Disaster Management Projects using Wireless Sensor Networks: An Overview

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***Abstract*— There are numerous projects dealing with disaster management and emergency response that use wireless sensor networks technologies. Indeed, WSNs offer a good alternative compared to traditional ad hoc networks. Air pollution monitoring, forest fire detection, landslide detection, natural disaster prevention, industrial sense and control applications, dangerous gas leakage, water level monitoring, vibration detection to prevent an earthquake, radiation monitoring are examples of the WSN applications related to disaster management. This paper presents an overview of the recent projects using WSN to collect data in disaster areas.**

Keywords*—*Wireless Sensor Networks; Disaster Management; Emergency Response; Information Systems.

I. INTRODUCTION

Collecting and sharing disaster information about damaged area is the most important activity to support decision-making in rescue processes.

Disaster Management Systems that use Wireless Sensor Networks (WSNs) have received much attention by researchers in the last five years. This interest comes from the increasing number of disasters all around the world, causing the loss of a huge number of lives and properties and on the easy use of these new and cheap technologies. Indeed, WSNs offer an interesting alternative to wired networks when infrastructures collapse, for instance, after an earthquake or a tsunami. In addition, WSN have attractive characteristics, they are known to be auto-configurable, auto-organizing, have small volumes, etc.

Different environment parameters can be detected by sensors, such as, the atmosphere humidity and temperature useful for detecting forest and building fires, toxic gases caused by an explosion, water level to detect and prevent floods, vibration level to detect chocks and earthquakes and many other data. Sensors can offer additional useful services. For instance, an estimation of the victim number by calculating the number of persons holding Bluetooth devices, a rapid localization of incidents and victims, a fast and wireless communication between sensors, first responders and command centers. Furthermore, multimedia sensors can take useful photos and videos of the affected area and transfer them in real-time to help first responders and decision makers getting a global idea about the current situation.

In the following section, we give general descriptions of some disaster management projects that use wireless sensor networks. Some were proposed to manage specific disasters such as earthquakes, landslides, air pollution and healthcare while others can be applied in many scenarios.

II. DISASTER MANAGEMENT PROJECTS

A. SENDROM

SENDROM (SEnsor Network for Disaster Relief Operations Management) was mainly proposed to be used in the case of earthquakes in Turkey as it is one of the most subject countries to earthquakes [1].

The architecture of SENDROM consists of sensor nodes deployed prior to a disaster and central nodes stored nearby strategic centers and linked to the SENDROM database.

The nodes are divided into several types; *Cnodes* are data Collector Nodes such as mobile computers. *Snodes,* deployed prior to a disaster, sense and report any living human in the vicinity. They are divided into *Standalone* nodes which are located, for instance, inside drawers and cabinets and *Embedded* nodes located, for example, in washing machines. This kind of nodes is capable of detecting vibration during an earthquake. *Inodes* are used for individuals and human beings. They are also divided into *Standalone* nodes which can be placed, for example, in pockets or in individual bags and *Embedded* ones in wristwatches, for instance. Cnodes invoke the Snodes and Inodes and then send the received data to the *Central SENDROM Database*. This latter is continuously updated by the EOCs (Emergency Operation Center) and Cnodes. Figure 1 (Cayirci et al. 2007) shows the SENDROM architecture after a disaster.

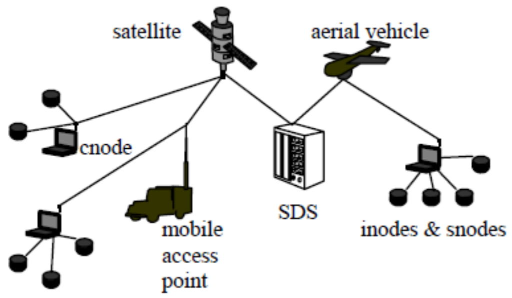

Figure 1: SENDROM after a disaster (Cayirci et al. 2007).

SENDROM Database Server (SDS) has the role of getting information about buildings and individuals. This server can be queried form Internet allowing rescue teams to get prior information while on the way to the site. Rescue teams and EOCs query the SDS via Cnodes. Snodes and Inodes send data to the SDS via mobile access points (UAVs, cars, etc.). Note that Inodes always generate reports while Snodes generate them only when they detect a living human being in their vicinity. Sensor nodes include in the report the task *id.* of the query and Cnodes use the directional antennae to broadcast the task depending on their regions.

B. INSYEME

The main aim of the IN.Sy.EME (Integrated System for Emergency) project is to define an integrated system to support emergency operations that integrate a pervasive Grid structure and a wireless communication network [2]. The network is composed of a variety of fixed and mobile processing nodes. The main characteristics of this network are the high heterogeneity, the mobility, and the dynamism of its nodes. In particular, Wireless Sensor Networks are needed to collect data from the environment in order to support forecasting methods to monitor and predict the disaster evolution. The vehicle grid then becomes a sink of the network which can be remotely accessed from the Internet.

Authors of INSYEME propose also to equip the sensing devices with interfaces to wireless access networks such as 2/3G, WLAN and WMAN enabling ubiquitous connectivity.

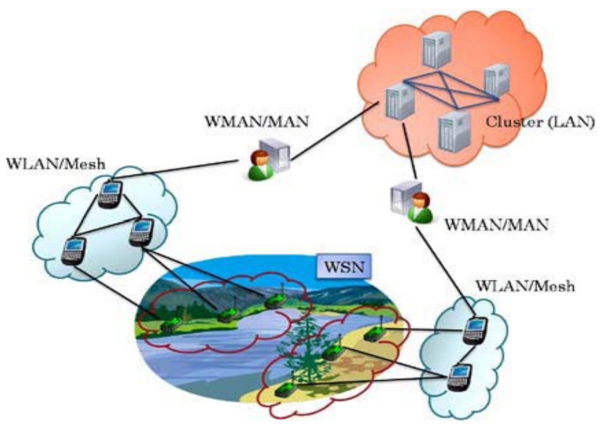

Figure 2: The forecasting model in INSYEME (Fantacci et al. 2010).

In addition, they propose to use WIMAX which can serve as a backbone for integrating WSNs and connecting heterogeneous networks. However, the WIMAX has to be optimized in order to provide an excellent Non Line of Sight (NLoS) coverage.

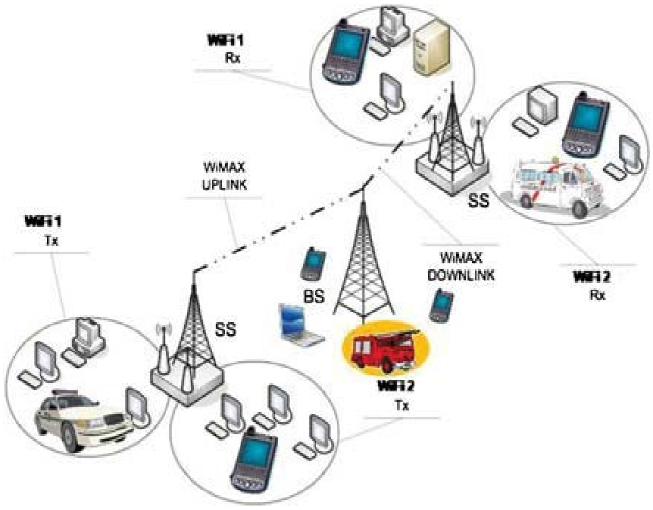

Figure 3: A heterogeneous WIFI-WIMAX network (Fantacci et al. 2010).

For routing purposes, authors propose to use an interconnection technique between an IEEE 802.11x network and a WIMAX network while maintaining the same QoS level between the two networks.

C. Telemedicine with WSNs

This project was proposed to relay gathered information from the disaster scene with a telemedicine system [3].

The proposed architecture supports multi hopping mechanism to transfer the information among multiple cells using Ad hoc relay stations that collect data from sensor nodes. Some of the nodes are also used as base stations in order to route the data from one location to another in critical emergency conditions. The base station is GSM based if a cellular network is available otherwise a WiMax based antennae is used. The purpose of using multi-channel cluster-based architecture is to provide energy efficient routing protocol among multiple sinks; each sink is responsible for maintaining a cluster tree and sending signal to the neighborhood.

The proposed network architecture is composed of three entities; Wireless Sensor Network, emergency response data center and satellite communication infrastructure.

- *Wireless Sensor Network*: the network is divided into four adjacent cells where each cell is composed of four ad hoc relay stations covering each cluster. Each cluster is directly interfaced with a sink node, responsible for maintaining communication path to the base station.

- *Emergency Response Database*: the role of this unit is to receive and store information about critical disaster conditions.
- *Satellite Communication Interface*: Information related to the disaster is transferred via this communication media towards some medical services such as mobile ambulances and hospitals using telemedicine based infrastructure.

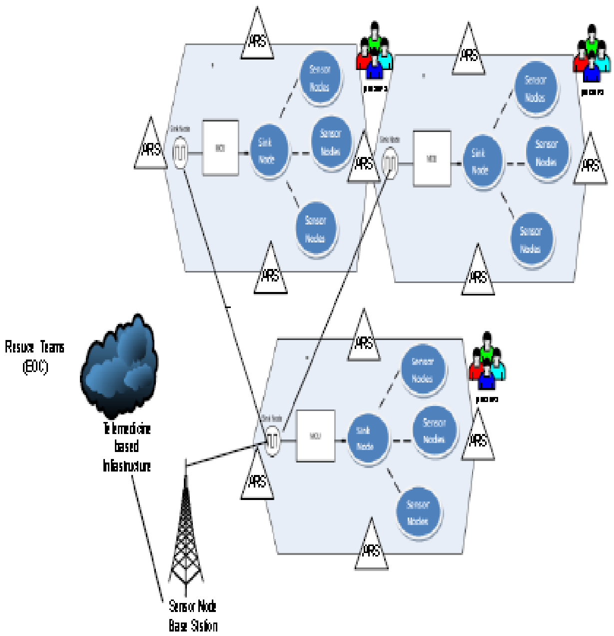

Figure 4: WSNs with Telemedicine (Ahmad et al. 2011).

Authors affirmed that their networked architecture allows reducing energy consumption; however, no performance analysis was conducted.

D. WINSOC

The aim of WINSOC (WIreless sensor Network with Self-Organization Capabilities for critical and emergency applications) project is to estimate the chance occurrence of landslides by detecting rainfalls using wireless sensor networks [4]. For that purpose, the authors designed a Deep Earth Probe (DEP) installed in the ground. The whole landslide prone area is divided into regions processing soil geological and hydrological properties, namely, Crown region, Middle region and Toe region with a set of sensors planted in each one.

The network architecture is composed of two-layers hierarchically. The lower layer consists of WSNs that sample and collect data from the DEP and transmit data to the upper layer. While the upper layer aggregates the data and forwards them to the sink (at the deployment site). For the experiments of WINSOC, twenty wireless sensor nodes of Grossbow MicaZ were divided hierarchically into clusters and gateways. Data are transmitted from the gateway to the Filed Management Center (FMC) through a Wifi network. In addition, the FMC incorporates a Very Small Aperture Terminal (VSAT) earth station used to transmit data from the deployment site to the Data Management Center (DMC) far away 300 km. The DMC is a database server and analysis station where results and analysis data are real-time streamed on Internet. Figure 4 (Ramesh 2009) shows in details the WINSOC components.

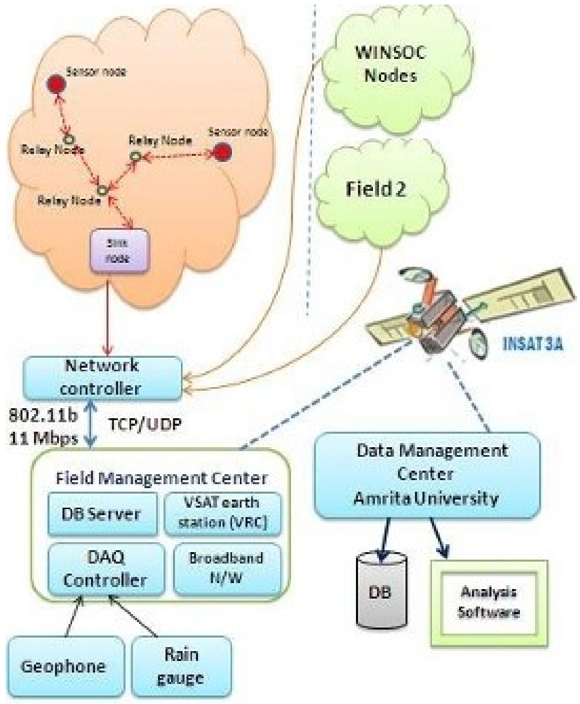

Figure 5: WINSOC Architecture (Ramesh 2009).

Notice that alerts are sent via E-mails, SMS and MMS. The solution is reliable since there is the alternative of replacing the VSAT by the broadband or GPRS if the connection to VSAT is unavailable. Also, the architecture is scalable as any node can be added through the WiFi network. In addition, to increase the lifetime of the solution, sensors are automatically recharged by solar recharging units using a charge controller.

E. USN4D

The goal of the project USN4D (Ubiquitous wireless Sensor Network For Development) is to provide early warning for Air pollution and to disseminate surveillance information for cities in order to support municipality service delivery and to provide enjoyment of the citizens and tourists [5].

The platform of USN4D is composed of four main components.

1) *Data collectors*: Sensed data can be collected through two types of sensors, ZigBee sensors and GPRS sensors. Each type is related to a network.

2) *Pyton code*: this part includes the two Gateway Interfaces between the system coordinator, the sensor

networks and the Database Interface linking the system coordinator to a MySQL database (See figure 6).

3) *Database*: an actual relational database (MySQL) was used.

4) *End User Interface*: the user can query the database and extract analyzed and localized data. Results can be shown via GoogleMaps services.

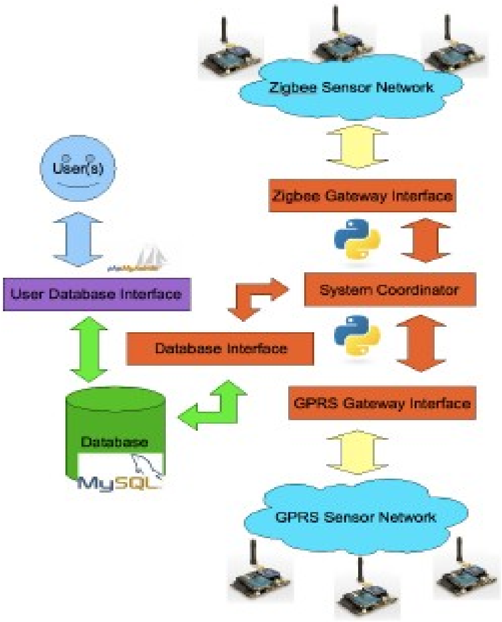

Figure 6: USN4D Platform (Bagula et al. 2012).

USN4D uses XBee Waspmotes [8] which work with both GPRS (enabling sending and receiving SMS) and ZigBee as dissemination protocols. In addition, Data are stored in SD cards available on the mote. The used Gas card of a Waspmote can support 11 different gas sensors (CO, CO_2, $C_6H_5CH_3$, etc) but only six can be piggybacked at once, in addition to temperature, humidity and atmospheric pressure sensors. Some experiments were successfully tested namely: (a) Monitoring a room's temperature every five minutes and sending SMS alerts if it is greater than 20°c. (b) During transportation of containers, sending SMS with GPS coordinates if a container is stolen. (c) Monitoring motor behavior by measuring the motor acceleration four times per second and sending SMS or with other wireless method the alert to a pc. (d) Measuring air pollution in Cape Town, by reading data every thirty (30) seconds from Gas sensors, storing them on SD card with date, time and position, and sending SMS to a given phone number when pollution reaches given threshold values.

F. AWARE

AWARE is the acronym of Platform for Autonomous self-deploying and operation of Wireless sensor-actuator networks cooperating with AeRial objects [6].

This European project consists in developing a platform enabling the cooperation of autonomous aerial vehicles (UAVs) with ground wireless sensor-actuator networks composed of static and mobile nodes. Additionally, the project also considers the self-deployment of the network using autonomous helicopters that have the ability to transport and deploy loads. The main goal of this project is to build a middleware enabling the cooperation of heterogeneous objects including aerial vehicles, static-actuator nodes and mobile nodes carried by ground vehicles and agents, so that the whole system can detect events (e.g. fire) by means of temperature sensors and wirelessly communicate these events [6][9].

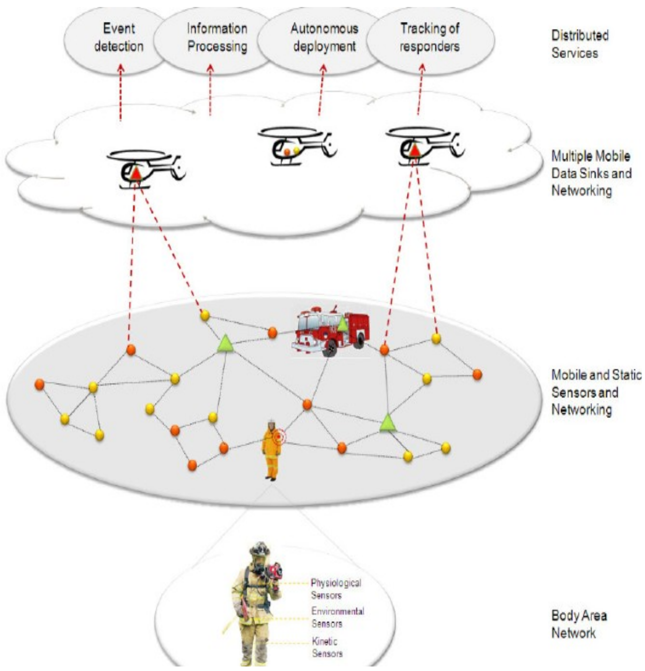

Figure 7: AWARE Architecture (Erman et al. 2008).

The platform consists of two different networks, a High Bandwidth Network (HBN) and Low Bandwidth Network (LBN), connected through "gateways". HBN is composed of personal computers, Ground Camera Nodes and mobile robots capable of transmitting data through IEEE 802.3 or IEEE 802.11 networks. The LBN is composed of WSN nodes having very limited computing and data transmitting capabilities. In addition, any device capable of direct communication with both networks might act as a gateway (see figure 7 and 8).

The AWARE middleware contains three main components: Routing Engine, Filtering Engine and Gateway Management Engine. For routing, researchers used some variants of flooding gossiping, AODV as well as geographic routing. The filtering engine is responsible of the data processing and aggregation and message suppression. Location is one of the main factors used in the filtering phase.

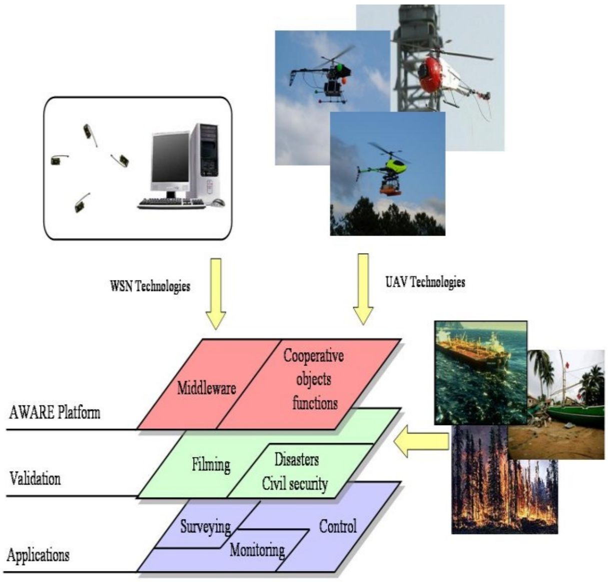

Figure 8: AWARE (Ollero et al. 2007).

The used helicopters are equipped with sensors, cameras, a GPS, and a 400 MHz real-time computer.

G. MiTag

The main concern of Medical Information TAG (miTag) is to automatically track patients throughout each step of the disaster response process, from disaster scenes, to ambulances, to hospitals [7]. The system is characterized by (a) cost-effective sensor hardware, (b) self-organizing wireless network and (c) scalable server software that provide an analysis of sensor data and delivers real-time updates to handheld devices and web portals. The miTag system uses a variety of wireless sensors such as GPS, pulse oximetry, blood pressure, temperature, ECG to measure heartbeats. The miTag supports two-way communication by sending messages to and from patients. Members of the distributed response team such as treatment officers, incident commanders, receiving hospitals and public health officials, can log onto a web portal to review real-time patient information. Each miTag sends and receives data with a transmission bandwidth of 250kbps and the indoor range is about 20m.

MiTag supports two types of wireless networks: an on-body short range network of sensors caring about collecting patient measurements and an off-body long-range network of repeater nodes responsible of transmitting these measurements to the receiver. Data are first aggregated via the body area network and then forwarded to a long-range mesh network. Moreover, the repeater nodes are dispensed by responders on the scene.

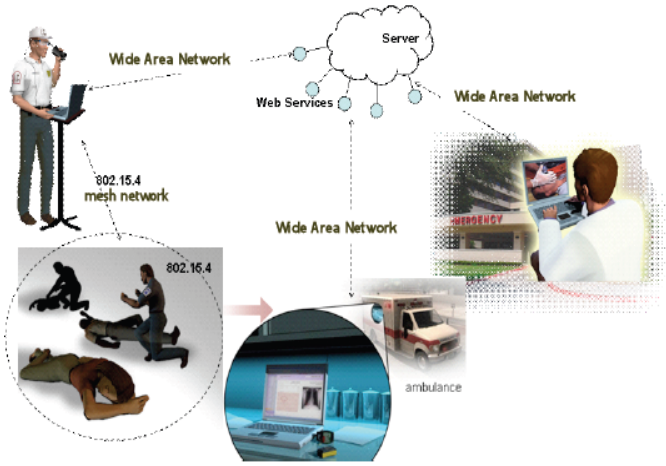

Figure 9: Real-time communication with miTag (Gao et al. 2008).

Repeaters can be strategically placed in locations to route around sources of interference. Comparatively to traditional tools such as papers and radios, MiTag improves the information sharing delay among the geographically distributed responder groups. MiTag sensors generate more detailed patient information; hence, allowing more accurate patient diagnostics and treatment.

III. DISCUSSION

The common point of the projects presented in this paper is the use of a Wireless Sensor Network as part of their architectures. The roles of such networks are collecting data from the disaster area and wirelessly transmit them to a central database. In addition, we have tried to present some systems dealing with different disasters, among others: earthquakes, air pollution, landslides, and forest fires.

Some of these projects propose to use wearable sensors; others propose to deploy static sensors in buildings in addition to mobile sensors carried out by agents. All of the presented projects use wireless communication to be more robust in case where infrastructures collapse after the disaster.

Still are some challenges that should be considered in designing such projects. Routing emergency messages with delay constraints is one the important tasks. In addition, locating emergency responders and victims is also an essential aspect while the energy consumption is a fundamental problem in WSNs that should be considered when using such technology.

The following table summarizes the main characteristics of the above projects in addition to the challenges that we believe should be considered for further improvements of these projects.

TABLE I: DISASTER MANAGEMENT PROJECTS

Project	Main Scenario	Supported Networks	Challenges
SENDROM [1]	Earthquake Detection	WSN	Indoor Localization
INSYEME [2]	Emergency Operations	WSN, WiFi, WiMax	Localization and Security
WSN with Tele-medicine [3]	Evacuating Victims	WSN, GSM, WiMax	Heterogeneity of networks
WINSOC [4]	Landslide Detection	WSN, WiFi, Satellite communication, GPRS	The DEP-sensor deployment
USN4D [5]	Air Pollution Detection	WSN, GPRS, ZigBee	Real-time Routing
AWARE [6][9]	Surveying and Filming, Fire Detection	WSN, Mobile WSN, Multimedia WSN	The choice among Multitude of routing protocols
MiTag [7]	Tracking patients	WSN & RFID, Mesh, WAN	Radio Interferences

IV. CONCLUSION

In this paper, we have presented some disaster and emergency management projects that use wireless sensor networks in their architectures to measure and communicate useful data. The role of a sensor node is to sense the environment, communicate and exchange sensory data with other nodes in the area, locally process its own data and make smart decisions about what it observes. Many national and international projects that use WSNs have been investigated in order to facilitate the response management and hence save lives. To the best of our knowledge, this paper is the first that surveys the projects dealing with disaster management and emergency response and that use the technology of wireless sensor networks. Since these projects are based on WSNs, they inherit all the advantages and the limits of such networks, so, designers must take this point into consideration.

In order to benefit from previous projects and experiences, we plan soon to design a novel architecture based on wireless mesh sensor networks that responds to emergency requirements such as the mobility of first responders and real-time routing and localization while taking account of the energy conservation of the sensor network.

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