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## THE USE OF BGAN TO IMPLEMENT A ROBUST TSUNAMI EARLY WARNING SYSTEM

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for the degree of Master of Science in Technology

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**Abstract of the Master's Thesis**

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<p>A tsunami is a series of waves created when a body of water, such as an ocean, is rapidly displaced probably by an oceanic earthquake. The effects of a tsunami for the population can be devastating due to the immense volumes of water and energy involved</p> <p>The EU-funded Distant Early Warning System (DEWS) project is currently implementing a reference model for a national and regional warning dissemination system of possible hazards or disasters, especially in the prevention of tsunamis. In DEWS several universities and companies are participating specially coming from Europe and from the three countries of interest Sri Lanka, Indonesia and Thailand.</p> <p>The Department of Communications and Networking of the Helsinki University of Technology (TKK) is a consortium member of the DEWS project working on the development of the communications architecture between the different Emergency Centres, first responders and general public.</p> <p>In this thesis report we present the implementation of a backup satellite communications system between DEWS centres and governmental authorities in order to enable the warning dissemination in case the terrestrial communication structures are disrupted due to the hazard effects.</p> <p>The backup communications structure would employ the BGAN Inmarsat service for the data transmission. BGAN ensures the coverage in almost global earth area and support mobility on its terminals, offering adequate characteristics for an emergency communications system. To that end, we design and describe this communications architecture and discuss its performance in the possible scenarios based on simulations.</p>	
<b>Keywords:</b>	BGAN, Early Warning System, DEWS, Tsunami

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<p>Un tsunami es una serie de olas creadas cuando una gran masa de agua es rápidamente desplazada posiblemente debido a un terremoto subacuático. Los efectos del tsunami para la población pueden ser devastadores debido a los inmensos volúmenes de agua y energía envueltos.</p> <p>El proyecto DEWS fundado por la UE actualmente está implementando un modelo de referencia para la creación de un sistema nacional y regional de diseminación de alarmas frente a posibles desastres, especialmente focalizado a tsunamis. En DEWS están participando varias universidades y empresas provenientes de Europa y de los tres países de interés: Sri Lanka, Indonesia y Tailandia.</p> <p>El Departamento de Electrónica y Comunicaciones y Redes de la Universidad Tecnológica de Helsinki es miembro del proyecto DEWS trabajando en el desarrollo de la arquitectura de comunicaciones entre los diferentes Centros de Alarma, las autoridades y el público en general.</p> <p>En este texto presentamos la implementación de un sistema de reserva basado en comunicaciones por satélite entre los centros DEWS y las autoridades para permitir la diseminación de la alarma en el caso de que el resto de vías estén inutilizadas</p> <p>El sistema de reserva está basado en el servicio BGAN de Inmarsat. BGAN tiene cobertura en la mayoría del territorio terrestre y soporta movilidad en sus terminales, ofreciendo las características adecuadas para un sistema de alarma. Con este fin se ha diseñado la arquitectura de comunicaciones de este sistema y se ha discutido su rendimiento basado en las simulaciones desarrolladas</p>	
<b>Palabras Clave:</b>	BGAN, Sistema de Alarma Anticipada, DEWS, Tsunami

# **PREFACE**

This Final Project Thesis report has been developed based on the work performed for the DEWS project in Communications Laboratory at the Department of Electrical and Communications Engineering in the Helsinki University of Technology.

First of all, I would like to thank Dr. Edward Mutafulungwa for the opportunity to write this thesis for the DEWS project and for his assistance and valuable guidance during the course of my work. I am also grateful to the Professor Jyri Hämäläinen for his help in the development of my work. Finally, I am thankful also to Krisztina Cziner for giving me the opportunity to collaborate with the Communications Laboratory.

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I would like to thank my family and all my friends for the support and care given during this period. Finally, I dedicate this thesis to the good friends known along my period in Finland, we will all continue with our different paths in live but we will always remember.

Espoo, June 2008

Jose de la Fuente Abad

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# LIST OF ACRONYMS

ACK	Acknowledgment
API	Application Programming Interface
APN	Access Point Name
BGAN	Broadband Global Area Network
BMG	Badan Meteorologi Dan Geofisika
BPPT	Badan Pengkajian Dan Penerapan Teknologi
BTS	Base Transceiver Station
CAP	Common Alerting Protocol
CBR	Constant Bit Rate
CDMA	Code Division Multiple Access
CONDWA	Committee on National Disaster Warning Administration
COPNDWS	Committee on Policy of the National Disaster Warning System
CS	Circuit Switched
DEWS	Distant Early Warning System
DHCP	Dynamic Host Configuration Protocol
DMC	Disaster Management Centre
DVB-RCS	Digital Video Broadcasting - Return Channel via Satellite
ESA	European Space Agency
ETSI	European Telecommunications Standards Institute
EWG	Early Warning Centre
FEC	Forward Error Correction
FTP	File Transfer Protocol
GITEWS	German Indonesian Tsunami Early Warning System
GSM	Global System for Mobile communications
GPS	Global Positioning System
GFZ	GeoForschungsZentrum Potsdam
HMI	Human Machine Interface
HNS	Hughes Network Systems
ICT	Information and Communications Technology
IEC	International Electrotechnical Commission



IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
INCO	International Cooperation
IP	Internet Protocol
IPSec	Internet Protocol Security
ISO	International Organization for Standardization
JMA	Japan Meteorological Agency
L2F	Layer 2 Forward Protocol
L2TP	Layer 2 Tunnelling Protocol
LAN	Local-Area Network
LLC	Limited Liability Company
MPPE	Microsoft Point-to-Point Encryption
NAT	Network Address Translation
NCDM	National Council for Disaster Management
NDWC	National Disaster Warning Centre
NEITWC	National Earthquake Information and Tsunami Warning Centre
NGO	Non-Governmental Organization
OBU	Ocean Bottom Unit
OSI	Open Systems Interconnection
PASTI	Pasifik Satelit Nusantara
PDP	Programmed Data Processor
PEP	Performance Enhancement Proxy
PPP	Point-to-Point Protocol
PPTP	Point-to-Point Tunneling Protocol
PS	Packet Switched
PTWC	Pacific Tsunami Warning Center
QoS	Quality of service
REITWC	Regional Earthquake Information and Tsunami Warning Centre
SAS	Satellite Access Stations
SOA	Service Oriented Architecture
SMS	Short Message Service
TC SES	Technical Committee for Satellite Earth Stations

TCP	Transmission Control Protocol
TDMA	Time Division Multiple Access
TFT	Traffic Flow Templates
TISS	Terrestrial Interface SubSystem
TOT	Telephone Organization of Thailand
UDP	User Datagram Protocol
UML	Unified Modeling Language
USB	Universal Serial Bus
UT	User Terminal
VBR	Variable bit rate
VPN	Virtual Private Network
VSAT	Very Small Aperture Terminal
WAN	Wide Area Network
WP	Work Package

# 1. INTRODUCTION

## *1.1. Motivation*

At December 26 of 2004 an earthquake with a magnitude from 9.1 to 9.3 took place next to the west coast of Sumatra, Indonesia. As a consequence of the earthquake a set of tsunamis were formed, resulting in thousands of casualties in eleven countries. At that moment there were no prevention systems among the Indian Ocean and no warning systems to make the population be aware of the imminent tsunami event.

Several natural or human-made disasters may occur, such as, earthquakes, epidemics, terrorism, in any given country. The preparation and planning against these possible events reduces the human casualties and material losses. The tsunami of 2004 made the authorities realize the necessity of developing effective warning systems to alert the population of impending tsunami hazards and improve the international cooperation among the possible affected countries.

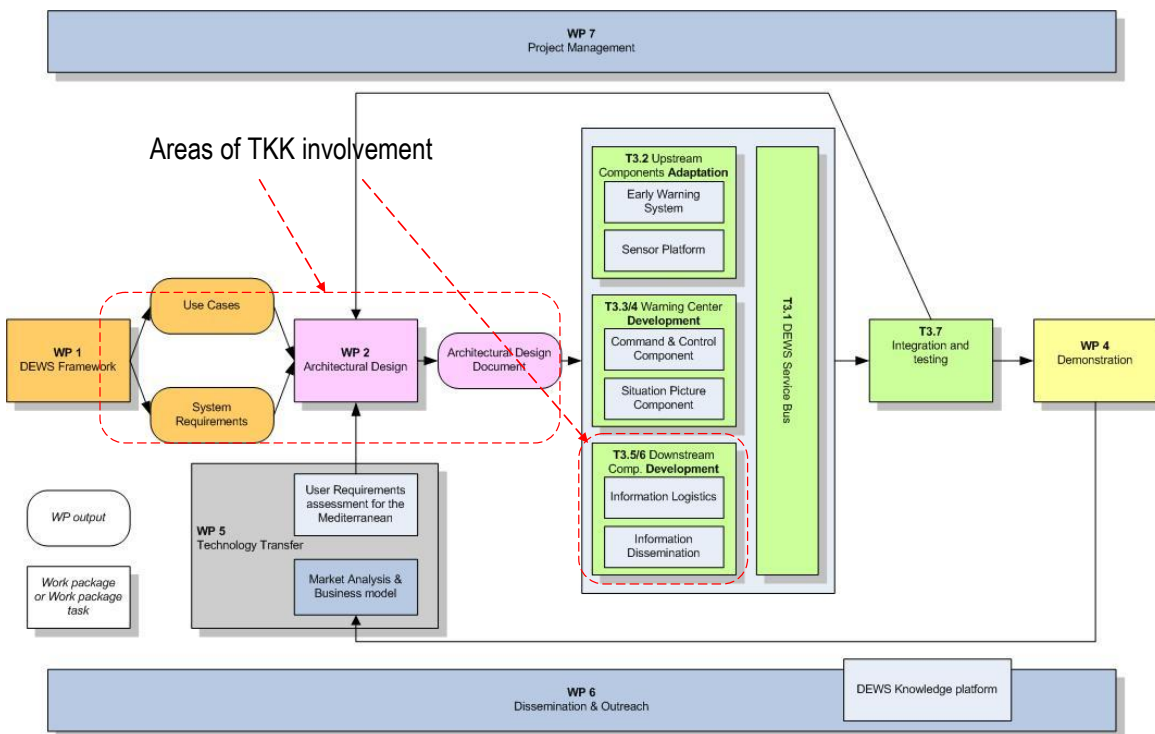
A tsunami is a series of ocean surface waves generated by a submarine earthquake, submarine volcanic eruption, landslide, or meteor impact. Offshore earthquakes are by far the most common cause of tsunamis [50]. The detection of a tsunami is possible due to the use of seismic and sea level sensors and ground movement monitoring, enabling the reduction of the time between when the earthquake occurs to the moment when the warning centers are aware of the tsunami and are able to send the warning to the authorities and population.

## *1.2. Background on DEWS Project*

One of the many initiatives being implemented in response to this requirement for tsunami warning systems is the European Union (EU) funded Distant Early Warning System (DEWS) project. The objective of the DEWS project is to design a Reference Model to promote the integration of the warning capacities which already exist by the creation of an innovated tsunami early warning system in Indonesia, Sri Lanka and Thailand, henceforth referred to as INCO or Indian Ocean Countries. The DEWS project brings together partners from academia, industry and public authorities, from the EU as well as the INCO countries,

sharing knowledge and technology to perform the different tasks to develop the DEWS model.

The design and implementation of the DEWS system is divided into seven work packages (WP), each constituting several key tasks. Among these seven packages the Helsinki University of Technology is involved in WP1, WP2 and WP3 (see Figure 1). The objective of the WP1 is to provide a deep understanding for the design and development of DEWS by compiling information about the user requirements, system requirements and relevant standards among the countries of interest. WP2 will design the DEWS architecture and create the technical specifications for the implementation. The WP3 involves the development of interfaces of the service bus between the DEWS centers with the sensor platform and other DEWS centers; and dissemination of alerts, warning or notifications messages to external user groups [15].



**Figure 1 Logical flow of technical activities in the DEWS project**

### ***1.3. Main Research Contribution***

This thesis analyzes the performance of the satellite communication links between Early Warning Centres and first responders based on the Broadband Global Area Network (BGAN) technology. The telecommunication system among the DEWS centres is simulated using the multi-core enabled network simulation software Qualnet.

BGAN enables the DEWS centres to implement a telecommunications system independent of the situation of the terrestrial infrastructures. This service can be used as a backup of the usual technologies of the different centres as well as to obtain direct communication links with first responders. Therefore, the DEWS communications architecture is made robust by the use redundant satellite links in order to assure an appropriate performance in the dissemination of the warning messages.

The BGAN backup will provide the Early Warning Centres (EWC) with the same services obtained in the common access to the telecommunications networks in order to assure the adequate communication between EWCs and EWC and first responders.

In the simulations we analyze the performance of these BGAN links on the possible scenarios of DEWS based on the different technologies and characteristics of the dissemination processes. The User Terminal model, the type of warning message to disseminate, the characteristics of the emergency system structure and so forth will influence in critical performance indicators such as the time delay of the message transmission.

The thesis also contributes with the recompilation for the WP1 of IT national statistics in the countries of operation in order to provide reliable arguments for the necessity of including satellite links to achieve appropriate performance.

### ***1.4. Organization of the Report***

The background and main research contribution of this report has been summarized in Section 1. The rest of the report is organized as follows. Section 2 provides a general introduction in areas of interest in the telecommunications field. After, the Section 3

provides the necessary information about the DEWS system structure and flows of work within it.

Section 4 describes the objectives of the simulation process as well as the technologies employed. Then Section 5 provides an analysis of the results achieved in the simulations and Section 6 summarizes the conclusions. In addition the Annexes contain the statistical information compiled in the first part of our work performed for DEWS.

## **2. PROBLEM STATEMENT**

The model developed by DEWS promotes the integration of national and regional warning centers controlling and managing flows of upstream information, from the sensors to the warning centers, and of downstream information, from the warning centers to the authorities and population. DEWS will cover the technical field, such as the interaction with the different sensors and the design of the dissemination channels of communications, and also the organizational field, working with the cooperation and communication between different warning centers of different regions or countries.

The reference model works from an Enterprise field, providing business processes in early warning systems based on international standards, an Information field, dealing with the analysis of the upstream and downstream information and a Computational field, focused in the decomposition of the system into a set of services [1].

### ***2.1. Communications view***

The designed model establishes a communication system to send the upstream information from the sensors to the warning centers and the downstream information from the warning centers to the authorities and population.

#### **2.1.1 Warning Centers**

The warning centers will manage data from the different flows of upstream information and they will create a situation picture to determine the risks and the possibilities of an imminent tsunami in order to prepare the communications channels to disseminate the warnings.

The implementation of the DEWS reference model consists of three national early warning centers each attending their own independent set of sensors and several regional centers that enable exchange of measurement data and other information between the three centers [1].

### 2.1.2 Upstream flow

The upstream components will acquire data coming from different sensors such as seismic sensors, buoys, tide gauges, and so forth. Since the most of the sensors already installed are designed for different scientific disciplines, the objective of the sensor system is to collect the different data and offer all the information via a standard interface.

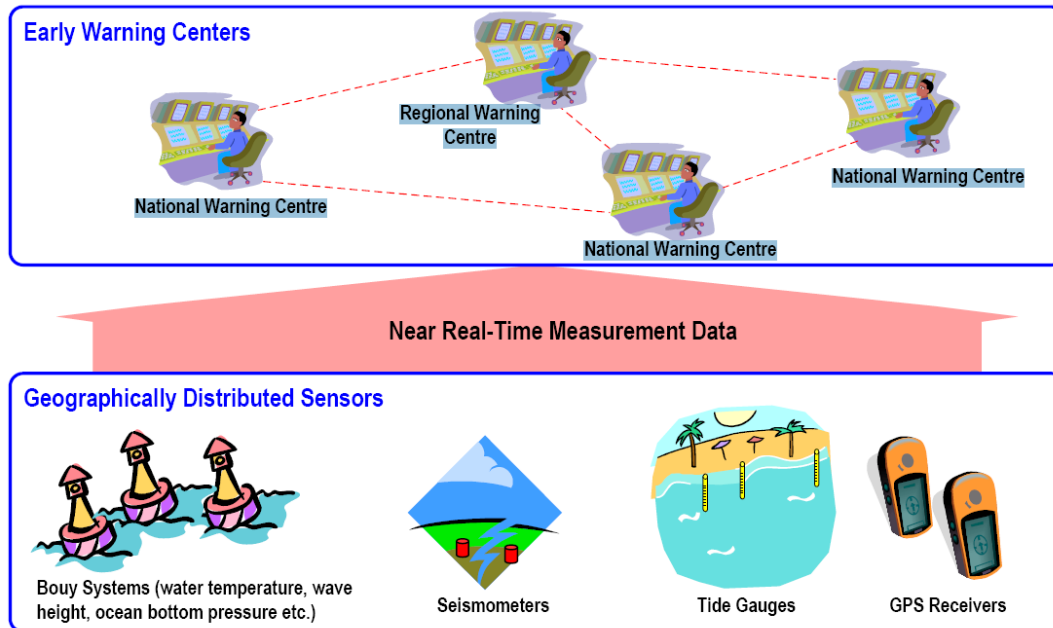


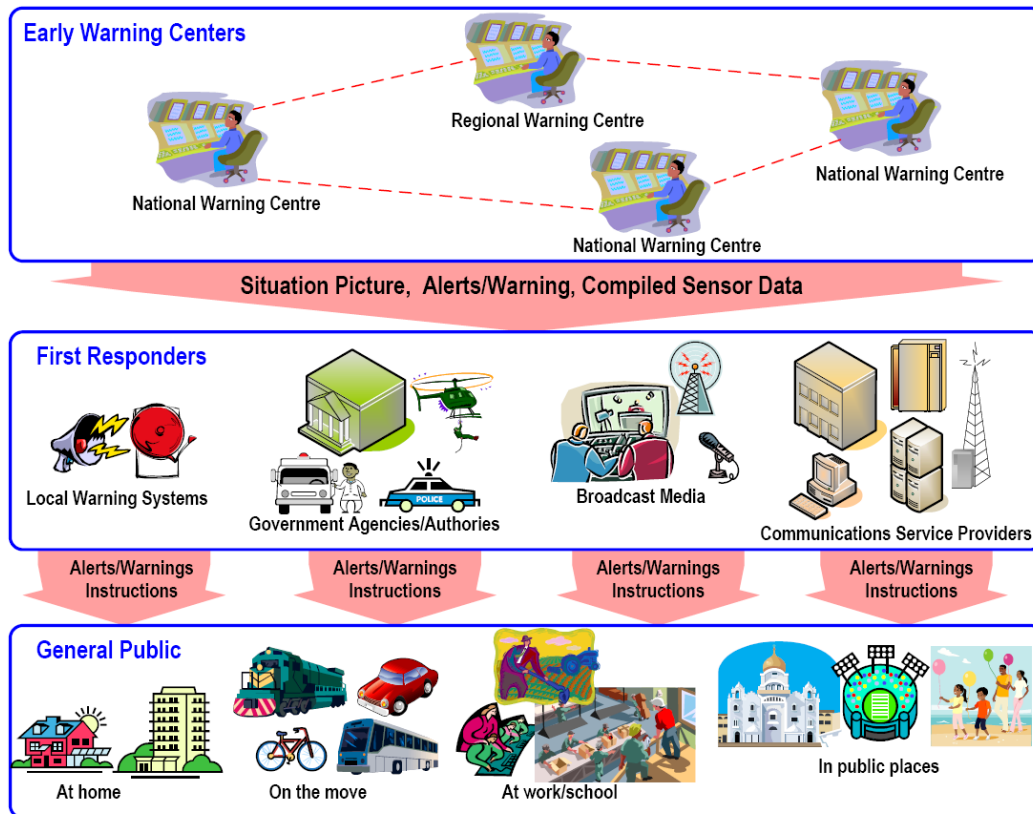
Figure 2 Upstream information flow

The upstream components also develop an evaluation of the measures in order to monitor the data obtained. The sensor and the tsunami monitoring system are contribution of the GITEWS project already developed by GFZ in the Indian Ocean [24].

### 2.1.3 Downstream flow

The downstream component will disseminate the warning message after defining the objective recipients and the information which may be appropriate to be broadcasted. The communication network will allow the broadcasting of the warnings by several different channels with the possibility of including priorities in the dissemination and communication between the different warning centers with backup channels in case of line failures. The DEWS downstream segment constitutes two key components: the information logistics component and the information dissemination component.





**Figure 3 Downstream information flow**

The information logistics component acquires the content of the warning messages based on the situation picture and prepare their compilation in a standard form, in order to be sent to the different possible users:

- Authorities
- Local warning systems
- Media
- The public

The information dissemination component converts the warning messages into data formats suited to particular outbound physical communication channels.

### 2.1.4 Service Objectives

The authorities must ensure that sufficient information about an imminent disaster can reach the maximum number of people in the areas of risk, in addition private organizations, charities and NGOs must also be aware of the situation [18]. The dissemination of the

warning messages has to deal with the different possible scenarios where the public may be located such as:

- Citizens in their own dwelling.
- Citizens at their place of work.
- Citizens in public venues (i.e. sports complexes, shopping malls, etc.).
- Citizens traveling on foot.
- Citizens traveling in a vehicle.

To reach all this possible contexts a wide number of possibilities in the dissemination channels are offered in order to assure the notification to the entire population at risk.

In addition the messages should be distributed in a standardized model only to the people at risk in an understandable way, also taking into account the possibility of people with other languages or disabilities.

### **2.1.5 Possible Communication Channels**

The reference model designed in DEWS must ensure the dissemination of the warning messages to all types of public, in all the possible scenarios. In addition, simple channels could be more effective than the modern technologies available in the area. The most important possibilities would be:

- The media such as Broadcast Television and Radio are one of the most important options in order to reach the population in a fast and effective way; both of them have high levels of penetration even in non-developed countries and involve an appropriate way to reach rural areas.
- Siren systems also provide an effective channels to disseminate the warning message, allowing the authorities to activate the devices by radio in order to broadcast pre-recorded messages.
- In developing countries mobile phones have higher penetration rates than fixed lines what brings us a new possible channel to disseminate the warning; however the possibilities of overloading the network in the moment of the disaster oblige the warning system to provide more options.

- Furthermore, Internet and email systems have relatively low usage in the possible risk areas so their use is still limited in the context disseminating warning messages to the general public.

The majority of the telecommunications infrastructures supporting these different channels of dissemination will be at risk during the natural disaster. In addition, terrestrial antennas and repeaters may not have enough coverage in the areas [53]. Therefore, the use of satellite communications gives a reliable backup solution which will be the main focus for of the studies presented in the next chapters.

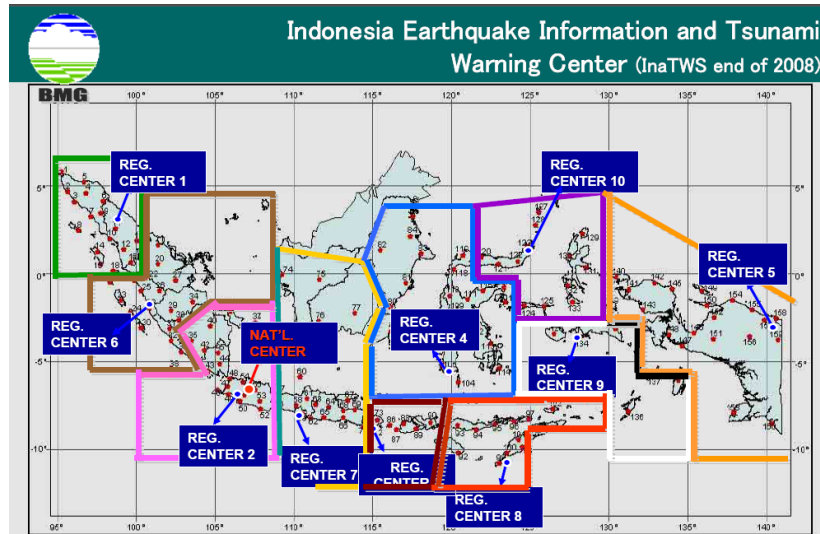
## ***2.2. Regional Overview***

### **2.2.1 Indonesia Overview**

In Indonesia the government has already developed the National Earthquake Information Centre in Jakarta hosted by the meteorological agency Badan Meteorologi Dan Geofisika (BMG) and is being upgraded into the Indonesian National Earthquake Information and Tsunami Warning Centre (NEITWC), replacing the interactive data processing with automatic processes.

In addition ten Regional Earthquake Information and Tsunami Warning Centers (REITWC) exist in Indonesia; all of them receive data of their particular network of seismograph sensors in order to determine possible tsunamis in their areas. The Regional Centre situated close to Jakarta would act as backup for the National Centre.

The NEITWC will send information to the different REITWC and they will activate the dissemination of the warning using the possible channels.



**Figure 4 Nation and Regional Centers in Indonesia [4]**

By 2005 there were no dedicated telephone lines for the communication between the different centers so at the moment radio links are being developed for local level and satellite links for a national level.

The NEITWC will prepare the data compilation from the Regional Centers and develop the decision making in order to disseminate the warning. When a significant earthquake is detected by the NEITWC the following decision making procedure is applied [36]:

- Earthquake Magnitude > 5 Richter: Send SMS to BMG staff
- Earthquake Magnitude > 6 Richter: Send SMS to officials in relevant agencies
- Earthquake Magnitude > 7 Richter: inform the Ministers of Science and Technology, Communications and Information, Transportation, Internal Affairs and the Office of the President

The warning can be delivered by a multiple set of possible channels so the most appropriate must be chosen to perform a successful dissemination. The decision will be based in the national statistics (see Annex A: ICT Gathered Indicators). The BMG can cut into the television and radio to broadcast warning messages, the use of these media will be one of the most useful channels due to the high penetration rates of television and radio, by contrast the dissemination to the population by internet would be almost useless due to the poor penetration.

Currently warning messages are broadcast to government authorities and leaders by SMS and phone calls, and the general public can also subscribe to these SMS messages reception. The penetration of fixed lines is poor but the mobile cellular subscribers' rate is high and has a good grown rate making it also a good channel to disseminate the warning.

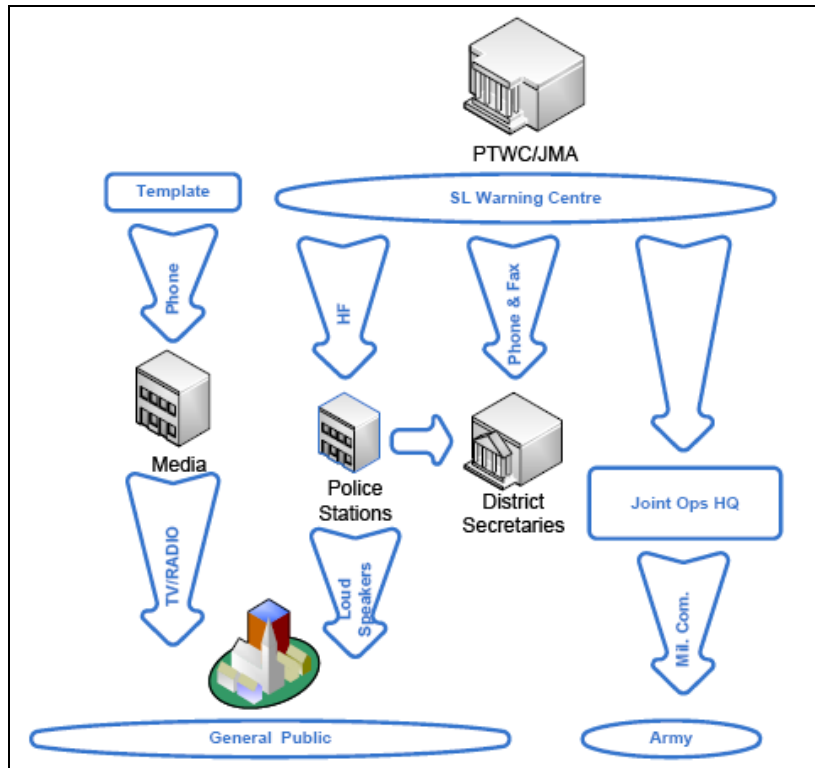
The mobile technologies used by the different providers in the country are GSM and CDMA, and each provider has a different coverage area in the country (see Annex B: GSM and CDMA Coverage Areas).

### **2.2.2 Sri Lanka Overview**

The Disaster Management Act No.13 of 2005 provides the legal basis for a disaster risk management framework in Sri Lanka. The Act establishes the National Council for Disaster Management (NCDM), chaired by the President, and the Disaster Management Centre (DMC) will perform the designated operations [34].

In the country there are several governmental organizations with sufficient communications networks to disseminate the warning message among the population if a connection with the authorities is created. In addition, the police force is divided in several districts, all of them connected to the Command Centre of the police; these connections are secure enough to not be affected by a natural hazard.

The decision to disseminate the warning is made after the confirmation of an imminent tsunami by the Pacific Tsunami Warning Centre (PTWC) and the Japan Meteorological Agency (JMA) (see Figure 5 below).



**Figure 5 Last mile dissemination channels in Sri Lanka**

The Warning Centers will inform the television and radio stations by telephone lines in order to start sending the warning among the population and also to the police force by HF radio so the police personnel can help in the dissemination. The military telecommunications network is also used to perform the warning process.

Fixed lines have a poor penetration rate in Sri Lanka even if some providers have good coverage areas, on the other hand mobile lines have high penetration rates with good growth rates, making the mobile communication a possible way to disseminate the warning. Again the technologies used by the different providers are GSM and CDMA (see Annex B: GSM and CDMA Coverage Areas).

### 2.2.3 Thailand Overview

In Thailand the Committee on Policy of the National Disaster Warning System (COPNDWS) deals with the legal issues related with the warning project and systems,

while the Committee on National Disaster Warning Administration (CONDWA) provides with technical advice [35].

The National Disaster Warning Centre (NDWC) established in 2005 functions under the COPNDWS and CONDWA, and is responsible for receiving and monitoring data coming from seismic and water-level sensors, national and also from networks in Europe, Asia and USA, receiving this data by the use of telephone, fax or email. Its main tasks are to manage this information in order to be ready to send it to the different officials, emergency agencies and general public, coordinate with other warning systems of other communities and prepare the processes for decision-making.

The NDWC is able to disseminate warning messages via the TV Channel 5 and also to activate the warning system towers, situated among the risk areas and connected to the NDWC by satellite, which are able to send the warning message in different languages or dialects depending on the area.

As in the other two studied countries the penetration of the fixed lines is poor even if TOT-Public Company Limited, having the monopoly in the fixed telephone network, provides communications also to rural communities. On the other hand, again the mobile telephone penetration is much higher and the providers use GSM and CDMA technologies (see Annex B: GSM and CDMA Coverage Areas).

## ***2.3. Satellite Communications***

### **2.3.1 Satellite Communications Introduction**

For the Early Warning System the satellite communication presents an attractive alternative communications technology in order to reach the maximum amount of warning systems, authorities and citizens in all kind of zones and regions in alert.

The satellite communications industry is migrating from its role as trunk connectors between networks to a role of broadcasting media to the end users as a consequence of the increasing installation of optical fiber and demand of mobile and IP-based services.

These satellite links provide the communications network with enough bandwidth to integrate web-based services between the different centers. Nowadays, the majority of operating systems and vendors have achieved a culture of development of Service Oriented Architecture (SOA) web services. The use of web services provides the DEWS system with higher level of flexibility and actualization, simpler processes of online information access and reduction of software development costs [45]. However the SOA services consume higher amounts of bandwidth than traditional distributed applications and will need minimum levels of latency to avoid WAN congestion [38].

### **2.3.2 Satellite Standards Overview**

In the actual satellite communications situation many standards and technologies are used by the different satellite companies and Internet providers [17]. In order to achieve a consensus standard in this field, the Technical Committee for Satellite Earth Stations (TC SES) is trying to harmonize the existing standards for reduced fragmentation.

Nowadays the two most relevant standards for the satellite telecommunications are BGAN and DVB-RCS. BGAN, Broadband Global Area Network, is the network offered by the newest generation of communication satellites for mobile terminals of Inmarsat. This service provides a global area of coverage except the poles, enabling the use of small user terminals (UT) for communications at high data rates. It enables the users to access point-to-point services on portable or semi-fixed mobile platforms, offering bit rates about 500 kbps. In addition, the UT supports constant bit rate (CBR) and variable bit rates (VBR) applications with different QoS depending on the model of terminal.

Still in process of development is the BGAN Air interface and Platform extension, which belong to a project of the European Space Agency (ESA). The objectives of the extension of BGAN reside in the intention of developing an efficient support of multicast in this technology [19]. This project will increase the performance of BGAN in maritime, aeronautical and land-mobile environments improving the basic service and supporting omni-directional terminals.

The BGAN system is able to offer both circuit switched (CS) and packet switched (PS) connections. Circuit switched is commonly focused to voice and narrowband data



applications while packet switched is chosen for linking communication between the end user and Internet or any private Intranet. On the other hand, DVB-RCS, Digital Video Broadcasting – Return Channel via Satellite, offers bi-directional or two-way transmission of digital data employing combinations of the C, Ku and Ka bands.

The use of a basic ground station will serve as the gateway infrastructure to provide the satellite management and the interface with the terminals and WANs. This technology allows the Internet Service Providers (ISPs) to implement their telecommunications networks over bent pipe satellites located in geostationary orbits.

DVB-RCS offers unicast access services to the users connected to a terminal or indirectly connected to a terminal by a private LAN. The user will be able to access one ISP Network, which will provide him access to Internet or Private Network.

### **2.3.3 Satellite Protocols Overview**

In the transport layer of the satellite communications the protocols used are Transport Control Protocol (TCP) and User Datagram Protocol (UDP). TCP provides error checking, retransmission and congestion avoidance and even if it works well in satellite links, its performance can be limited by the latency and bandwidth of these links. On the other hand UDP does not provide error checking, retransmission or congestion avoidance facilities, but it works without any limitations under satellite communications except some influence of the latency of the link and a rare occurrence of packet loss [21].

To provide end-to-end security and Virtual Private Network (VPN) implementations, encryption of the data is necessary. The Sequence Number, Acknowledgment Number, and Window bit fields control data flow between two TCP devices [16]. When the window is exhausted, the sender must stop until it receives another Acknowledgment Number with a Window size. In this way, each side of a TCP connection controls the rate at which it receives data.

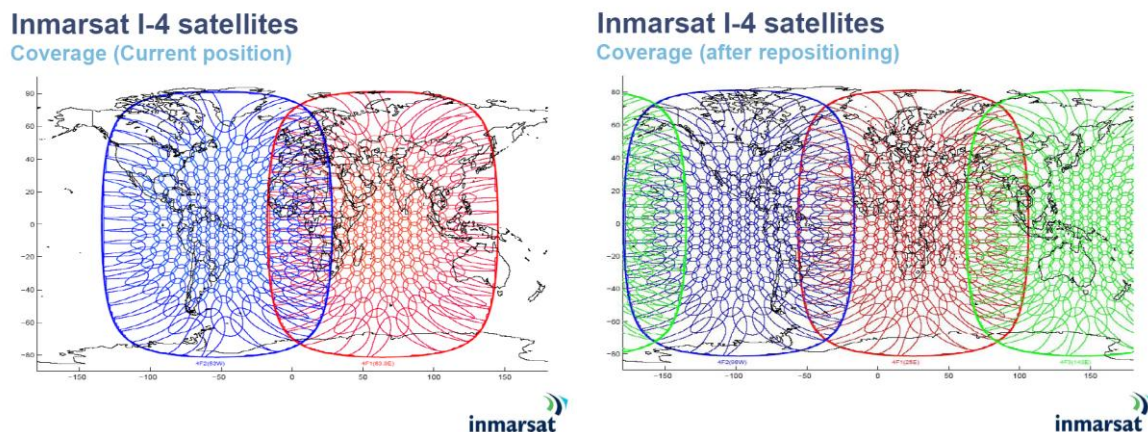
In VPNs IPsec not only encrypt the data portion of packets, they also encrypt the TCP port number and IP address of the sender's computer, so only the VPN software at the remote site can decipher where packets originated and acknowledge receipt of data [51] resulting in

substantial throughput degradation. To avoid the throughput cap the TCP session is broken in three segments by installing Performance Enhancement Proxies (PEP) at each side of the satellite link. Prompt ACKs from the PEP give the sender permission to send more data, even before the previous window of data reaches the far-end earth station. The customer can send at the same rate available on the LAN, up to the capacity of the satellite circuit.

### 2.3.4 Satellite Communications DEWS

The coverage area of the communications satellites range from narrow spot beams with smaller areas than a continent, to the areas about a third of the earth's surface, and both options usually available in the same satellite. They allow us to reach rural, remote and also maritime areas in order to disseminate the warning.

In the area of the three countries of interest, the company Inmarsat provides a wide range of services in its areas of coverage (See Figure 6). The telecommunications networks can use the land service BGAN in order to deliver the warning message being able to broadcast data to the whole surface of these countries.



**Figure 6: Actual and future BGAN Coverage [26]**

Iridium Satellite LLC provides voice and data communications solutions with a complete coverage in a global area with a satellite constellation of 66 low-earth orbiting satellites, in addition, Iridium satellites are prepare to transfer the data also from maritime zones serving the DEWS warning centers to receive the data from buoys and GPS sensors.

Another opportunity is the Palapa satellites series owned by Telkom Indonesia for distribution of voice, video and data in the area. These satellites are used by this company for the telecommunication network being combined with terrestrial solutions.

VSATs are also available for use with antennas smaller than 3 meters (most VSAT antennas range from 75 cm to 1.2 m) and offering transportable, on-the-move (with phased-array antennas) or mobile maritime communications.

### 3. Generic DEWS Model of Reference

The model developed by DEWS is based on the results of the German Indonesian Tsunami Early Warning System (GITEWS) developed by GeoForschungsZentrum (GFZ) Potsdam. As an innovation DEWS provides a new generation of interoperable early warning systems. The model structures the collaboration of the national and regional warning centres developing their communications service bus with standardized protocols [10].

#### 3.1. General Architecture

A logical overview of the structure of DEWS model is offered in Figure 7, where inside the integration platform square, the contributions of GITEWS are designated in blue and the innovations developed by DEWS are in orange.

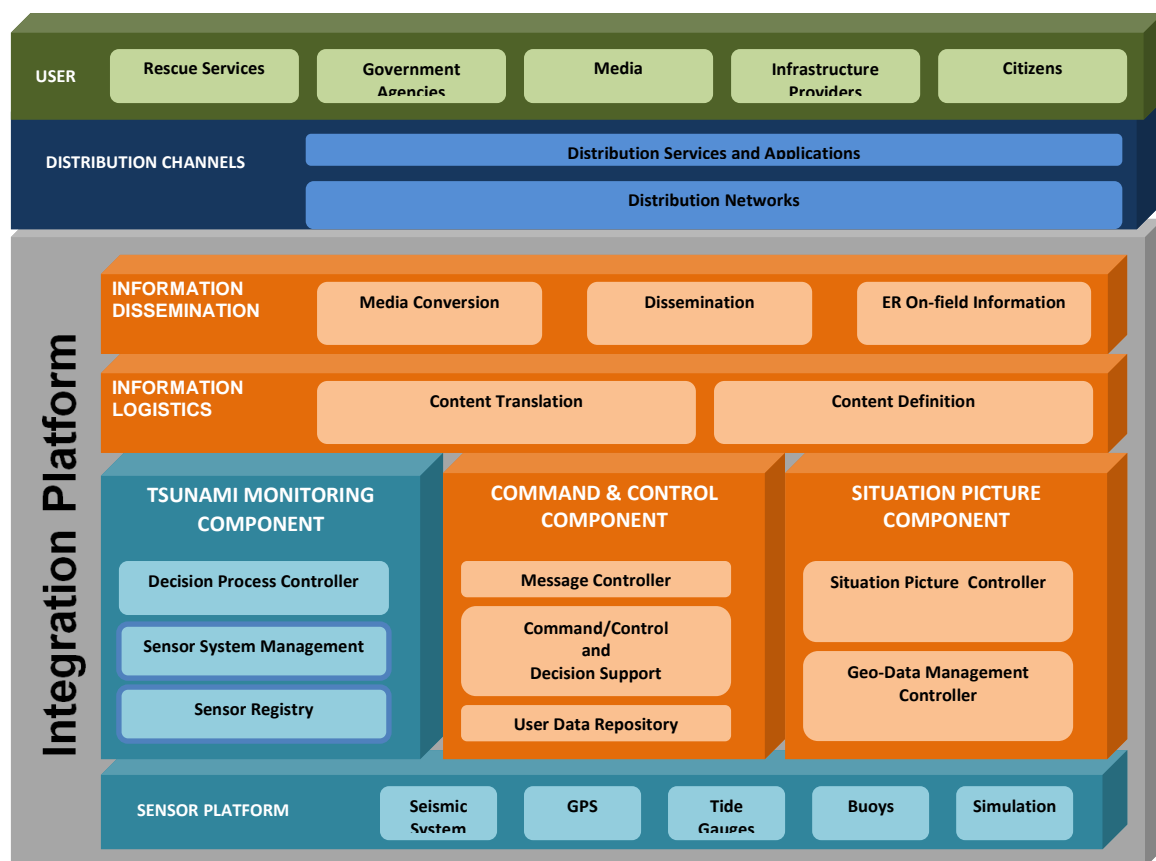


Figure 7: Schematic Architecture of DEWS

The Sensor System offers a service bus compiling the data coming from buoys, seismic sensors, etc and providing a standardized interface to the Tsunami Monitoring Component.

The Tsunami Monitoring Component generates tsunami events messages after an evaluation of the data achieved from the Sensor System. It offers a user interface which allows the activation of these sensors and the recompilation of their data. In this component the Decision Process Controller is in charge of the execution of the standardized processes for the detection of an imminent tsunami and of the decision making involved. The Sensor System Management and the Sensor Registry are in charge of the registration and maintenance of the sensor technical parameters and their availability.

The Situation Picture Component will create the situation picture to provide an overall view of the current situation based on spatial data. Using the information available it will create map products to be distributed to target groups in the areas in danger. The subcomponent Geodata Management Controller will develop the topography and risk maps and the Situation Picture Controller will be responsible for the maintenance of the graphic version of the situation picture and secure its availability to be accessed by the authorities.

The Command and Control Component is the central component of DEWS. It receives information from the other Early Warning Systems and the situation picture study developed by the Situation Picture Component and is also in charge of disseminating the warning messages to the end users. The Command/Control and Decision Support controls the decision making processes and provides with the Human Machine Interface (how the users interact with the system) of DEWS. The Warning and Message Controller will manage the communication between the Situation Picture Component and all the components related with the dissemination of the warnings to the authorities and population. Finally the User Data subcomponent supports the Command & Control and Decision subcomponent by storing pre-defined information such as warning message distribution lists or operational plans.

The Information Logistics Component will acquire and store content and information about the users such as authorities, media and the public, in order to reduce the time of delivering the warnings and translate it into the different languages. For the Content Definition and Translation we have the Information Logistics Controller, responsible of executing the needed processes to create the warning messages, the Information Aggregation, which compile significant event data and prepare it in standardized messages, the Content

Conversion, which adopt the messages to the different channel and languages requirements and finally, the Demand Management, responsible of the recompilation of information of the users groups and their information requirements.

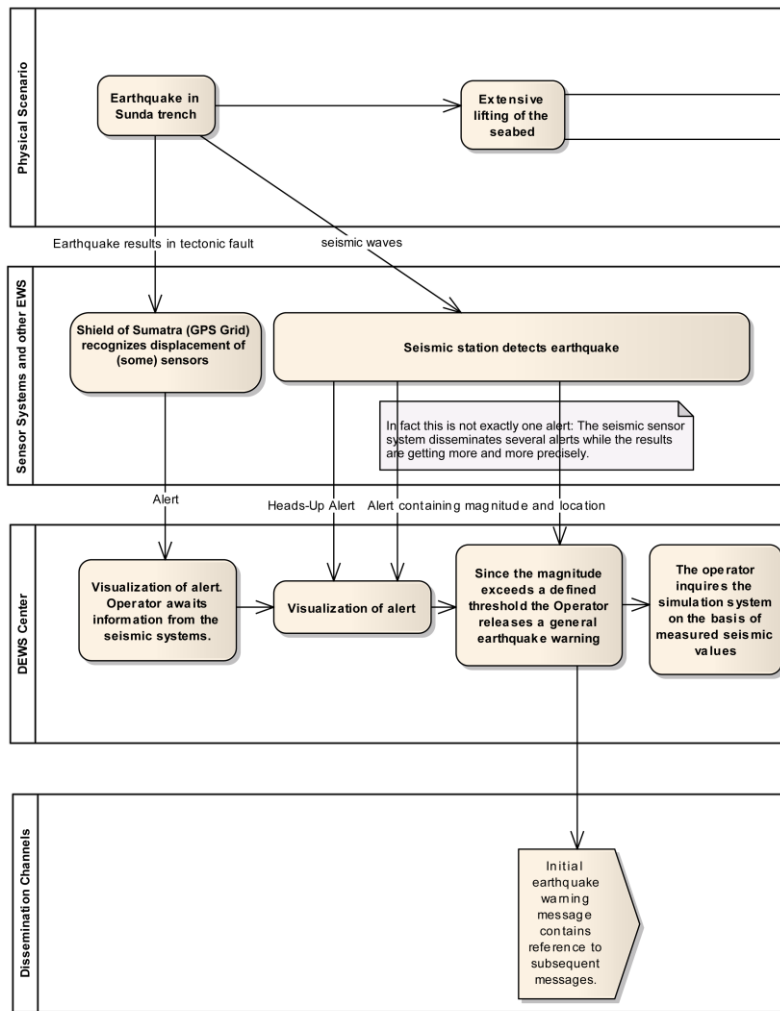
The Information Dissemination Component is responsible of transforming these warning messages into bit streams and the activation or deactivation of its transmission through the different physical connections.

### ***3.2. Tsunami Disaster Decision Making***

The tsunami-related activities fall within the domain of multiple organizations and government agencies. Therefore, there is a clear need for all the possible decision and action making processes to be established in advance in order to assure the faster dissemination of the warning messages when a hazard is detected.

Nevertheless, the large amount of processes involving the DEWS model makes impossible to represent all the workflow into activity diagrams, however in this chapter we introduce the decision and action processes referring to the main possible hazard, a tsunami disaster.

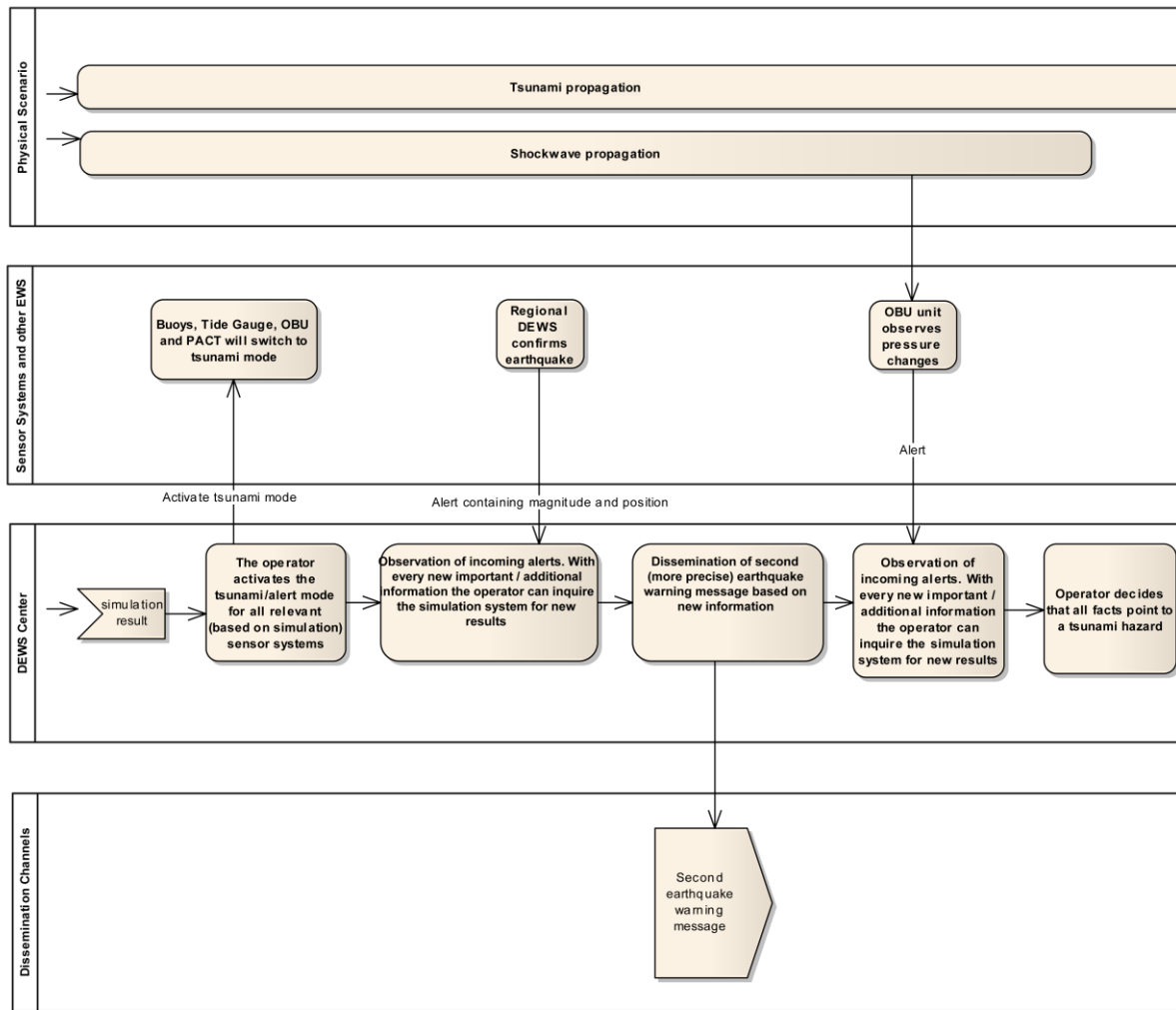
The process is separated into four phases from the detection of the earthquake to the post tsunami scenario and the activities are separated into four scenarios, the physical scenario, the sensor system, the DEWS centres and the dissemination channels. The process is represented using the UML activity diagram type [10].



**Figure 8: Initial phase, the earthquake detected**

In this phase is represented the actions to be taken after the detection of an earthquake, the sensor system is going to send the alert to the DEWS centres, where the situation is going to be rationalized and managed.

If the magnitude of the earthquake exceeds a pre-determined threshold the different centres will disseminate an earthquake warnings to the authorities and will start the simulations with the measured valued of the earthquake to determine the possibility of an imminent tsunami.

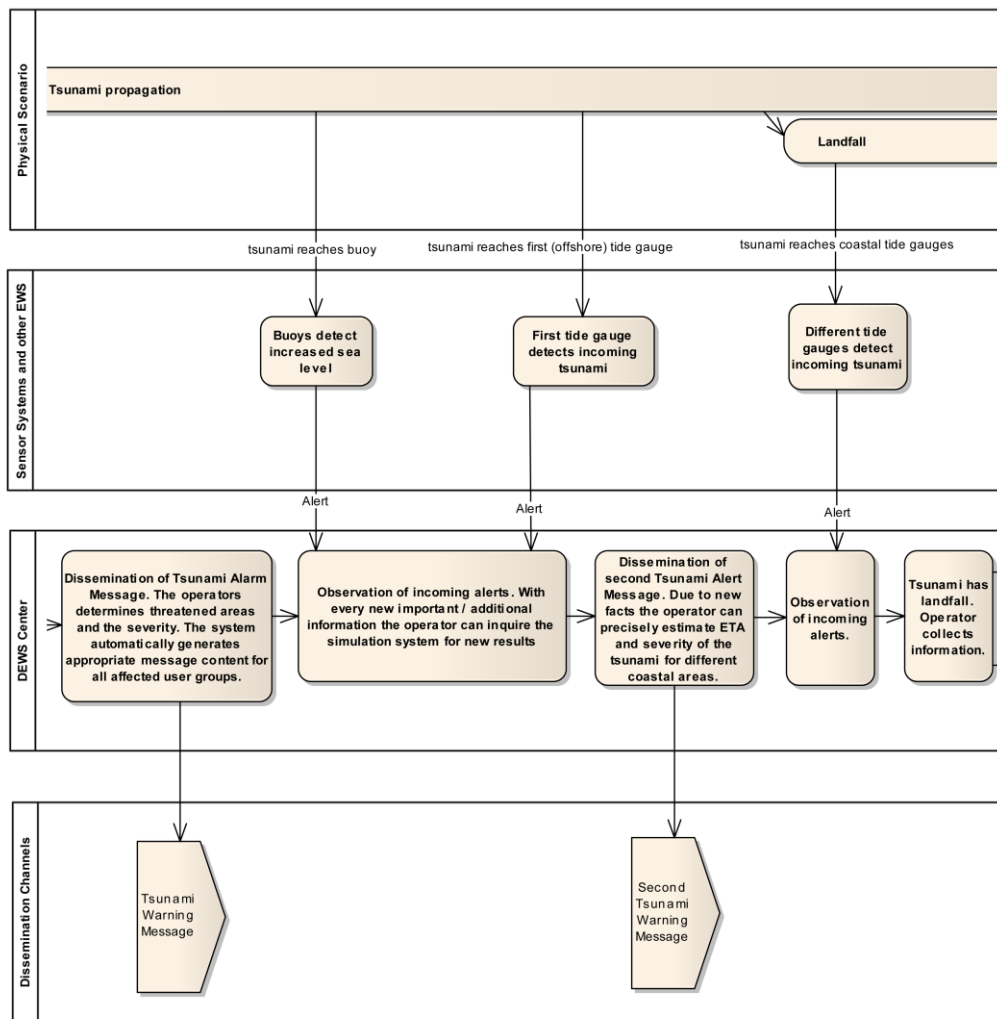


**Figure 9: Second phase, from the earthquake to the tsunami detection**

The second phase starts when based in the results of the simulations the centres recognize the tsunami possibility, in this case the marine sensors such as buoys, tide gauge, and so forth, are activated and data about the earthquake is expected from the Regional Centres in order to perform more specific simulations.

With them, the DEWS centres will disseminate a new and more detailed earthquake warning and will initiate the decision process to determine if an incoming tsunami is possible using the new data available.

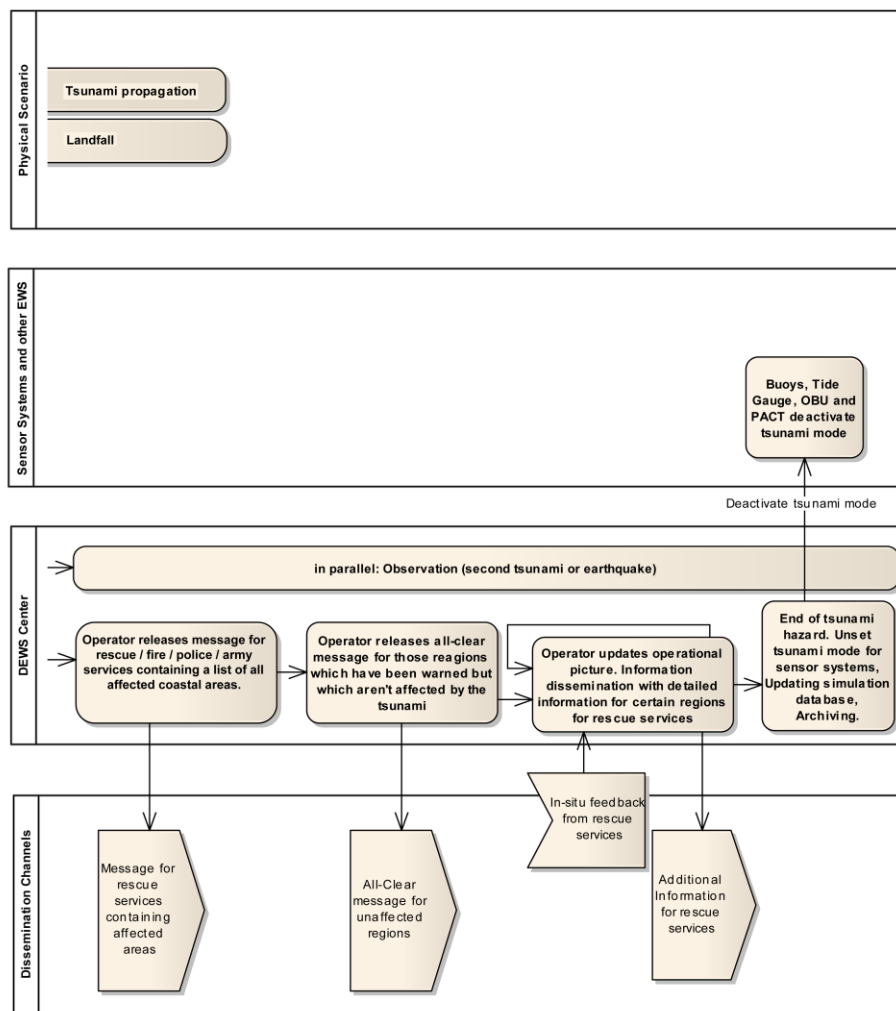




**Figure 10: Third phase, from the tsunami detection to the landfall**

If a tsunami is expected, the DEWS centres will determine the areas in danger and disseminate the first tsunami warning message to the affected groups with the appropriate content.

After the new data coming from the buoys and tide gauges the centres will perform the dissemination of the second tsunami warning message with more specific information and will start the recompilation of new information of the coming events and the situation of the landfall.



**Figure 11: Fourth phase, post tsunami communication**

The final phase is developed mainly from the DEWS centres where messages about the areas affected will be delivered to the authorities and rescue services to help in their performance.

They also will maintain the marine sensors activated during these processes to be aware if a second tsunami is approaching, at the end of the tsunami hazard risk these sensors will be deactivated again.

The amount of time to develop successfully this process by the BMG is estimated around 10 minutes [52], nevertheless the target for 2008 is to be able to develop this processing time to be around 5 minutes [3].

### **3.3. Dissemination Channels**

At the moment the DEWS project has been developing the definition and characteristics for the communication model in Indonesia, designing the architecture for the different DEWS stakeholders and the services and processes which would take place between them.

The previous early warning system GITEWS established four application servers at BMG, which works as the National Warning Centre in Indonesia, two of them for managing the sensor system and the other two for the decision support system. In each pair one of the two servers will function as a backup for the other one.

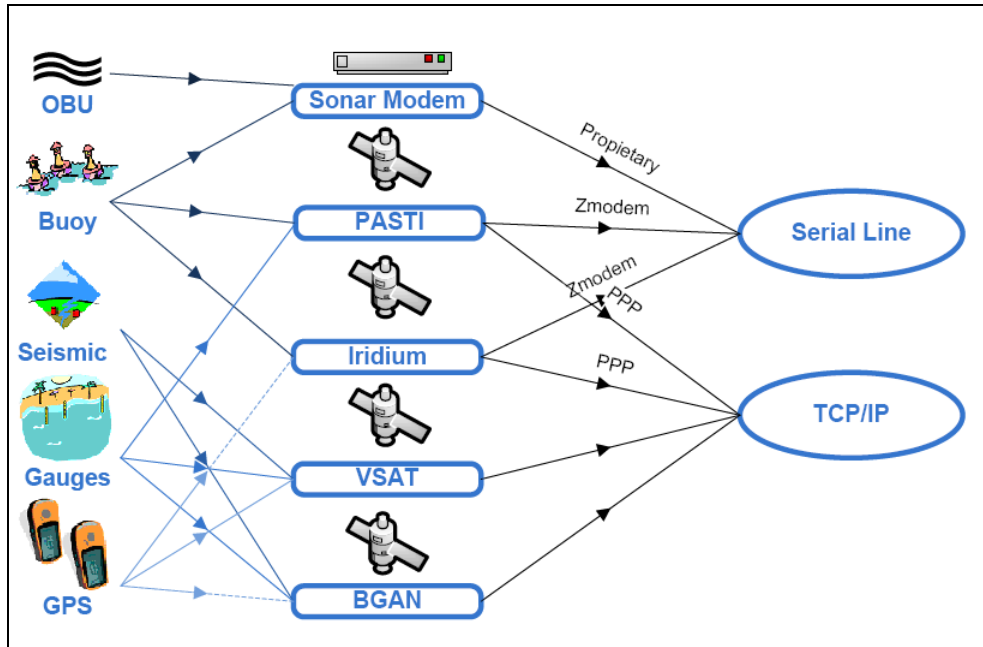
During one year of operations the data coming from Buoys, Gauges, GPS-Master Stations and Seismic Sensors Wave Data are estimated not to exceed 2,5 TB (2400 GB). According to this estimate, data can only be stored for approx six months because the system will use the Sun Storage 3510 FC with a storage capacity of 1,2 TB [11].

In addition to the hardware components, the possible communication networks and their availability in a selected scenario are also defined including the channels and protocols used in the architecture.

#### **3.3.1 Upstream Communications Architecture**

The data flow from the sensor system to the DEWS centres is defined mostly based in the already existing networks developed by GITEWS. Even if during any communication only the main channel will be used, the reference model provides multiple communication options from the sensor system.

The following figure provides an overview of the communication hardware and protocols options where the different alternatives can be observed, the dotted lines represent options which remain to be confirmed for the development of the system [12].



**Figure 12: Upstream Communication Architecture**

A VPN will be created among the different partners and the protocols used will be:  
TCP/IP-based:

- TCP
  - BGAN
  - VSAT
- Point to Point Protocol (PPP) for TCP/IP
  - PASTI
  - Iridium

Serial Line Based (Modulator - Demodulator):

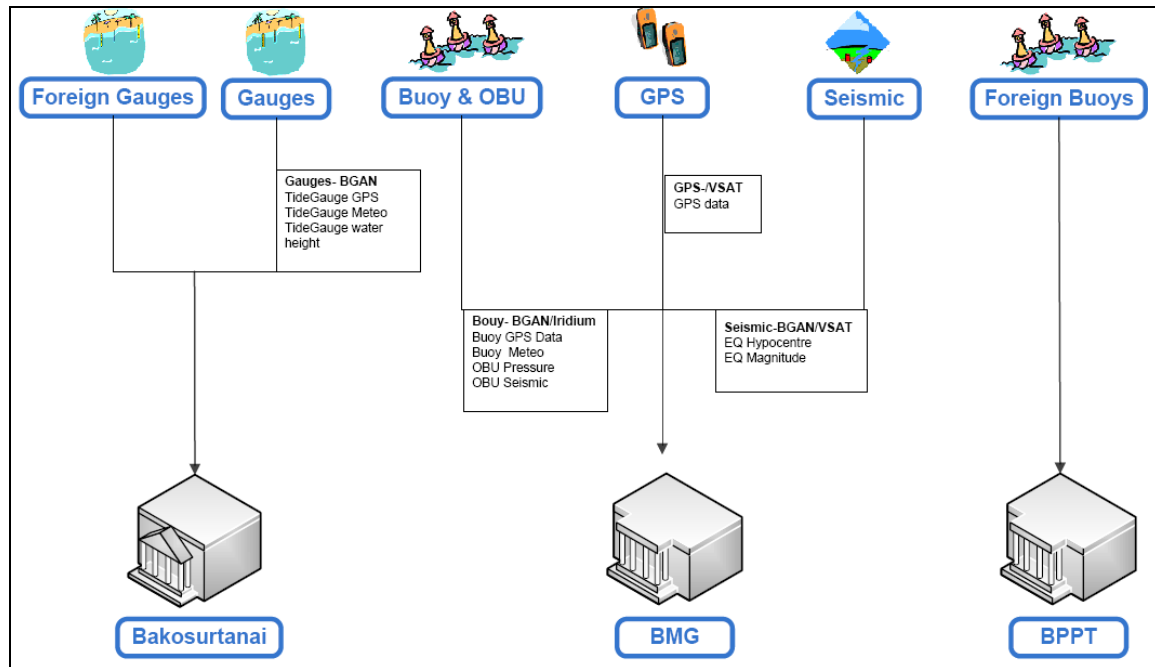
- Custom
  - The sonar modems for OBU/PACT use proprietary protocols
- ZModem [mutually exclusive with PPP]
  - PASTI
  - Iridium

In addition the stakeholders who will receive and manage the information from the sensor system will be:

- Bakosurtanai (Badan Koordinasi Survei dan Pemetaan Nasional): The Indonesian National Coordinating Agency for Surveys and Mapping.
- BPPT (Badan Pengkajian Dan Penerapan Teknologi): The Indonesian National Technology-Centre for Marine Exploration

- BMG (Badan Meteorologi Dan Geofisika): The Indonesian Geophysical Service who hosts the national Tsunami Early Warning Centre.
- GFZ-Potsdam: GFZ Departments are involved in the development of the Gauges, Buoy-, GPS- and Seismic components for the GITEWS project.

The data is received following the infrastructure shown in figure 13:



**Figure 13: Upstream Communication Infrastructure**

### 3.3.2 Downstream Communications Architecture

In order to disseminate the warning successfully, broadcast communications will be used by the model. Without any filters or interaction, the messages will be sent between the source partners to the destinations.

The messages will contain specific information in a simple format in order to facilitate its transmission through the wide range of possible channels due to the low bandwidth needed. The exchange of messages should also provide tracking to provide with information to post-tsunamis analysis and knowledge management, looking for developing the system by learning how was the performance of the dissemination.

In the dissemination of the warning the stakeholders will have different roles and information needs, they will be:

- DEWS Centres: The regional centres will assure a minimum level of decision making among the affected areas and will provide with supplementary information to the neighbour centres, they also will replicate all the information messages to the national centre [9].
- Disaster Management Institutions: They will manage all the information coming from the sensors and are in charge of activating the alerting process and their cancellation if it is a false warning or if it is finished.
- Central Government: Must be periodically informed and must be given a continuously updated overview of the emergency situation.
- Local authorities, police, fire brigades, military, hospitals, etc: Must prepare to the event, organize first intervention and first aid measures. They are mostly recipient of alert and cancellation messages.
- Media companies, tourist organizations: Must spread the news in a controlled way, assist and look after foreign people. They are mostly recipient of alert and cancellation messages [12].

### **3.3.3 Communication between EWCs**

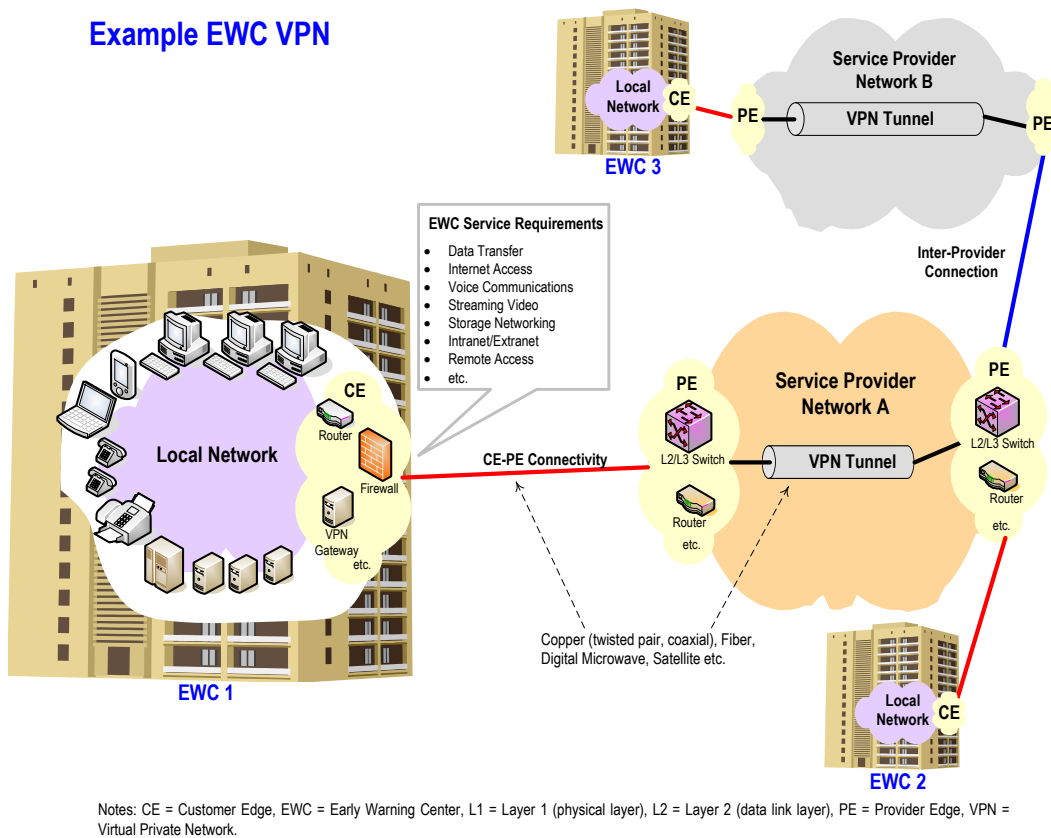
The Warning Centres will need to maintain a continuous communication both in national level and international level sharing data and coordination their actions. The best approach for this connectivity is the creation of a Virtual Private Network (VPN) due to its secured channels established among public networks, its flexibility and the large costs saving [14].

A VPN combines the advantages of using a private network and the advantages of using and public network. It provides an illusionary private network using a public network to transmit the data between the nodes. With a VPN the users are able to access to network-to-network and remote-user-to-network connections via an encrypted link through the public internet network.

The use of a VPN partially eliminates the necessity of installing all the hardware needed to develop a private network and are especially profitable in long distances communications where arranged lines would be more expensive. On the other hand, VPNs induce to questions about security, reliability and the possibility of poor performance.

The EWC will receive the VPN services from network operators or providers, configuring it between the different centres. This VPN can be provided by one single operator if the rest of EWCs are within its area of coverage, otherwise the VPN would be supported by multiple providers.

In the DEWS project the VPN will communicate the national centres and regional centres allowing reliable transmission, robustness, tampering resistance and adequate speed [12]. An example inter-EWC VPN is shown in Figure 14.

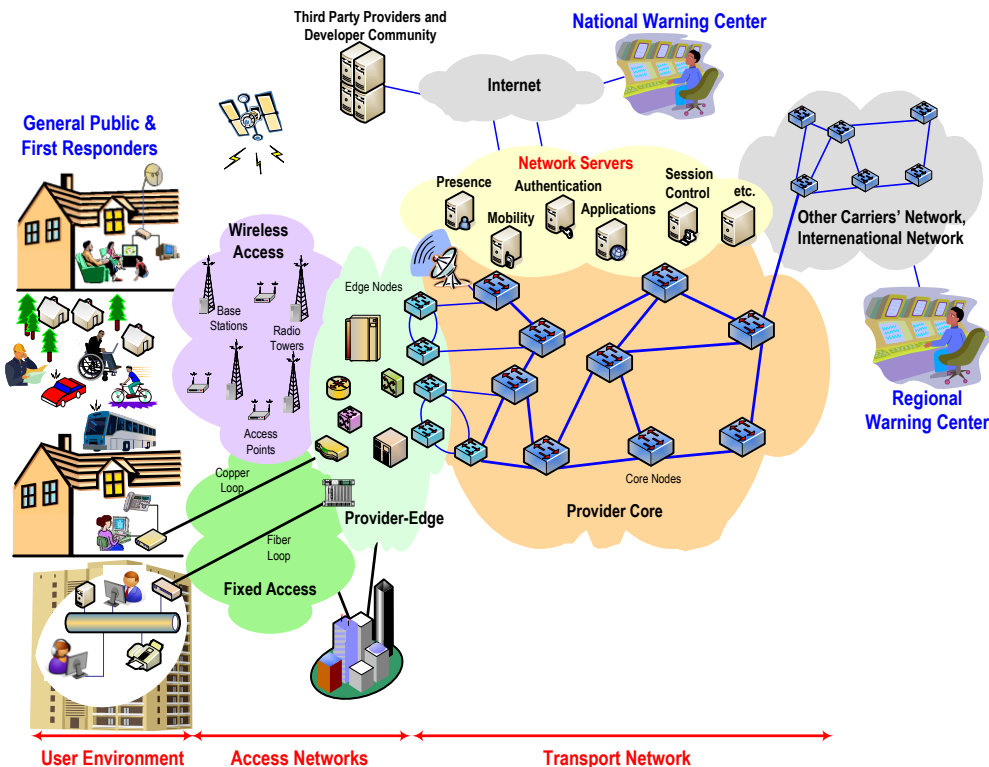


**Figure 14: Example of two EWC using the VPN**

### 3.3.4 Communications between EWCs and first responders and general public

The first responders will belong to organizations such as emergency services, security forces, government agencies, and so forth, organizations responsible for maintaining the safety and security of the general public. In case of hazard warning they will also be in charge of the timely and reliable distribution of the warnings and instructions to the population.

Therefore it is essential to develop a permanent or rapidly configurable connectivity between the EWC and the first responders in order to provide the capacity of sharing key data and disseminating warning messages. For this reason DEWS advocates for the implementation of VPNs between the National EWC and the first responders. Connectivity from the EWC to both the general public and first responders is typically provided over a range of public fixed and wireless networks (see Figure 15 below).



**Figure 15: EWC to first responders and general public communications**

As a complement to these networks we test the implementation of a backup links via satellite technologies using the BGAN service. Their objective will be to serve as a communication channel independent of the possible consequences of the hazard among the terrestrial structures. This backup will provide the same services of the common access to the telecommunication networks in order to disseminate the warning among the first responders and therefore among the general public.



### ***3.4. Message Composition***

The warning message will have different characteristics and size depending on the information and data to be sent. DEWS has based the development of the warning message on the Common Alerting Protocol (CAP) in order to standardize the content of the notifications which are going to be sent to first responders and government agencies working in different fields inside the emergency response and in different countries with several languages.

The common alerting protocol (CAP) provides an open, standardized, XML-based message format for exchanging all-hazard warnings, alerts or notifications, over diverse dissemination channels. CAP message includes hazard-specific information elements, such as, event category, event description, instructions, sender ID, time stamps, level of urgency, level of certainty, level of severity, area description and also supports the inclusion of associated multimedia content e.g. digital maps [32], [13].

The routing information in the message includes elements for enabling the location-based message delivery in the target area, distribution type, distribution status, description of roles and their tasks (for sender, receiver, consumers etc.), and keywords describing the message content.

The format, size and content/detail and level of difficulty of the messages delivered to a specific group are designed based in two factors. First, the level of expertise necessary to understand and effectively performance the needed tasks included in the standardized CAP message and in the associated resources. Second, the inherent limitations in the type and size of message formats (e.g., text, audio, image files etc.) that could be delivered over a particular dissemination channel and displayed in a targeted user terminal.

User groups such as Public Authorities or Government Agencies, Emergency Response Organizations, etc will receive warning messages with a high level of expertise. They will need this information in order to coordinate rapid provisioning of state resources for evacuation operations covering the areas targeted by the warning messages.

On the other hand, organizations such as Telecommunications Service Providers, Broadcast Media, Local Warning Systems and the General Public will receive the warning message and will re-distribute simplified warning messages to the customers connected to their networks, audience of a TV or radio channel, or to the segment of the public within the area of the Local Warning System. All the process has the final objective of reaching the general public, whose role is to be primary message consumers.

The size of the files to be sent will range from a few kB if the message is composed only by a text based in CAP, to a few MB if the message will include multimedia data such as maps, audio and so forth.

## 4. Specifications of the Simulation

### 4.1. *Objectives of the Simulation*

In this stage we develop the simulation processes of the communications networks to obtain an approximated performance of the real implementations for the following cases:

- Between two or more Early Warning Centres
- Between Early Warning Centres and local authorities, local warning systems, emergency warning centres, government agencies authorities etc.

The purpose of this thesis is to analyze the performance of the BGAN service as the core technology for the DEWS communications, simulating its characteristics with the means offered by Qualnet Simulator. These estimated results will help to design an appropriate communications structure in order to cope with the DEWS requirements in terms of delivery time, data transmission rates achieved, management of different User Terminal models, etc. Our proposal is the use of the BGAN service for DEWS communications to provide a reliable backup for the commonly used channels in case they are disrupted as a hazard consequence.

Managing the different possible types of digital messages to be sent in case of emergency and the physical and technical characteristics of our communications network we are able to measure their effects in the performance of the system.

### 4.2. *Basis and resources of the simulation*

#### 4.2.1 Simulation Tool Description

Qualnet is communication networks evaluation software which simulates wireless, wired and mixed platform links and devices performance. The tool enables the user to represent the entire network in a digital scenario with the specific devices, terrain effects, atmospheric effects and human interaction effects [41].

Qualnet Model works with ISO stack based layer architecture, in addition, application programming interface (API) are enabled between the different layers in order to provide a higher modular programming interface and suitability.

The Qualnet Product Family consists of Qualnet Developer plus a number of model libraries, for the simulation in study the Satellite Model Library will be used. Qualnet Developer integrates the following tools for the design and measure of the simulations:

- Qualnet Scenario Designer prepares the model of the scenario to be studied. It covers the input of the different characteristics for the physical connections and functional parameters of the networks installed.
- Qualnet Scenario Animator and 3D Visualizer provides an animated visualization of the scenario simulation while it is running. The user can observe the packets and data flows as well as issues such as the devices' mobility, the packet queues, the devices' signals, etc.
- Qualnet Analyzer provides statistical graphics displaying an amount of measures involving the performance of the network during its running. It includes statistics from the physical layer to the application layer.
- Qualnet Packet Tracer enables the user to perform a packet level monitoring, providing data about the packet's contents and statistics during its transmissions.

#### **4.2.2 Tool and Simulations Limitations**

The simulator tool presents a number of limitations for the complete implementation of the BGAN system into the scenarios. Some particular technical specifications of the service are not available in Qualnet due to the relative infancy of the satellite library of the simulator. Furthermore, a bent-pipe configuration of the satellite is employed in the simulations. This contrast to the Inmarsat I-4 satellites which operate an on-board digital processing payload architecture for functions, such as, beam routing in multibeam systems; frequency mapping between uplink and downlink; gain control and data rate conversion.

Despite these feature limitations and unavailability of some inputs in the simulation interface, the Qualnet and the Satellite Library used in this work allow sufficient specifications in providing a fairly reliable approximated behavior of BGAN system. To that end, the limitations the BGAN technical specifications have been configured into the

simulations as well as the characteristics of devices such as the User Terminals in order to display trusty transmissions patterns in the results.

### ***4.3. Justification for using BGAN***

Inmarsat is an international telecommunications company founded in 1979. The company owns the most advanced fleet of commercial communications satellites, covering around 85 per cent of the world's landmass and 98 per cent of the world's population [26].

Among its services BGAN represents the most adequate option for the installation of the satellite communications links among the DEWS system, providing emergency and disaster response operations with reliable connections.

First, BGAN offers coverage among the areas of interest in Indonesia, Sri Lanka and Thailand as well as among cooperative countries such as USA, Europe or Japan (see Figure 6). This characteristic will permit DEWS to implement an international cooperation system.

Secondly, the BGAN standards is designed to provide a wide range of appropriate services for the use in Warning System such as internet and intranet solutions, video on demand, video-conferencing, fax, e-mail, telephone and high-speed LAN access. On the other hand, other standards like DVB are more focused to perform a specific service such as video broadcasting.

Thirdly, BGAN provides a reliable communications option in hazard environments. Under normal circumstances the EWCs will have access to the terrestrial communications networks such as fixed broadband Internet access, fixed/mobile phone lines, etc. by the common point of access and therefore the use of satellite communication terminals may be minimal. Nevertheless after the hazard apparition the terrestrial telecommunications structures of the affected areas may be disrupted. The possession of BGAN User Terminals by the EWCs of the system will serve as a backup in case the common channels are not available.

The possession of BGAN terminals by the emergency responders can easily restore a communication network in case the terrestrial structures are disrupted. Especially for vehicular and on-terrain emergency response units, BGAN offers communication with the

mobility advantage. The small dimensions of BGAN terminals make them easy to quickly be setup and pointed to I-4 satellites, in contrast to VSATs terminals which could even require 2m dishes.

In addition Sri Lanka, Thailand and Indonesia situated equatorial climate zones, one of the most rainy areas of the world rainfall rates of more that  $120\text{mmhr}^{-1}$  (rainfall rates of more than 120 milliliters per hour along the 0,01% of a year)(See Annex D) . The use of the C- and L-band of the spectrum of BGAN achieves the negligible disruption due to rain fading (see Figure 16 below).

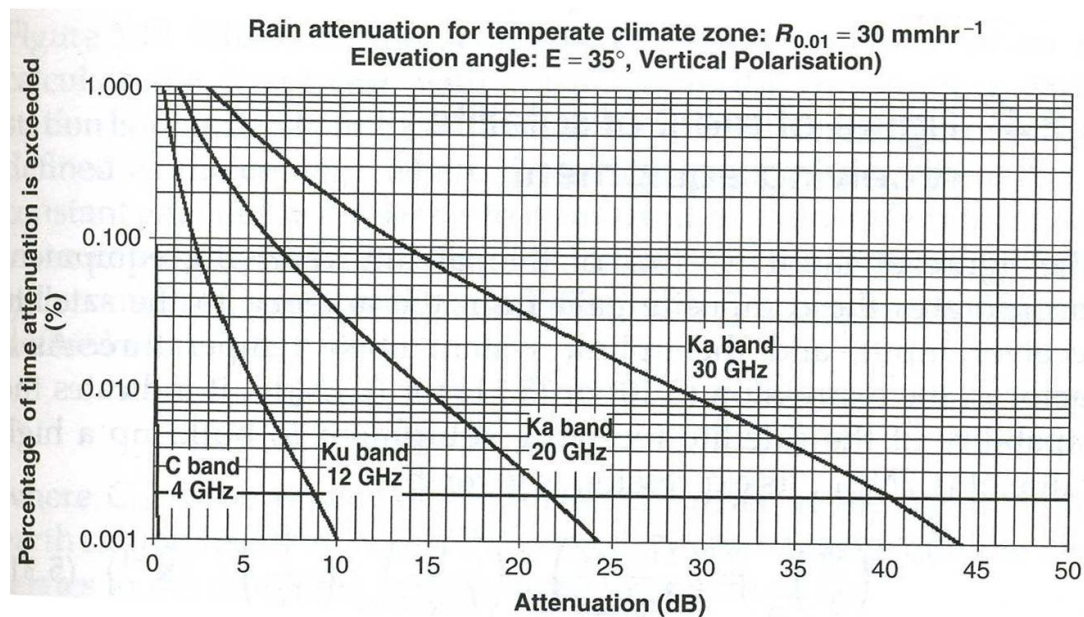


Figure 16: Rain Attenuation for the different Spectrum bands [37]

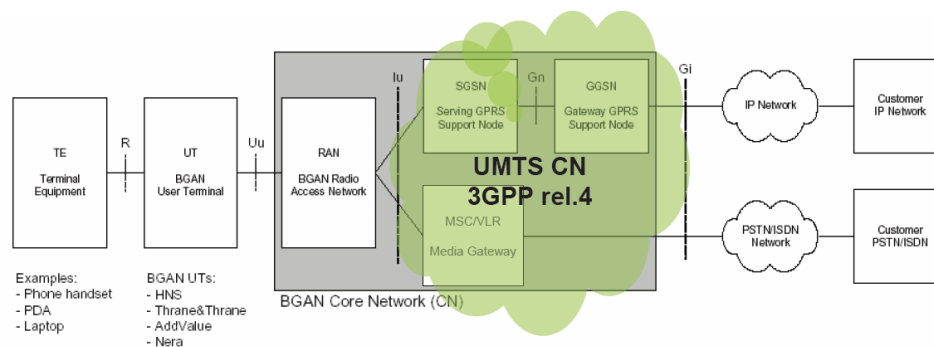
BGAN provides the warning system with combination of voice and high data rates communications which assure operability from the first moment of the hazard appearance, even when the terrestrial networks are disrupted [27]. For this reason BGAN is currently being used by many disaster and recovery organizations around the world such as Red Cross, Red Moon, Oxfam, etc as well as by government agencies e.g. in the case of the hurricanes Katrina and Felix in USA [7].

#### 4.3.1 BGAN Network Architecture

BGAN is designed as a customer's service. However it is being developed as one of the most important standards to define satellite communications. The BGAN function is based

in the Inmarsat 4-F1, F2, and F3 satellites, designed to be around 100 times more powerful and provide a ten-fold increase in communications capacity compared to earlier generation of Inmarsat satellites. Inmarsat 4-F1 and F2 were launched in March and November of 2005 respectively and Inmarsat 4-F3 in planned to be launched in 2008.

The satellites Inmarsat I4 F1, F2 and F3 operate with a bandwidth of 34 MHz in each spot beam. The channelisation is performed by the division of this bandwidth into 200 kHz TDMA channels [49]. The system links the data flows of the users coming from the terminals through the satellites and connects to the public and private telecommunications networks by three Satellite Earth Stations situated in London (England), Fucino (Italy) and Burum (Netherlands). The BGAN communications architecture allows the connections between user terminals and IP and Circuit Switched Networks (See Figure 17 below).



**Figure 17 BGAN Logical Architecture [49]**

The external devices can connect with the User terminal through several possibilities such as WiFi, USB, Ethernet and so forth (see 4.3.2.1 Technical specifications of the terminals). The forward and return satellite links with the User Terminals work in the L-band of the spectrum (1.5/1.6 GHz) while the forward and return satellite links with the Satellite Earth Stations work in frequencies of the C-band (4/6 GHz). The telecommunications system stipulates a 3.5dB link margin and uses and Turbo Coding Forward Error Correction (FEC) [28].

The management of the channels resources for the different applications from the User Terminal is controlled by the use of the Packet Data Protocols (PDP) contexts. One PDP is opened with each IP connection activated and in each of these contexts, the characteristics such as data rate, QoS, routing, etc. will be defined.

BGAN communications work with the use of Traffic Flow Templates (TFT), which represent a set of filters with the mission of ensuring that any specific data traffic for one application does not have to share its connection with another application. The TFTs will be associated to the secondary PDP contexts managing the streaming connections we will mention later.

#### **4.3.1.1 BGAN IP Connections**

The satellite communication links in BGAN support two different types of IP data connections, first, the standard IP and secondly, the streaming IP [29]. When a standard IP connection is opened the system activates a primary PDP context and when a streaming IP connection is activated after it, a secondary PDP context is set.

The standard IP connection is designed for typical office applications and services such as internet access, email, FTP, etc. Depending on the terminal it offers data rates up to 492kbps over a shared connection.

The streaming IP connection is suited for video and audio applications. It works with the possibility of opening different streaming connections sharing the link with the standard connection. The streaming IP supports different available data rates to be chosen separately for the video and audio streaming of 32kbps, 64kbps, 128kbps (only HNS 9201 and Explorer 500 user terminals) and 256kbps (only HNS 9201). This traffic rates will be controlled by the TFTs, only allowing the specific rate to flow.

When the streaming connections are activated, the terminal negotiates a specific QoS with the BGAN network, nevertheless, the observed throughput can be inferior to the one selected due to the overheads and the interconnection with terrestrial networks.

For a standard IP connection is recommended the use of the TCP protocol since it is suited for applications such as web browsing, FTP, etc. and the packet delivery must be guaranteed by the packet-retransmission.

For the streaming IP connection a protocol configured for time-critical applications, giving more preference to the rapid delivery than to the losing of packets, such as UDP is more suited. The achieved data rates will be more close to the selected since UDP manage their transmission according to the channel capacity but without the packet retransmission.



#### **4.3.1.2 VPN over BGAN structure**

BGAN service enables the users to connect with other users or organizations through Virtual Private Networks (VPN) over the public telecommunications networks. By the use of tunnelling protocols the data is encrypted and sent over the physical channels to the receiver, where the data is decrypted. The tunnelling protocols supported by BGAN are IPSec, PPTP/L2F and L2TP.

IPSec is composed by a set of protocols developed by the IETF in order to support the secure exchange of packets in the IP layer by the utilization of two different encryption modes: Transport and Tunnel. The Transport mode encrypts only the data part of the packets leaving the headers untouched while the Tunnel model encrypts both parts.

The Point-to-Point Tunnelling Protocol (PPTP) is used to secure PPP connections over TCP/IP links based in Microsoft Point-to-Point Encryption (MPPE) protocol to provide the encrypting methodology for the packets [39]. L2F have the same characteristics but it has been developed by Cisco Systems.

The L2TP protocol is created by merging the Cisco L2F and the Microsoft PPTP protocols. It acts like a layer link protocol for tunnelling network traffic between two peers over an existing network. IPSec is commonly used by this protocol to secure its packets and in addition it adds the use of a pre-shared key for the authentication of the users.

The necessary compression and encryption of the data for its transmission over VPNs is usually going to increase the packets size. However in BGAN the final size of the data is not increased in most of the cases since the compression is done before the encryption [30].

### **4.3.2 BGAN User Terminals Specifications**

#### **4.3.2.1 Technical specifications of the terminals**

The terminals work in frequencies from 1525.0 to 1559.0 MHz in the reception and from 1626.5 to 1660.5 MHz in the transmission of data from and to the satellite, with an Equivalent isotropically radiated power (EIRP) from 10 dBW (1dBW=30dBm) to 20 dBW depending on the terminal [43] [47] and using QPSK modulation [23].

The interface between the terminal and the connected device can be established by USB, with the USB specification 1.1 standard, by Ethernet/LAN with the ISO/IEC 8877:1992 and IEEE 802.3 1998 edition standards, by WiFi with IEEE 802.11 a/b/g standards or Bluetooth with the Power Class 1 standard. The support of WiFi operations allows almost all kind of devices to connect to the User Terminal.

BGAN has a classification of Class 1, Class 2 and Class 3 for different terminal types [8]:

- Class 1 BGAN terminals are best suited for professional applications, used under extremely dusty, rainy, cold or hot conditions. Class 1 equipment features full BGAN bandwidth of 492 kbps uplink / 492 kbps downlink and streaming possibilities of up to 256 kbps guaranteed bandwidth. The terminals HNS 9210 and Thrane & Thrane Explorer 700 belong to this category.
- Class 2 BGAN terminals are best suited for professional and semi-professional users. The equipment is light and user-friendly, capable of support communication under most conditions. Bandwidth is 464 kbps uplink / 448 kbps downlink and streaming possibilities up to 128 kbps guaranteed bandwidth. Class 2 equipment can be shared by several multiple users.
- Class 3 BGAN terminals are best suited for light users. The products have less features, its performance is focused on its cost-efficiency and the equipment is not water-proof. Bandwidth is 384 kbps uplink / 240 kbps downlink and streaming possibilities up to 64 kbps guaranteed bandwidth. Class 3 equipment is only available for single users.

The terminals involved in the simulations are the Thrane & Thrane Explorer 110, 300, 500 and 700 and the HNS 9210 (see Figure 18 below).

		 Wideye-Sobre1 Voice and data, single-user device	 EXPLORER® 110 Smallest, lightest device in the range	 EXPLORER® 300 Highly compact, robust device	 EXPLORER® 500 High bandwidth, highly portable device	 HNS 9201 High performance, multi-user device	 EXPLORER® 700 Multi-user device with extensive functionality
Standard terminals	Manufacturer:	Addvalue Communications www.wideye.com.sg	Thrane & Thrane www.thrane.com	Thrane & Thrane www.thrane.com	Thrane & Thrane www.thrane.com	Hughes Network Systems www.hns.com	Thrane & Thrane www.thrane.com
	Size:	259 x 195mm (1.6kgs)	200 x 150mm (<1kg)	217 x 168mm (1.4kgs)	217 x 217mm (<1.5kgs)	345 x 275mm (2.8kgs)	297 x 399mm (3.2kgs)
	Standard IP:	Up to 240/384kbps (send / receive)	Up to 240/384kbps (send / receive)	Up to 240/384kbps (send / receive)	Up to 448/464kbps (send / receive)	Up to 492kbps (send & receive)	Up to 492kbps (send & receive)
	Streaming IP: (send & receive)	32, 64kbps	32, 64kbps	32, 64kbps	32, 64, 128kbps	32, 64, 128, 256kbps	32, 64, 128, 256kbps
	ISDN:	N/A	N/A	N/A	64kbps via USB	64kbps via RJ-45	64kbps via ISDN RJ-45
	Voice:	Via RJ-11 or Bluetooth handset / headset	Via RJ-45 ISDN or, Bluetooth handset	Via RJ-11 or Bluetooth handset / headset	Via RJ-11 or Bluetooth handset or 3.1kHz audio	Via RJ-45 ISDN handset, via ISDN TA w/two RJ-11 ports or 3.1 KHz audio fax	Via RJ-11 (x2), Bluetooth handset or 3.1kHz audio
	Data Interfaces:	Ethernet, Bluetooth	Ethernet (with adapter), USB, Bluetooth	Ethernet, Bluetooth	Ethernet, USB, Bluetooth	Ethernet, USB, WLAN 802.11b	Ethernet (x2), USB, Bluetooth, WLAN 802.11g, Digital I/O
	Ingress protection:	IP 54	IP 44	IP 54	IP 54	IP 55	IP 52 (terminal), IP 66 (antenna)

**Figure 18: UT Technical Comparison**

#### 4.3.2.2 PDP Contexts Management

Each model of terminal has a different method to manage the PDP issues and the combination of PDP primary and secondary contexts. The most advanced and commonly used terminals models are the HNS 9201 of Hughes Network Systems and the Explorer Series of Thrane & Thrane.

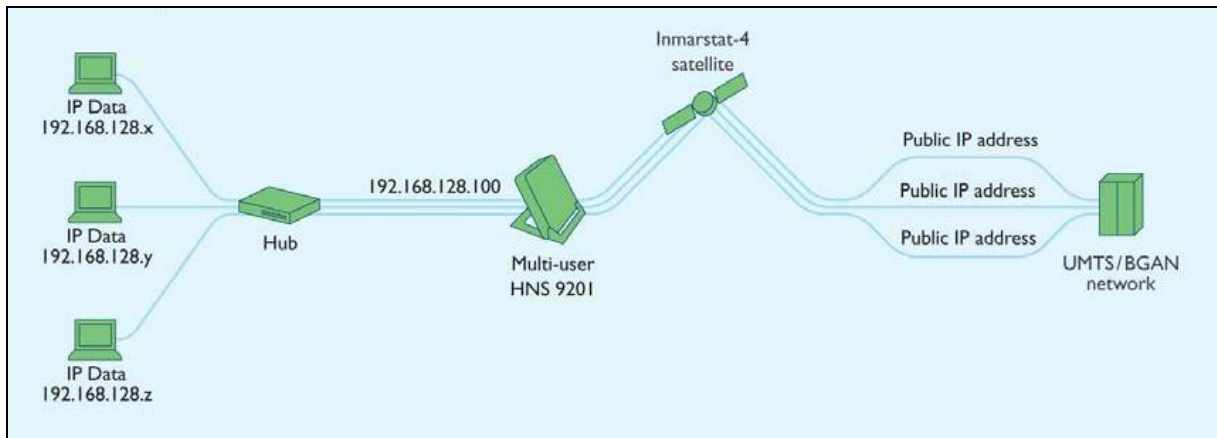
HNS 9201 is able to support up to eleven PDP primary or secondary contexts simultaneously, providing to each one with a different IP address and enabling each context to connect to a different APN with a specific QoS. On the other hand the Explorer Terminals are able to open one primary PDP context on a LAN interface simultaneously with another primary context in the USB interface. All the users connected to the LAN interface will share the same context.

#### 4.3.2.3 IP Addressing of the UT

Once the terminals connect to the BGAN network they receive an IP address. Each different computer connected to the terminal obtains a private IP address directly from the terminal or from a router connected to the terminal.

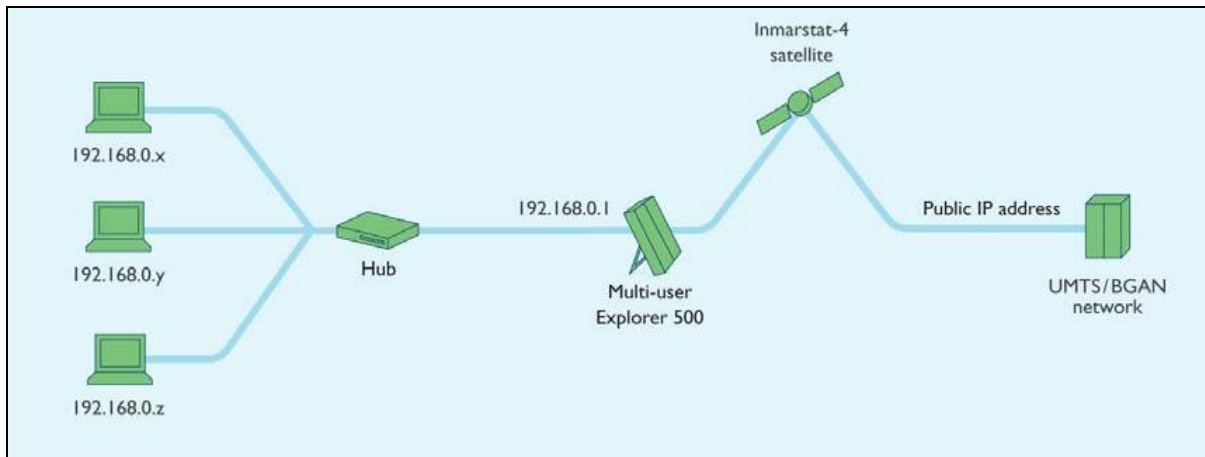
The HNS 9201 Terminal uses the DHCP to dynamically provide with the IP addresses to each computer connected to the LAN, up to eleven users. While the public IP address, which can be static or dynamic, of the terminal will be allocated by the BGAN Service Provider, the default private IP address of the terminal will be 192.168.128.100 and the connected devices will be allocated in addresses like 192.168.128.x (see Figure 19).

The DHCP server will map each private IP address of each connected device with a public IP address in the network. By this method the terminal enables each user to be connected without having to share the IP address with the other users.



**Figure 19: IP addressing on the HNS 9201 [29]**

Thrane & Thrane Explorer 500 and 700 support two different methods for the IP addressing management, NAT mode or router mode. NAT mode dynamically allocates the IP addresses to the connected devices, having 192.168.0.1 as default address for the terminal and providing the users with address such as 192.168.0.x. In the same way as in the HNS 9201 the public IP address for the terminal is allocated by the BGAN Service Provider. However in contrast to this terminal the different users of the Explorer 500 or 700 all the private IP addresses will correspond to just one public IP address and they will have to share the Standard or the Streaming IP connection (see Figure 20).



**Figure 20: IP addressing on Explorer 500 and 700 in NAT mode [29]**

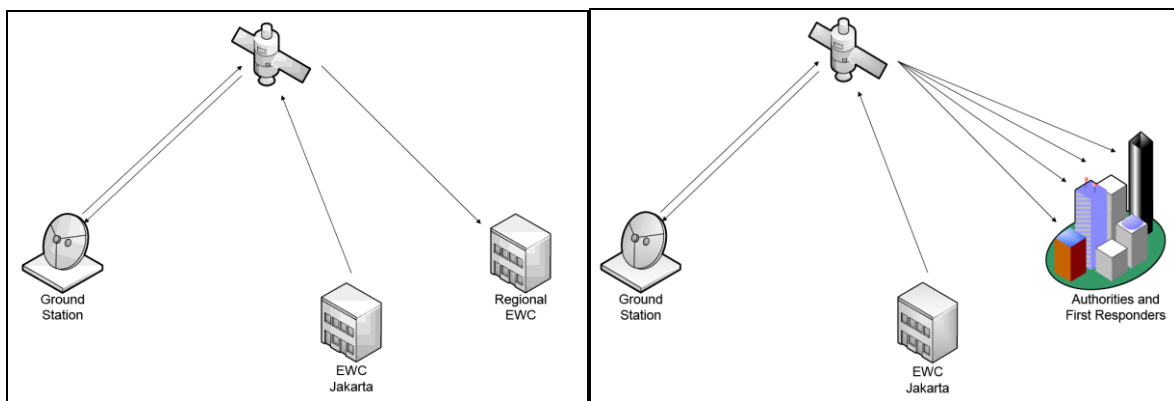
In the router mode the allocation of the IP addresses is not developed by the terminal. In this case the public IP address allocated by the BGAN Service provider is offered to only

one single connected device which can be a computer or a router. The case is a router would mean it receives the public IP address and it allocates the private IP addresses to its connected devices from its own pool of IP addresses.

#### ***4.4. Design of the Scenarios***

In the simulation we have been working in two possible scenarios of the DEWS system, first the exchange of data between two EWCs and second, the transmission of the warning message from the EWC to different authorities and government agencies of the area. The simulation scenario has been programmed to adequate the communication characteristics to the technical specifications offered by the BGAN service. Once the performance of these two scenarios is analysed, the influence of some possible factors is measured.

The computer devices inside an early warning centre will be connected by a hub to the satellite terminal of BGAN in order to communicate to the satellite. This LAN connection is based in the IEEE 802.3 1998 edition standard with a bandwidth of 100Mbps using IPv4. The IP addressing design of the scenarios is based on the dynamic mode of the HNS 9201 as well as in the NAT mode of the Thrane&Thrane Explorer Series mentioned above.

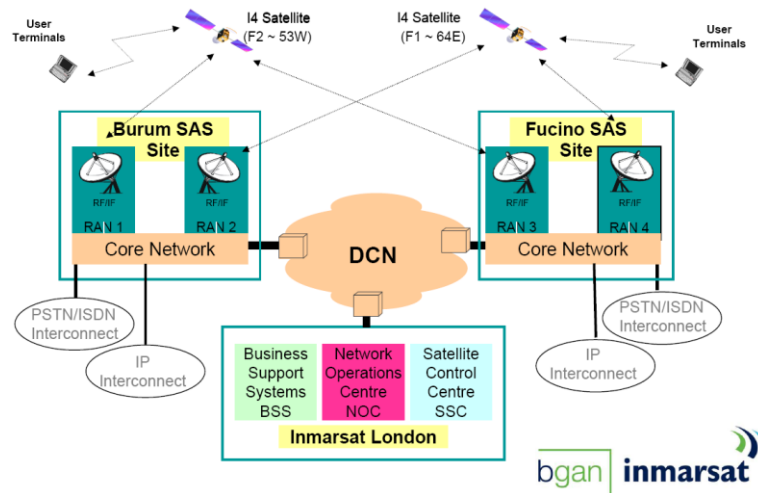


**Figure 21: Qualnet Simulation Scenarios Architecture**

Based on the different possible models of the User Terminals, the characteristics and data rates are established in the simulation. In addition the satellite communication links are designed to work in the L-band of the spectrum and to correspond to a bandwidth of 200 kHz offered by BGAN in the channelisation (See Annex C).

In a UT to UT communication the demodulated signals may not match with the quality requested by the terminals, due to the power attenuation in the downlink and uplink with

the satellite, the limitation in the satellite transponder radio frequency power and the small size of the User Terminals [37]. For this reason the BGAN structure uses the Satellite Access Stations (SAS) of Fucino, Burum and London as a hub station with more powerful transmitters. This BGAN operation is implemented in the developed simulations in Qualnet to provide more realistic results.



**Figure 22: Schematic for BGAN Ground Network**

The processes of the simulations have been managed to cope with the different possibilities to be designed in the model of disseminating alerts/warning messages in the system. As mentioned before each first responder will have different roles in the dissemination of the warning and different task to perform in the affected areas. For this reason the sent messages will have different characteristics and size and the communications channels will affect them in different ways. After running the simulations, the statistics of interest provided by Qualnet are compiled and analyzed.

## **5. Analyses of the Results**

In this study, where the time of alerts/warning dissemination is crucial, much interest is centred on the consequences of the channelisation of the satellite links as well as on the performance of the possible user terminals offered in the market for BGAN communications. These consequences will be provoked not only by the type of BGAN communication channel and by the model of User Terminal used, but also by the characteristics of the message itself.

The dissemination of basic and low-expertise alerts/warning can be implemented by the transmission of text messages with the crucial information for the authorities and population of the affected areas. This scenario will imply low warning message sizes low capacity demands and short delivery times.

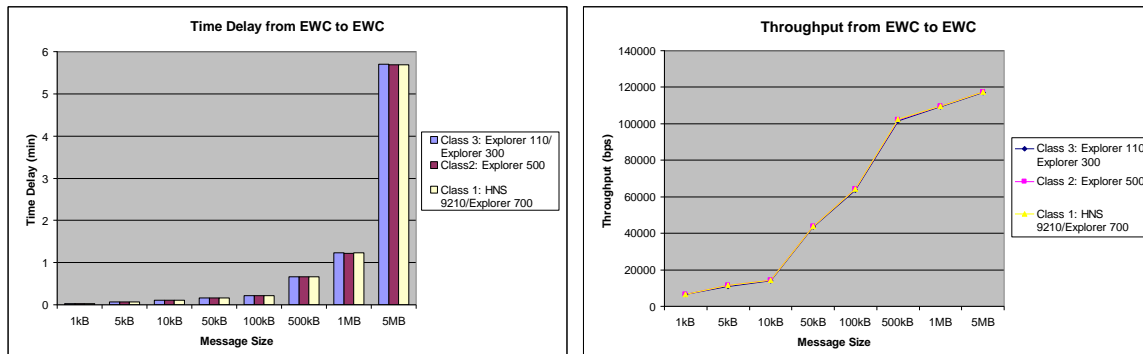
In contrast the dissemination of high-expertise level warning messages will involve the transmission of more complicated CAP format messages which may include multimedia information such as maps of the affected areas developed in the DEWS Situation Picture Component. In this case the performance of the dissemination will reach higher values of time delay.

### ***5.1. Scenarios***

#### **5.1.1 EWC to EWC**

Along the transmission of warning messages between two different national or regional EWC the satellite links will have enough resources to deliver them properly, according to the reaction time limitations in the emergency process. This appropriate performance will allow the system to achieve low levels of time delay in the message dissemination from one centre to another.

The dedication of an entire BGAN communication channel only for the transmission of the warning message provides enough bandwidth resources in the satellite links. The process will achieve low time delays even for large messages (see Figure 23 below).



**Figure 23: Time Delays and Throughput from one EWC to another**

Despite the differences of capacity of maximum data rates between the different models of UTs, in this scenario the time gaps between the performances of the different models do not reach values superior to milliseconds.

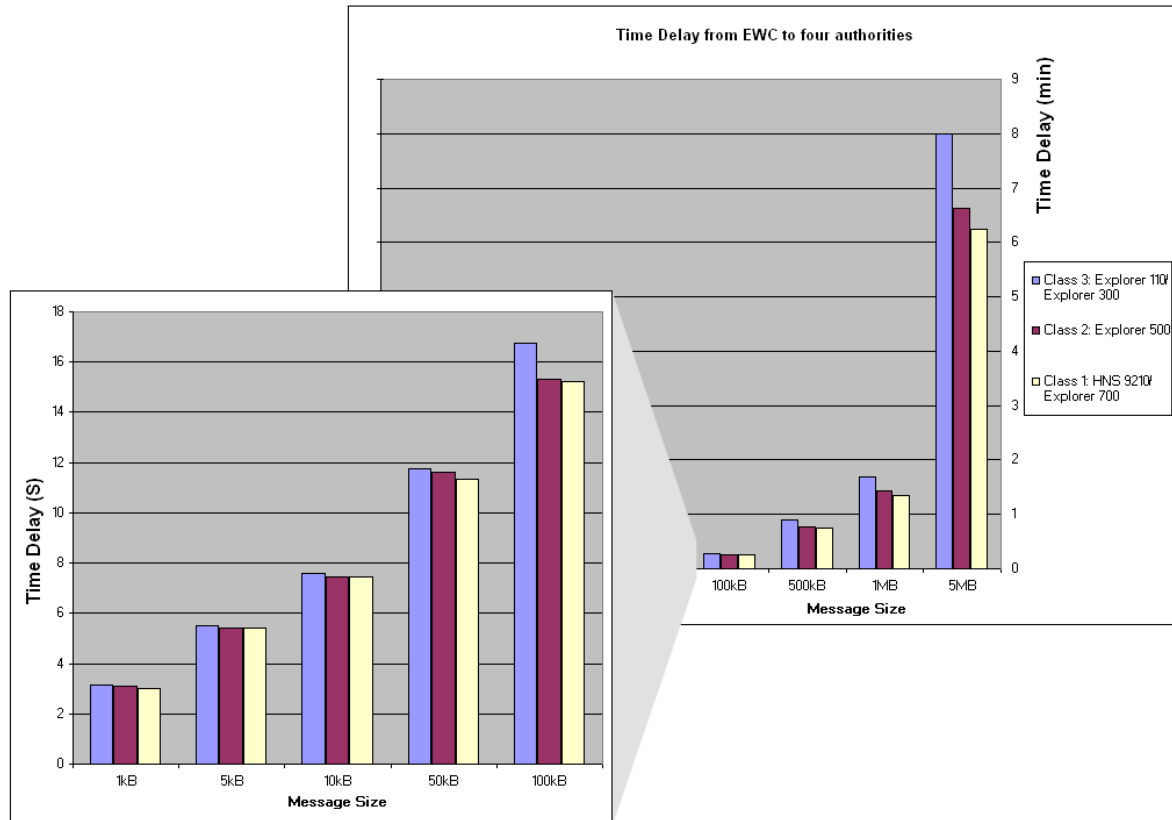
Depending on the size of the warning message to be sent, the capacities of the satellite line will be seized to different levels. In a scenario where two EWC share a direct communication between their User Terminals through the BGAN network the maximum performance of the line in terms of throughput will only be reached with large files.

### 5.1.2 EWC to multiple authorities

In order to disseminate the warning to the population the National EWC will not have enough resources to use all the possible communication options, for this reason this centre will have to be able to send the message to the regional authorities and government agencies which will have the appropriate power.

The consequences of which different model of User Terminals is used into the performance of the warning implementations are going to have more significance in this scenario. In addition the performance gaps between the different implementations will tend to become more obvious as the size of the warning message increases. The figure below shows the results of the communication between a EWC and a default number of four authorities where we can appreciate this effect.





**Figure 24: Time Delays between EWC and four authorities**

Similarly to the previous scenario, in the communication between one EWC and an amount of governmental authorities the capacities of the channels are seized as the size of the message increase. However, in this scenario the performance in terms of throughput of the different user terminals will have larger gaps than when transmitting just between two EWC. In addition the maximum throughput to be achieved in the channel will be reached with smaller size of messages than in the previous scenario.

In comparison between the two scenarios, by sending the different warning messages to several authorities rather than just one single EWC, we will obtain higher values of time delay and low levels of possible maximum throughput rates to be achieved.

## 5.2. Factors of Influence

### 5.2.1 Number of Authorities receiving the warning

The number of authorities participating in the dissemination of the warning and therefore participating in the communications with the EWC will influence in the performance of the system. The congestion of the line will provoke higher time delays and decrease the throughput of the different channels. In the next figure we present the influence of the number of authorities to receive the warning in a transmission of 1MB message with different terminals.

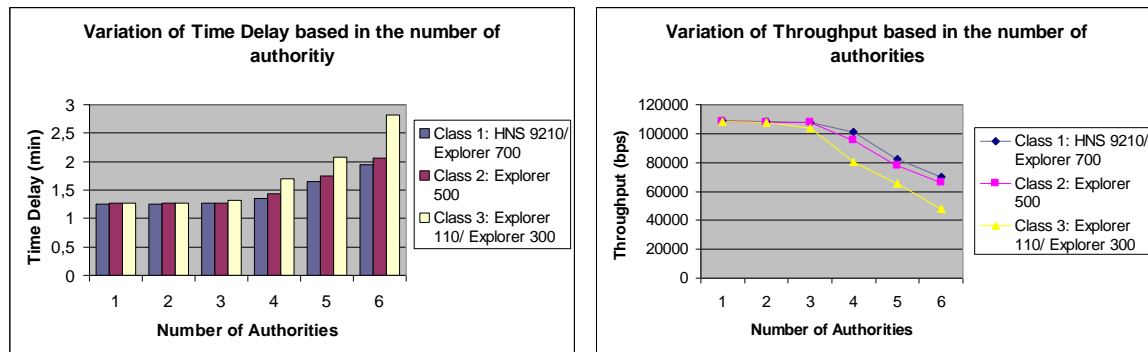


Figure 25: Influence of the amount of Authorities to receive the warning

Since the different authorities in this scenario will have different rates of time delay and throughput, we have taken in account only the worst case rates in order to be aware of the most inconvenient performances.

### 5.2.2 Updating the Warning Information

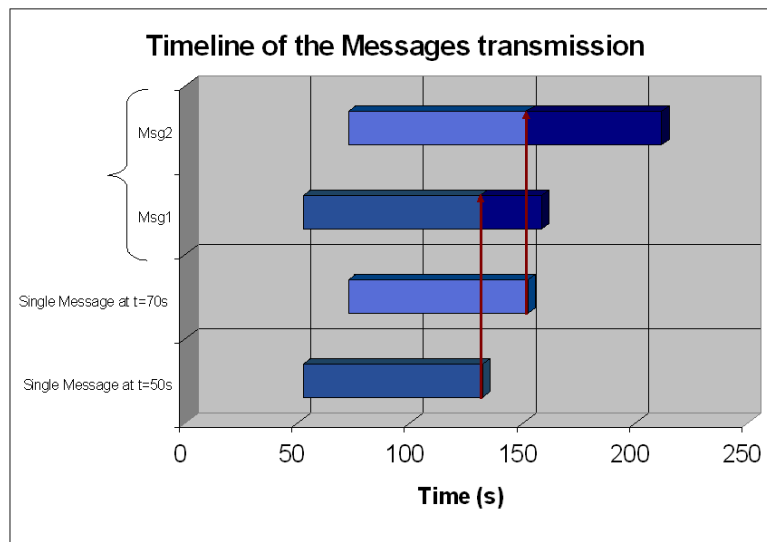
In Section 3.2 it was noted that the tsunami decision process involved sending multiple message types in the warning dissemination process, such as, the detection of the earthquake, the possibility of tsunami, the detection of tsunami, etc. In addition once the incoming tsunami has been detected, the dissemination of new messages in order to update the information may be necessary.

In a situation where the updated message is sent when no other messages are being transmitted, the time delays rates will be equal to the measured above. However both transmissions can coincide in time in a situation with a short time margin between the last message transmission and the updated message incoming transmission. In the time range

where both messages' packets are being sent the congestion of the communication channel will produce higher rates of time delay, affecting in more extent to the second transmission.

Nevertheless in the scenario with communications between two single EWC the influence of channel congestion increase was not appreciable in the simulations results. A situation where while a first warning message is being sent, a second transmission for a new incoming warning message starts was measured in the simulator. The time range for receiving the messages in this scenario distinguished in less than a second from the time range when the messages were sent without interferences.

On the other hand, in a scenario with communications from one EWC to a default number of four authorities the transmission interference of two different messages had important consequences in the time delay rates. In the figure below the timelines of three different tested situations are shown, one single message sent at  $t=50s$ , one single message sent at  $t=70s$  and one message sent at  $t=50s$  with another transmission starting at  $t=70s$ . The messages had a size of 1MB and were transmitted by the User Terminal HNS 9210.



**Figure 26: Timeline with transmission interference**

We can appreciate the extension of the transmission time of the messages in the scenario with both transmissions coinciding in time. This may significantly affect the updating message, with the increase of the transmission time reaching values of minutes, durations of which are undesirable for an early warning system where the response time is crucial.

### 5.2.3 Influence of the Background Traffic

In the communication between the EWCs and between EWCs and first responders there is the possibility of transmitting key information in addition to the warning messages. The key data transmission will be transmitted continuously, in contrast to the warning messages which are only sent in particular situations such as when an earthquake is detected, when a tsunami is possible, and so forth.

We assume this background traffic to be composed by key information such as data measurements, voice, messaging communication, video conferencing or media files with useful information. For this reason the bandwidth range employed to these transmissions can vary, affecting in different extents to the transmission of a warning message. The prioritization of alerts/warning message traffic maybe important to be considered in the design of the system in order to avoid disruption from background traffic

The simulations have shown the influence gap of the different background traffic rates depending on each scenario, displaying a higher tolerance to its consequences in a EWC to EWC situation. In the communications between EWC and several authorities the same consequences were reached with lower background traffic rates (see Figure 27). Note that the graphs stop displaying the values of the variables once the results have become useless (due to the excessive time delay).

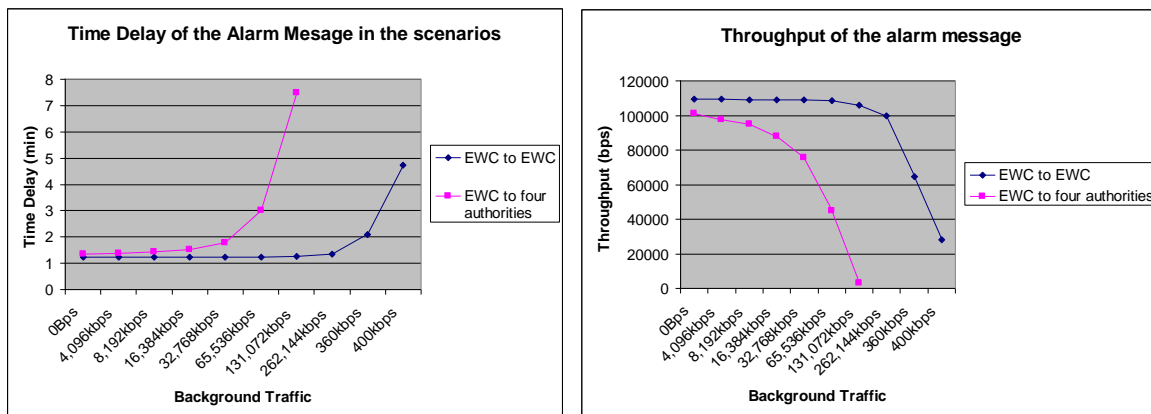


Figure 27: Influence of Background traffic in both scenarios

With low rates of background traffic the performance of the transmission in both scenarios is affected in a low extent. However, as well as the background traffic rates increase the performance quickly achieve unacceptable values in terms of time delay of the warning

message dissemination. We can appreciate the sensibility difference between the two scenarios and the limitations of the permitted background traffic rates in order to achieve the appropriate time delays for the warning message.

In addition it was observed in the simulation results a similar development of the transmission measures of the background traffic packets for both scenarios. The time delay and throughput rates for this traffic increased with similar growth paths achieving time delays up to 1.5 seconds per packet.

## 6. Conclusions

### 6.1. Discussion

This thesis report proposes and analyzes the BGAN technology to serve as a backup for the telecommunications channels of the DEWS centers. By means of Qualnet the possible scenarios in the DEWS architecture have been tested with the adaptation of the BGAN technical specifications into the simulations.

The compilation of the simulations results display the approximated performance statistics of the BGAN service in the dissemination of the warning messages. Even if the QualNet simulator' limitations impede the full implementation of the technical specifications of BGAN, the results show a reliable approximation of the behavior trends in the system. The variation of the dissemination performances serve as a point of importance for the designing of the possible communications backup structure.

The short time range from the detection of the hazard to its apparition forces the DEWS system to seek for the most time saving implementations. For this reason the main performance indicator taken in account in the results is the time delay spent in the transmission of the warning message in order to develop the dissemination to the general public.

The EWC to several authorities communications scenario demonstrates a higher sensibility to the possible factors affecting the dissemination channels. The User Terminal model implemented in the system provokes important time delay gaps in the transmission of the messages, in addition these gaps become larger as well as the message expertise increase. In the use of the BGAN based communication implementation, the architecture of the dissemination plan plays an important role since the sensibility of this scenario is aggravated with the increase of the number of authorities or first responders receiving the warning messages.

On the other hand, in a single EWC to EWC scenario the performance of the transmission channel will be less influenced by the User Terminal used in the communication structure. The different simulations have similar time delay results irrespective the UT model implemented. The time delay rates will increase as the message expertise and therefore the

message size augment. However, the maximum capacity of the channel is not fully utilized except for rare cases where the message size could be considered to be extremely large in the context of the assumptions of this study.

Additional factors will influence in the system performance and should be taken in account in the communications structure design. The protocol of the message dissemination can alter the time delay rates when, in order to update the actual information, the transmission of the updated message coincide with other warning message transmission. The communication between a EWC to a default number of first responders was affected with an increase in the time delay of both message transmissions, while the EWC to EWC scenario presented high resistance to the influence of this factor.

The existence of possible background traffic in the line, in addition to the warning message transmissions, has relevant consequences into the performance of both possible scenarios. The traffic rate levels which provoke excessive time delays of the warning messages have different values depending on the scenario we are treating. In the two scenarios tested the time delay trends follow similar growth paths but the inappropriate levels are reached with different amount of background traffic rates, showing more capacity in the EWC to EWC scenario.

The development of the BGAN backup structure would need the design of the technical characteristics of the system such as the type of message, the information contained on it, the maximum permitted time to disseminate the warning and so forth. Based on the modeling and design results the behavior of the system can pre-approximated in order to select the appropriate implementation of the system to achieve the optimum performance.

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## Annex A: ICT Gathered Indicators

In the work performed for DEWS involving this thesis, a statistical research was performed at the beginning. The recompilation of ICT indicators in the countries of interest is shown in the Annexes A and B.

Indonesia (reference: ITU)

### Basic Indicators

<i>Population</i>					
2004		2005		2006	
<i>Total</i>	<i>Density</i>	<i>Total</i>	<i>Density</i>	<i>Total</i>	<i>Density</i>
<i>(M)</i>	<i>(per km2)</i>	<i>(M)</i>	<i>(per km2)</i>	<i>(M)</i>	<i>(per km2)</i>
222.61	116	222.78	116	225.46	117

<i>GDP (one year before)</i>					
2004		2005		2006	
<i>Total</i>	<i>per capita</i>	<i>Total</i>	<i>per capita</i>	<i>Total</i>	<i>per capita</i>
<i>(B US\$)</i>	<i>(US\$)</i>	<i>(B US\$)</i>	<i>(US\$)</i>	<i>(B US\$)</i>	<i>(US\$)</i>
237.4	1'104	256.8	1'154	287.0	1'288

<i>Total Telephone Subscribers</i>					
2004		2005		2006	
<i>Total</i>	<i>per 100</i>	<i>Total</i>	<i>per 100</i>	<i>Total</i>	<i>per 100</i>
<i>(000s)</i>	<i>inhabitants</i>	<i>(000s)</i>	<i>inhabitants</i>	<i>(000s)</i>	<i>inhabitants</i>
40'328.2	18.13	59'682.2	26.79	78'623.7	34.87

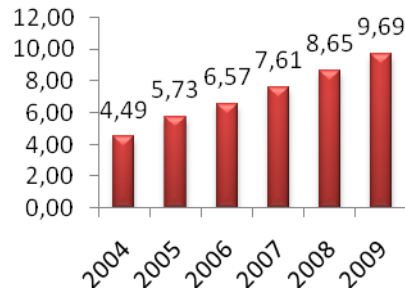
### Main Telephone Lines

<i>Main telephone lines</i>					
2004		2005		2006	
<i>CAGR(%)</i>		<i>CAGR(%)</i>		<i>CAGR(%)</i>	
<i>(000s)</i>	<i>1999 - 04</i>	<i>(000s)</i>	<i>2000-05</i>	<i>(000s)</i>	<i>2001 - 06</i>
9'991.6	10.4	12'772.3	13.9	14'820.7	15.5

<i>Main telephone lines per 100 inhabitants</i>					
2004		2005		2006	
<i>CAGR(%)</i>		<i>CAGR(%)</i>		<i>CAGR(%)</i>	
<i>2004</i>	<i>1999 - 04</i>	<i>2005</i>	<i>2000-05</i>	<i>2006</i>	<i>2001 - 06</i>
4,49	8.7	5,73	12.2	6,57	13.8

**Main telephone lines per 100 inhabitants**



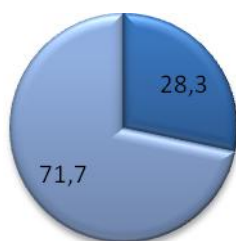
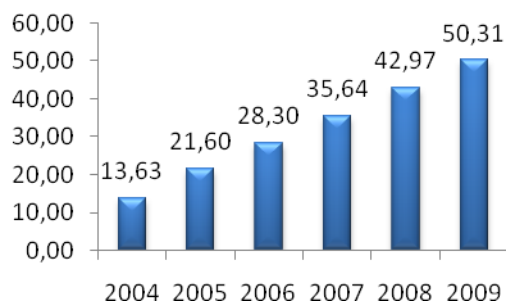
#### Mobile cellular subscribers

<i>Mobile cellular subscribers (2004)</i>					<i>As % of total telephone subscribers 2004</i>
<i>(000s)</i>	<i>CAGR (%)</i>	<i>per 100 inhabitants</i>	<i>% Digital</i>		
<i>2004</i>	<i>1999 - 04</i>	<i>2004</i>	<i>2004</i>		
30'336.6	68.7	13,63	33.9		

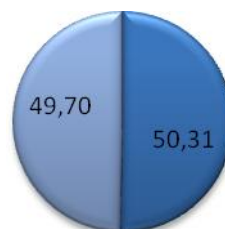
<i>Mobile cellular subscribers (2005)</i>					<i>As % of total telephone subscribers 2005</i>
<i>(000s)</i>	<i>CAGR (%)</i>	<i>per 100 inhabitants</i>	<i>% Digital</i>		
<i>2005</i>	<i>2000 - 05</i>	<i>2005</i>	<i>2005</i>		
46'910.0	66.5	21,60	21.9		

<i>Mobile cellular subscribers (2006)</i>					<i>As % of total telephone subscribers 2006</i>
<i>(000s)</i>	<i>CAGR (%)</i>	<i>per 100 inhabitants</i>	<i>% Digital</i>		
<i>2006</i>	<i>2001 - 06</i>	<i>2006</i>	<i>2006</i>		
63'803.0	57.8	28,30	16.1		

### Mobile cellular subscribers



■ Mobile cellular subscribers (2006)

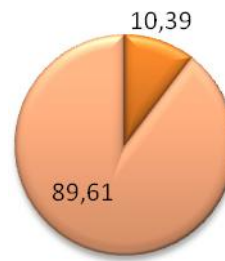
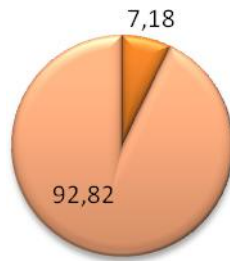
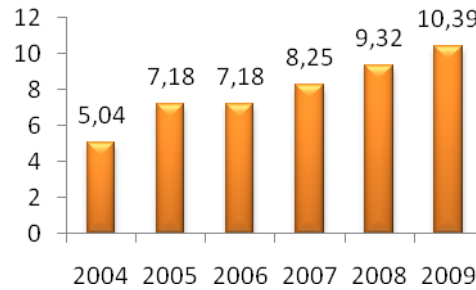


■ Mobile cellular subscribers for 2009

### Internet

Internet(2004)				Broadband Subscribers(2004)	
Subscribers	Subscribers per	Users	Users per	Total	Per 100
(000s)	100 inhab.	(000s)	100 inhab.	(000s)	inhab.
1'087.4	0.49	11'226.1	5,04	84.9	0.04
Internet(2005)				Broadband Subscribers(2005)	
Subscribers	Subscribers per	Users	Users per	Total	Per 100
(000s)	100 inhab.	(000s)	100 inhab.	(000s)	inhab.
1'500.0	0.67	16'000.0	7,18	108.2	0.05
Internet (2006)				Broadband Subscribers(2006)	
Subscribers	Subscribers per	Users	Users per	Total	Per 100
(000s)	100 inhab.	(000s)	100 inhab.	(000s)	inhab.
1'500.0	0.67	16'000.0	7,18	108.2	0.05

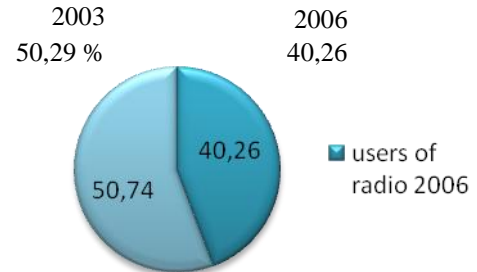
**Users per 100 inhab.**



Users for 2009

### Radio[Source: Badan Pusat Statistik (BPS-Statistics Indonesia)]

*Percentage of population aged over 10 years who listened the radio*

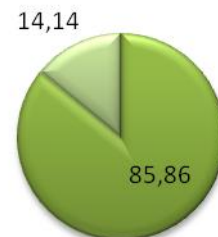


users of radio 2006

### Television [Source: Badan Pusat Statistik (BPS-Statistics Indonesia)]

*Percentage of population aged over 10 years who watched television*

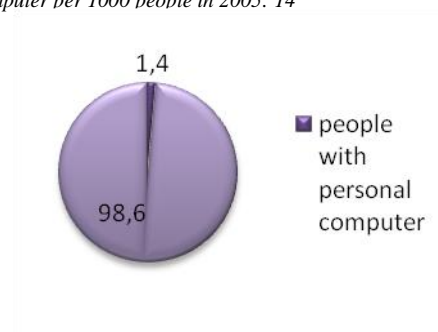
2003 84,94 %  
2006 85,86 %



users of television 2006

## Personal Computers (Source:World Bank)

Personal computer per 1000 people in 2005: 14



## Thailand (reference: ITU)

### Basic Indicators

Population					
2004		2005		2006	
Total (M)	Density (per km2)	Total (M)	Density (per km2)	Total (M)	Density (per km2)
63.69	124	64,23	125	64.76	126

GDP (one year before)					
2004		2005		2006	
Total (B US\$)	per capita (US\$)	Total (B US\$)	per capita (US\$)	Total (B US\$)	per capita (US\$)
143.2	2'267	163.5	2'567	176.6	2'749

Total Telephone Subscribers					
2004		2005		2006	
Total (000s)	per 100 inhabitants	Total (000s)	per 100 inhabitants	Total (000s)	per 100 inhabitants
34'190.3	53.68	38'171.2	59.43	47'888.9	73.95

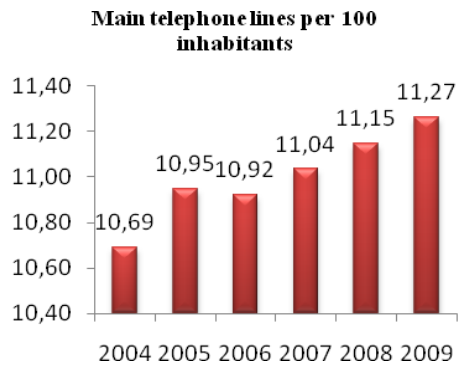
### Main Telephone Lines

Main telephone lines					
2004		2005		2006	
CAGR(%) (000s) 1999 - 04		CAGR(%) (000s) 2000-05		CAGR(%) (000s) 2001 - 06	
6'811.6	5,50	7'034.7	4,70	7'073.4	3,20

Main telephone lines per 100 inhabitants					
2004		2005		2006	
CAGR(%) 2004 1999 - 04		CAGR(%) 2005 2000-05		CAGR(%) 2006 2001 - 06	
10,69	4,50	10,95	3,80	10,92	2.3



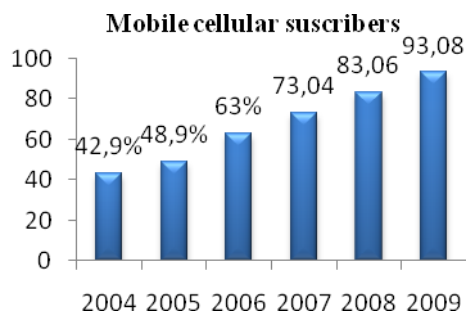


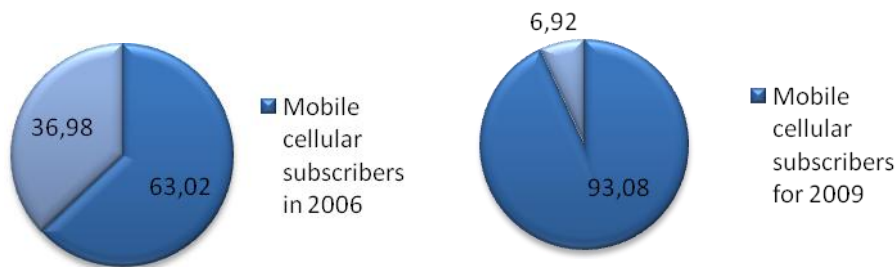
### **Mobile cellular subscribers**

<i>Mobile cellular subscribers (2004)</i>				<i>As % of total telephone subscribers</i>
<i>(000s)</i>	<i>CAGR (%)</i>	<i>per 100 inhabitants</i>	<i>% Digital</i>	
<i>2004</i>	<i>1999 - 04</i>	<i>2004</i>	<i>2004</i>	
27'378.7	63,60	42,98	99.5	

<i>Mobile cellular subscribers (2005)</i>				<i>As % of total telephone subscribers</i>
<i>(000s)</i>	<i>CAGR (%)</i>	<i>per 100 inhabitants</i>	<i>% Digital</i>	
<i>2005</i>	<i>2000 - 05</i>	<i>2005</i>	<i>2005</i>	
31'136.5	59.1	48,97	87.5	

<i>Mobile cellular subscribers (2006)</i>				<i>As % of total telephone subscribers</i>
<i>(000s)</i>	<i>CAGR (%)</i>	<i>per 100 inhabitants</i>	<i>% Digital</i>	
<i>2006</i>	<i>2001 - 06</i>	<i>2006</i>	<i>2006</i>	
40'815.5	40.1	63,02	66.8	

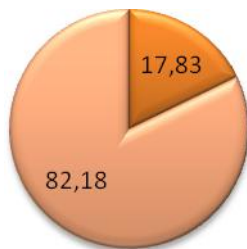
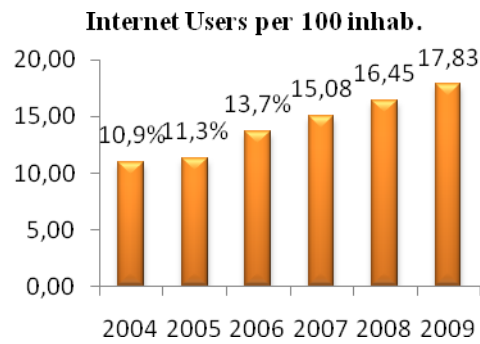




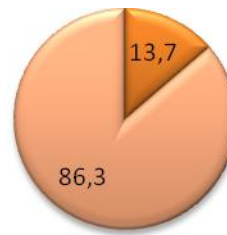
## Internet

Internet(2004)				Broadband Subscribers(2004)	
Subscribers (000s)	Subscribers per 100 inhab.	Users (000s)	Users per 100 inhab.	Total (000s)	Per 100 inhab.
2'403.7	3.81	6'971.5	10,95	75.0	0.12
Internet(2005)				Broadband Subscribers(2005)	
Subscribers (000s)	Subscribers per 100 inhab.	Users (000s)	Users per 100 inhab.	Total (000s)	Per 100 inhab.
2'403.7	3.81	7'284.2	11,34	105.0	0.16
Internet (2006)				Broadband Subscribers(2006)	
Subscribers (000s)	Subscribers per 100 inhab.	Users (000s)	Users per 100 inhab.	Total (000s)	Per 100 inhab.
2'403.7	3.81	8'465.8	13,70	105.0	0.16

CAGR: Compound Annual Growth Rate.



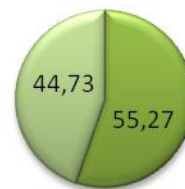
users for  
2009



internet  
users in  
2006

### Television (Source: Wikipedia)

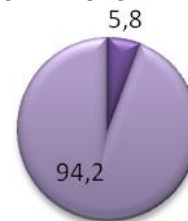
35.5 million televisions in use in 2005:



users of  
television in  
2005  
(aprox.)

### Personal Computers (Source: World Bank)

Personal computer per 1000 people in 2005: 58



people  
with  
personal  
computer

# Sri Lanka (reference: ITU)

## Basic Indicators

Population					
2004		2005		2006	
Total (M)	Density (per km <sup>2</sup> )	Total (M)	Density (per km <sup>2</sup> )	Total (M)	Density (per km <sup>2</sup> )
19.46	297	20.74	316	20.91	319

GDP (one year before)					
2004		2005		2006	
Total (B US\$)	per capita (US\$)	Total (B US\$)	per capita (US\$)	Total (B US\$)	per capita (US\$)
18.2	947	20.1	1'031	23.5	1'135

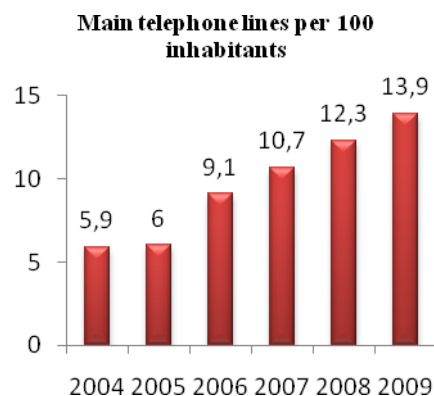
Total Telephone Subscribers					
2004		2005		2006	
Total (000s)	per 100 inhabitants	Total (000s)	per 100 inhabitants	Total (000s)	per 100 inhabitants
3'202.4	16.45	4'605.8	22.20	7'296.6	34.89

## Main Telephone Lines

Main telephone lines					
2004		2005		2006	
CAGR(%) (000s) 1999 - 04		CAGR(%) (000s) 2000-05		CAGR(%) (000s) 2001 - 06	
991.2	8.2	1'244.0	10.1	1'884.1	17.9

Main telephone lines per 100 inhabitants					
2004		2005		2006	
CAGR(%) 2004 1999 - 04		CAGR(%) 2005 2000-05		CAGR(%) 2006 2001 - 06	
5.90	6.7	6.00	7.6	9.10	15.3



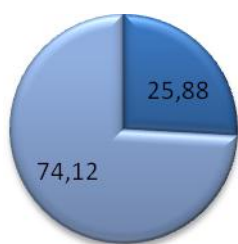
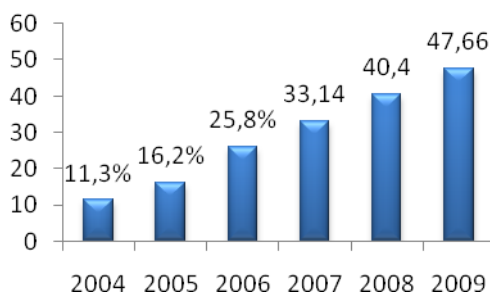
## Mobile cellular subscribers

Mobile cellular subscribers (2004)				As % of
(000s)	CAGR (%)	per 100 inhabitants	% Digital	total telephone subscribers
2004	1999 - 04	2004	2004	2004
2'211.2	53.8	11,36	49.5	69.0

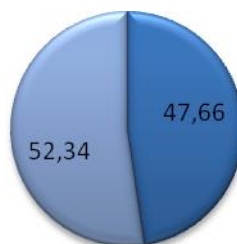
Mobile cellular subscribers (2005)				As % of
(000s)	CAGR (%)	per 100 inhabitants	% Digital	total telephone subscribers
2005	2000 - 05	2005	2005	2005
3'361.8	50.9	16,21	32.6	73.0

Mobile cellular subscribers (2006)				As % of
(000s)	CAGR (%)	per 100 inhabitants	% Digital	total telephone subscribers
2006	2001 - 06	2006	2006	2006
5'412.5	52.0	25,88	20.2	74.2

### Mobile cellular subscribers



■ Mobile cellular subscribers (2006)



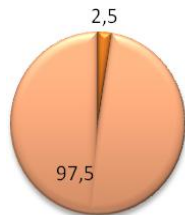
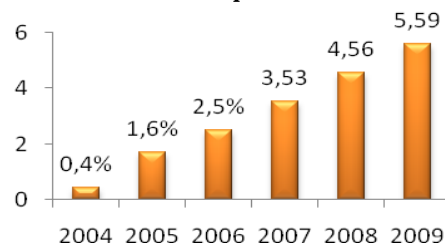
■ Mobile cellular subscribers for 2009

## Internet

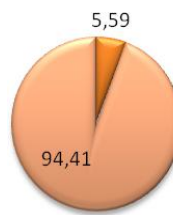
Internet(2004)				Broadband Subscribers(2004)	
Subscribers (000s)	Subscribers per 100 inhab.	Users (000s)	Users per 100 inhab.	Total (000s)	Per 100 inhab.
93.4	0.48	280.0	0,44	20.4	0.11
Internet(2005)				Broadband Subscribers(2005)	
Subscribers (000s)	Subscribers per 100 inhab.	Users (000s)	Users per 100 inhab.	Total (000s)	Per 100 inhab.
115.0	0.55	350.0	1,69	26.1	0.13
Internet (2006)				Broadband Subscribers(2006)	
Subscribers (000s)	Subscribers per 100 inhab.	Users (000s)	Users per 100 inhab.	Total (000s)	Per 100 inhab.
130.1	0.62	428.0	2,50	29.1	0.14

CAGR: Compound Annual Growth Rate.

**Internet Users per 100 inhab.**



■ internet  
users in  
2006

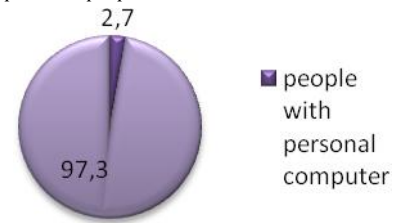


■ internet  
users for  
2009

## Personal Computers (Source: World Bank)

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*Personal computer per 1000 people in 2005: 27*



## Annex B: GSM and CDMA Coverage Areas in the DEWS countries

### Indonesia

#### GSM

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Excelcom (XL) [Source: <http://www.xl.co.id/> (2008)]

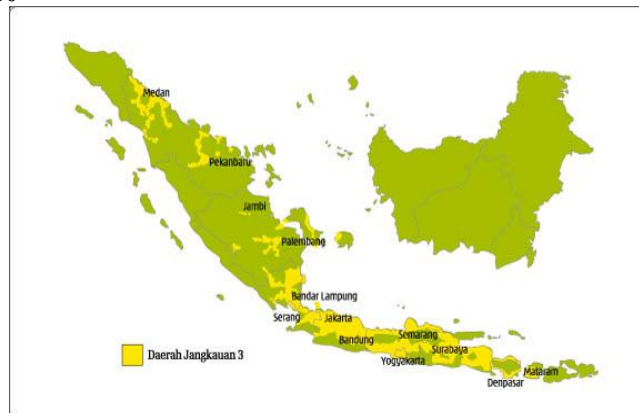
•Technology: GSM 900/1800

•XL Network has covered the main island of Indonesia:  
Sumatera, Java, Bali, Lombok, Kalimantan and Sulawesi



Hutchison CP Telecommunications (3) [ Source:<http://www.three.co.id/3coverage/> (2008)]

•Technology: GSM 1800





**PT Indonesian Satellite Corporation Tbk (INDOSAT) [ Source:GSMA]**

•Technology: GSM 900/1800



•Technology: GSM 1800



**PT Natrindo Telepon Seluler (Lippo Telecom) [ Source:GSMA]**

•Technology: GSM 1800



**PT Telekomunikasi Selular (TELKOMSEL) [ Source:GSMA]**

•Technology: GSM 900/1800



**CDMA**

The following networks operate in this country:

Operator	2G/3G	Type of system	Status	Infrastructure Vendor(s)	CDMA Coverage
<a href="#">PT Bakrie Telecom</a>	3G CDMA2000 1xEV-DO Rel. 0	- WLL,800 MHz	Launch TBA		Coverage Pending
<a href="#">PT Bakrie Telecom</a>	3G CDMA2000 1X	- WLL,800 MHz	Commercial	Nortel	Banten, DKI Jaya-Jakarta, West Java
<a href="#">PT Indosat</a>	3G CDMA2000 1xEV-DO Rel. 0	- Cellular/PCS,800 MHz	Commercial	Huawei,	Balikpapan
<a href="#">PT Mobile-8 Telecom</a>	3G CDMA2000 1X	- Cellular,800 MHz	Commercial	Samsung	Anyer, Bantar, Bekasi, Bogor, BSD, Carita, Cibadak, Cibinong, Cibitung, Cibubur, Cicurug, Cikampet, Cikande, Cikarang, Cikupa, Cilegon, Cileungsi, Cimanggu, Cisaura, Depok, DKI Jaya-Jakarta, Gebang, Gunung Putri, Jatisari, Karawaci, Karawang, Klari, Pandeglang, Parung, Puncak Pass,

						Purwakarta, Rangkas Bitung, Sadang, Sawangar, Sentul, Serang, Serpong, Sindanglaya, Sukabumi, Tajur, Tambun, Tangerang, Tol Serpong
<a href="#">PT Mobile-8 Telecom</a>	3G CDMA2000 1X	- Cellular,800 MHz	Commercial	Samsung		Arjawinangun, Bandung, Banjar, Banjaran, Cadas, Cagak, Ciamis, Cianjur, Ciater, Cikalong Wetan, Cilimus, Cimahi Kota, Cipatat, Ciranjang, Cirebon, Ciwidey, Cugenang, Garut, Gekbrong, Gunung Bengkung, Indramayu, Jatibarang, Jatiwangi, Karang Ampei, Kopo, Kuningan, Lembang, Losarang, Losari, Majalengka, Malangbong, Nagrek- Pasar Cicis, Padalarang, Pamanukan, Pangandaran, Pangeran, Patrol, Pengalengan, Piered, Rajapolah, Rancaekek, Singaparna, Soreang, Sukabumi, Sukaraja Sukabumi, Sumedang, Tanjung Sari, Tasikmalaya Ampel, Bandungan, Bangsri, Bangsri- Bebes, Banjarnegara, Bantul, Banyumanik, Bawen, Blora, Bojong, Borobudur, Boyolali, Bebes, Bumiayu, Cepu, Cilacap, Comal, Delanggu, Demak, DI Yogyakarta, Gombong, Gringsing, Imogiri, Jepara, Karang Awen, Karang Pucung, Karanganyar, Kartosuro, Kebumen, Kedu, Kendal, Klampok, Klaten, Klepu, Kopi Eva, Krumpit, Kudus,
<a href="#">PT Mobile-8 Telecom</a>	3G CDMA2000 1X	- Cellular,800 MHz	Commercial	Samsung		

PT Mobile-8 3G - Cellular,800 Commercial Samsung  
Telecom CDMA2000 MHz  
 1X

Kutoarjo,  
 Kutowinangun,  
 Lompong, Magelang,  
 Majenang, Margosari,  
 Masaran, Mranggen,  
 Muntilan, Ngroto, Pati,  
 Pekalongan, Pemalang,  
 Prambanan, Purwodadi,  
 Purwokerto, Purworejo,  
 Randublatung,  
 Rembang, Salatiga,  
 Secang, Semarang,  
 Slawi, Solo, Sragen,  
 Subah, Sukoharjo,  
 Surodadi, Tanjung,  
 Tawangmangu, Tegal,  
 Tulis, Ungaran,  
 Wanareja, Wates,  
 Wonogiri, Wonosobo,  
 Yuwono  
 Ambulu, Asembagus,  
 Babat, Bajulmati,  
 Balung Kota, Bancar,  
 Bangil, Bangkalan,  
 Banyuwangi, Basuki,  
 Batu, Beji, Blitar,  
 Bojonegoro,  
 Bondowoso, Bromo  
 Panajakan, Brondong,  
 Caruban, Cerme,  
 Dampit, Gedangan,  
 Gempol, Genteng,  
 Glenmore, Gresik,  
 Gunung Doek, Gunung  
 Kawi, Gunung  
 Kuncung/Trenggalek,  
 Jalur Bangil-  
 Probolinggo, Jatiroto,  
 Jember, Jombang,  
 Kalibaru, Kandangan,  
 Karangjati, Karangrejo,  
 Kediri, Kencong,  
 Kepanjen, Kertosono,  
 Ketapang, Klakah,  
 Kraksaan, Lamongan,  
 Lawang, Leces,  
 Lumajang, Madiun,  
 Magetan, Malang,  
 Milwang, Mojokerto,  
 Muncar, Ngandong,  
 Nganjuk, Ngawi,  
 Ngebel, Nguling,  
 Ngunut, Padangan,  
 Paiton, Pamekasan,  
 Panceng, Pandaan,  
 Pare, Pasir Putih,  
 Pasuruan, Ploso,

						Ponorogo, Prigen, Probolinggo, Puger, Purwosari, Rogojampi, Sampang, Saradan, Sarangan, Sedati, Sedayu, Sidoarjo, Singosari, Situbondo, Sukodadi, Sukorejo, Sukowono, Sumber Manjing, Sumber Pucung, Sumenep, Surabaya, Tanggul, Tanggul Angin, Tapen, Trenggalek, Tuban, Tulung Agung, Tumpang, Turen, Wates, Widodaren, Wlingi, Wongsorejo, Wonosalam
<a href="#">PT Sampoerna Telekomunikasi Indonesia</a>	3G CDMA2000 1X	- Cellular,450 MHz	Commercial	Huawei		Coverage Pending
<a href="#">PT Smart Telecom</a>	3G CDMA2000 1xEV-DO Rev. A	- PCS ,1900 MHz	Launch TBA	ZTE		Coverage Pending
<a href="#">PT Smart Telecom</a>	3G CDMA2000 1xEV-DO Rel. 0	- PCS ,1900 MHz	Launch TBA	ZTE		Jakarta
<a href="#">PT Smart Telecom</a>	3G CDMA2000 1X	- PCS ,1900 MHz	Commercial	ZTE		Coverage Pending
<a href="#">PT TELKOM Indonesia</a>	3G CDMA2000 1X	- WLL,800 MHz	Commercial	Samsung		Balikpapan, Denpasar, Surabaya
<a href="#">PT TELKOM Indonesia</a>	3G CDMA2000 1X	- WLL,800 MHz	Deployment	Ericsson		Bekasi, Bogor, Jakarta, Tangerang
<a href="#">PT TELKOM Indonesia</a>	3G CDMA2000 1X	- Cellular,800 MHz	Deployment	Samsung		Bali, Java, Kalimantan, Sulawesi

<a href="#"><u>PT TELKOM Indonesia</u></a>	3G CDMA2000 1X	-	WLL,800 MHz	Deployment	Motorola	Sumatra
<a href="#"><u>PT TELKOM Indonesia</u></a>	2G 95A	-	IS- Cellular,800 MHz	Commercial	Motorola	East Java, Surabaya
<a href="#"><u>PT TELKOM Indonesia</u></a>	2G 95A	-	IS- WLL,1900 MHz	Commercial	Motorola	Bandung, West Java

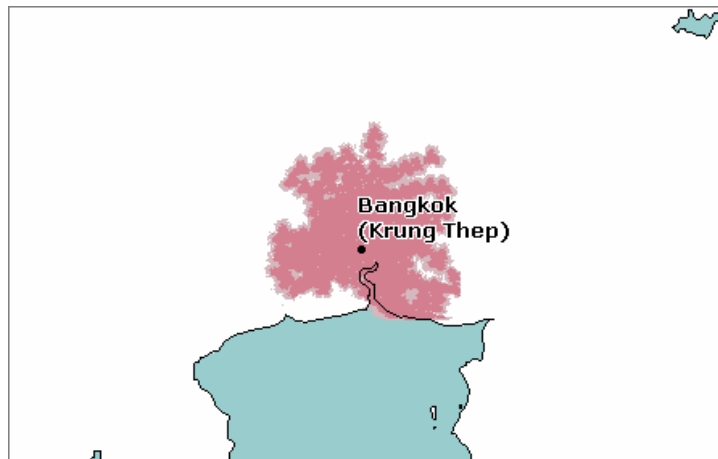
## Thailand

### GSM

The following networks operate in this country:

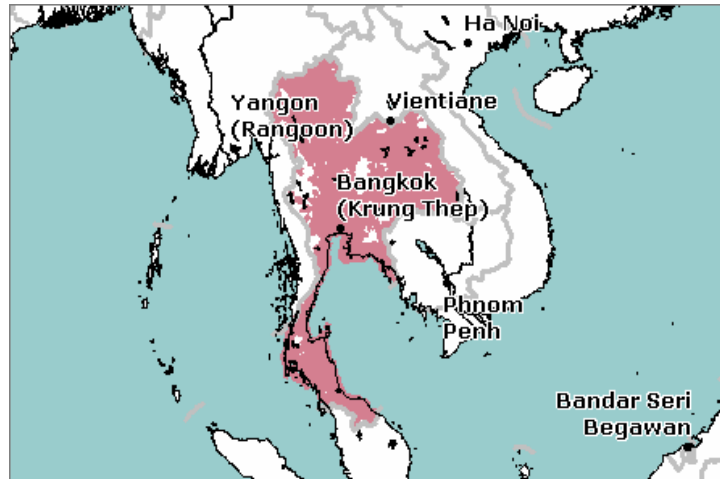
**ACT Mobile Company, Limited (ACT GSM 1900) [ Source:GSMA]**

•Technology: GSM 900/1800 and 3G 2100 still in planning process (planned for July 2008)



**Advanced Info Service PLC (AIS GSM)[ Source:GSMA]**

•Technology: GSM 900



**Digital Phone Co Ltd (GSM 1800) [ Source: GSMA]**

•Technology: GSM 1800



**Total Access Communications Co (DTAC) [ Source: GSMA]**

•Technology: GSM 1800



**True Move Company Ltd [ Source: GSMA]**

•Technology: GSM 1800



## CDMA

The following networks operate in this country:

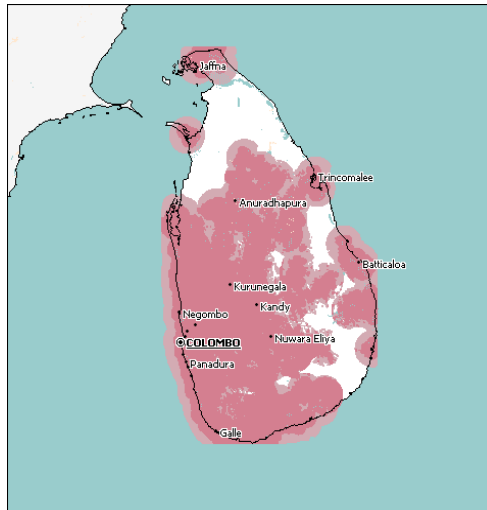
Operator	2G/3G	Type of system	Status	Infrastructure Vendor(s)	CDMA Coverage
<a href="#">CAT Telecom</a>	3G CDMA2000 1xEV-DO Rel. 0	- Cellular,800 MHz	Limited Commercial	Huawei	Phuket, Udonthani
<a href="#">CAT Telecom</a>	3G CDMA2000 1X	- Cellular/WLL,800 MHz	Limited Commercial	Huawei	Coverage Pending
<a href="#">Hutchison CAT</a>	3G CDMA2000 1xEV-DO Rel. 0	- Cellular,800 MHz	Commercial	Motorola	Bangkok



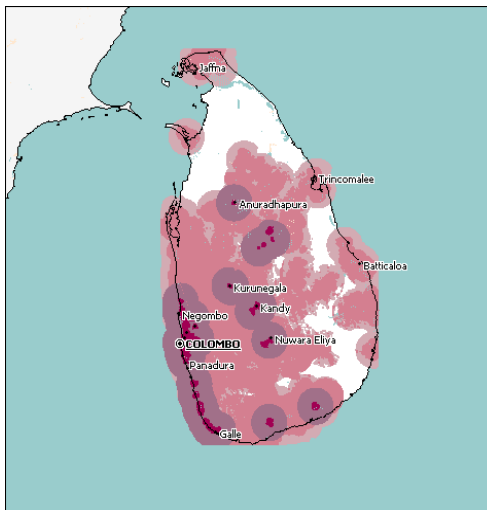
# Sri lanka

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01/07/08 Jose de la Fuente/ Helsinki University of Technology, Department of Electrical and Communications Engineering, Communications Laboratory 79

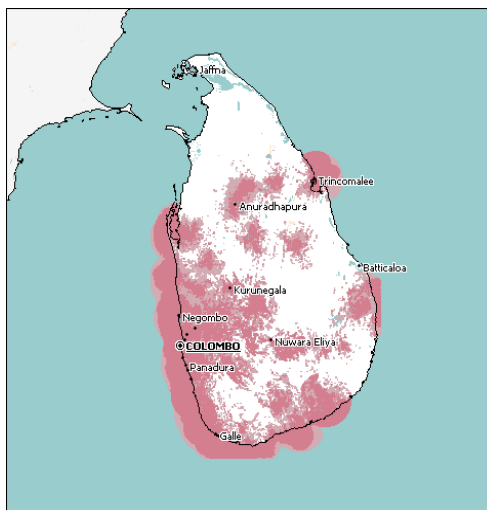


•Technology: 3G 2100



**Hutchison Telecommunications Lanka (Pte) Limited [ Source:GSMA]**

•Technology: GSM 900

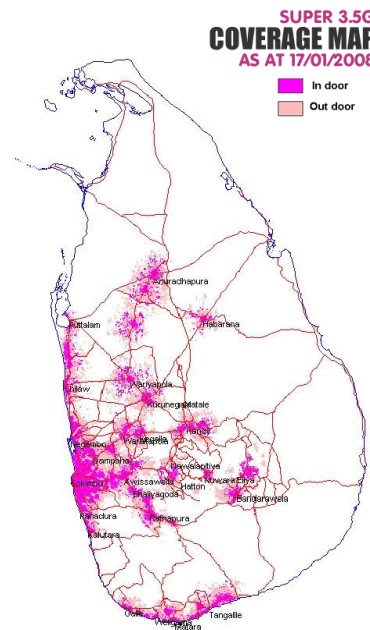


**Mobitel (Pvt) Limited [ Source: <http://www.mobitellanka.com/>]**

•Technology: GSM 1800

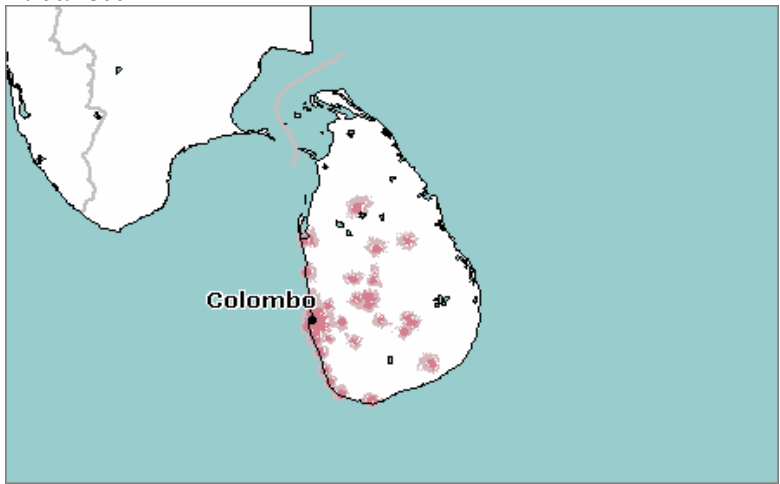


•Technology: 3,5G



**Tigo (Private) Limited** [ Source: <http://www.mobitellanka.com/>]

•Technology: GSM 900/1800



**CDMA**

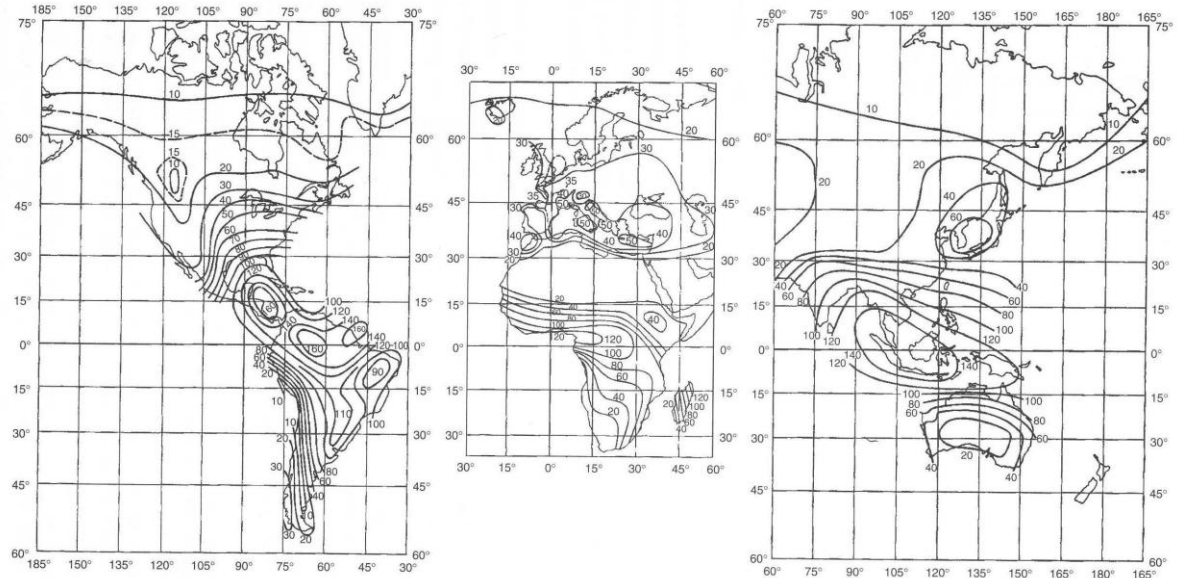
Operator	2G/3G	Type of system	Status	Infrastructure Vendor(s)	CDMA Coverage
<a href="#">Dialog</a>	3G CDMA2000 1X	- WLL, 450 MHz	Commercial	Huawei	Chillaw, Kalutara, Kandy, Kegalla, Kurunegala, Puttalam,

<a href="#">Lanka Bell</a>	3G CDMA2000 1X	- WLL,	Commercial	Huawei,	Ratnapura Ampara, Anuradhapura, Badulla, Chillaw, Colombo, Galle, Hambantota, Kalutara, Kandy, Kataragama, Kegalla, Kurunegala, Matale, Matara, Monaragala, Negombo, Nuwara-Eliya, Polonaruwa, Puttalam, Ratnapura, Trincomalee, Vavnya
		1900 MHz		ZTE	Islandwide
<a href="#">Sri Lanka Telecom Limited</a>	3G CDMA2000 1X	- WLL, 800 MHz	Commercial	ZTE	
<a href="#">Suntel</a>	3G CDMA2000 1xEV-DO	- WLL, 800 MHz	Trial	Huawei	Coverage Pending
<a href="#">Suntel</a>	3G CDMA2000 1X	- WLL, 800 MHz	Commercial	Huawei	Nationwide
<a href="#">Tritel Services Private Limited</a>	3G CDMA2000 1X	- WLL, 450 MHz	Launch TBA	Huawei	Islandwide

## Annex C: General Simulation Inputs

Channel Frequency	1.6 GHz
Network Protocol	IPv4
Satcom type	Bent pipe
Bandwidth	384/464/484kbps
Propagation Delay	270ms
Radio Type	Satellite RSV PHY
Channel Bandwidth	200 kHz
Preamble Size	64
Modulation Profile	QPSK
R-S Block and Code Size	REED-SOLOMON 204-188
R-S Shorten Last Codeword	YES
Convolutional Coding Profile	VITERBI 1-2
Guard Time	10us
Adjacent Channel Interference	18dB
Adjacent Satellite Interference	30dB
Intermodulation Distortion	25dB
Receiver Threshold	7dB
Error Model	Threshold-Based
Error Threshold	7dB
LAN Subnet MAC Protocol	802.3
802.3 Bandwidth	100Mbps
802.3 Prop Delay	2.5us

## Annex D: Rain Contours World Map



Source: Maral G. 2003