wireless mesh network prototype will be developed.

E. Wireless Patient Monitoring System

The ability to continuously monitor vital signs of patients are crucial especially in emergency situation. Wireless technology will be employed to allow monitoring to be done remotely. Several key tasks will be conducted in developing a wireless patient monitoring system such as:

(a) Feasibility studies on vital signs selection and sensor type as well as location identification.
(b) Development of efficient data compression algorithms to enable concurrent monitoring of a large number of patients.
(c) Design and development of advanced biomedical signal & image processing techniques for objective early diagnosis in particular.

(d) Integrating the above mentioned components into a workable system that can be quickly deployed at a disaster site, for large numbers of patients.
(e) Investigation and development of security system to ensure privacy and reliability of patient data.

F. RF & Thermal Energy Harvesting

In emergency situation such as disaster, energy usage is critical because the energy sources might be limited or have been compromised. Therefore, several advanced energy harvesting techniques will be deployed to provide sufficient energy to power critical devices needed in disaster situation. Two of the energy harvesting techniques and the scope of research are:

(a) RF Energy Harvesting
- Broad background research on RF energy harvesting on critical selection of the antenna, harvesting circuit and storage.
- Design and develop of the suitable and compact broadband antenna.
- Design and analyze the development the compact broadband RF circuit and storage circuit using lumped elements or microstrip circuit
- Design and development the compact broadband RF circuit.
- Integrate the antenna and the circuit and analyze the performance for a workable system that can be rapidly set up during the disaster.

(b) Thermal Energy Harvesting
- Investigation and simulation of different energy harvester specifications to find the optimum converted electrical energy using minimum cost.
- Investigation and simulation of different power management circuit configurations to find the optimum and continuous boosted electrical energy using compact electrical components.
- Design and development of the optimum energy harvester and power management circuits.
- Integration of the optimum energy harvester and power management circuits with microcontroller, wireless transceiver and sensors for proof-of-concept.
- Test and evaluate the performance of the thermoelectric generator and power manager for wireless sensor systems.

G. MEMS-based Energy Harvesting

Energy harvesting can also be done using Micro-Electro-Mechanical Systems (MEMS). Three stages of MEMS-based energy harvesting are:

(a) Stage 1: Design resonant based micro-generators.
- Piezoelectric based MEMS micro-generators in the form of cantilever will be designed to suit their natural frequencies to the real machinery excited frequencies operated in industries.
- The frequency responses of the piezoelectric cantilevers will be analyzed.
- Optimization on electrical power output from the devices will be carried out by means of mechanically and electrically.

(b) Stage 2: Fabrication and Integration of electronic components.
- The tailor-made micro-generators will then be integrated with other electronic component to make a complete wireless sensor node, which comprising of storage circuit, power conditioning circuit, micro-controller unit, sensors and radio frequency integrated circuit.
- The system will be designed based on low power and event triggered operations.
- The whole electronic system will be enclosed in a match-box sized housing for easy and convenient handling purposes.

(c) Stage 3: Test and evaluate the performance of the micro-generator
- The micro-generator will be tested at low level of vibration, with acceleration levels from 0.01 g – 1 g and frequency from 5 Hz – 2 kHz.
- The performance of the piezoelectric micro-generator will be analyzed and compare with other researchers' work.

H. Development of Evacuation Preparedness Algorithm for Critical Incident

An advanced algorithm to evaluate evacuation preparedness in critical incident will be developed. This algorithm is crucial because it can help assist various related agencies to respond to emergencies. The algorithm development will consists of:

(a) Soft Systems Thinking Approaches.
- 2D Model of Building (Geometry and logical model)
- Dynamic Implementation (Sprinkler and signage)

(b) Design, develop and test Route Calculation Algorithm.

V. CONCLUSION

The development concept of an integrated disaster management system based on advanced wireless communication technology has been presented in this paper. The development of a highly reliable and comprehensive disaster management system employing latest wireless telecommunication technologies will assist the related agencies to prepare, respond, recover and reduce the risk of a disaster comprehensively by employing the latest technology in wireless communication. The five main components of the system; Wireless Monitoring and Alert, Resilient Wireless Mesh Network, Energy Harvesting, Mobile Healthcare and Evacuation Management System, will enable first-hand information to be evaluated and acted upon instantaneously.

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