



Using WiMAX technology to improve volcano monitoring: the WEIRD System

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1. Introduction

IEEE 802.16 standards (IEEE, 2004; IEEE, 2005), commonly known as WiMAX (Worldwide Interoperability for Microwave Access Forum), is one of the most promising broadband wireless access technology for next generation all-IP networks. This access technology allows reaching high bit rate and covering large areas with a single Base Station (BS). Thanks to these features, IEEE 802.16 opens the way for the use and the introduction of wireless technologies in particular emergency scenarios, like volcano monitoring.

Active volcano surveillance is based prevalently on the analysis of geophysical and geochemical parameters gathered by monitoring networks. Of all, seismology is one of the most useful methods for volcano monitoring. In fact, several types of seismic signals, e.g. volcano-tectonic earthquakes (VT), long-period events (LP), volcanic tremor, can occur before and during an eruption. The analysis and interpretation of these seismic signals are a very important task for the volcanic eruption forecasting (Scarpa and Tilling, 1996).

WiMAX technology can be applied to provide broadband wireless access in volcano monitoring scenarios, in order to solve all the problems that today limit the possibility to realize a real-time and accurate monitoring of volcanoes activities in emergency situations. In particular, this paper focus on a novel solution, designed within the IST FP6 EU WEIRD (WiMAX Extension to Isolated Research Data networks) Integrated Project, to perform volcano monitoring using the features offered by IEEE 802.16 networks in order to improve transmission of data acquired by temporary seismic stations deployed during emergencies. Tests performed on field demonstrate the advantages offered by the use of WiMAX compared with other commonly used technologies.

2. Volcano monitoring and WiMAX technology

The permanent networks are fundamental to recognize a variation in the seismic behavior of an active volcano. Unlikely, in some circumstances, the data recorded only at the permanent networks are not enough to study in detail the spatial and temporal features of earthquakes preceding and accompanying eruptions. This is due either to the insufficient number of deployed seismic stations or to the instrument inadequacy (i.e. too few digital broadband equipments).

When a volcano shows an increase of geophysical and geochemical background parameters, the Permanent Seismic Network is improved with temporary digital stations deployed as soon as possible to enhance both the network geometry and the quality of the recorded data. The temporary instruments are portable digital seismic stations generally equipped with broadband seismometers and characterized by continuous local recording on removable media (e.g. hard disk, magneto optical disk, compact flash). They are provided with several communication ports (serial, LAN, USB) and absolute timing is obtained through a GPS receiver.

The local recording system agree with the necessity of a quickly improvement of the monitoring system in case of emergency and allows the better deployment of the temporary stations. In fact, owing to the not necessary direct link with an acquisition centre, the stations can be installed in the field both to integrate and to optimize the running permanent network. Moreover, thanks to their handiness, the temporary stations can be quickly removed and then reinstalled according to the seismicity behavior. On the other hand, the use of the Temporary Seismic Stations has some limitations that could be improved in order to be able to exploit their use in the best way.

In fact, the local recording needs a periodic maintenance to retrieve the data and therefore the data itself are not available in real-time. For this reason, the fast integration between permanent and temporary seismic networks is not always easy. Moreover, there is the need for scientists to reach all the temporary seismic station to download data, especially during emergency in which the amount of collected data is huge. Finally, the recording media have finite storage capacity, and during seismic swarms there is the possibility to fill all the memory.

Whilst a Permanent Seismic Network acquires data continuously and transmits them to the Acquisition Centre by means of a dedicated data connection already available, Temporary Seismic Stations are deployed during emergencies and they are not provided with a communication link to the Acquisition Centre. The need to create a communication link between Temporary Seismic Stations and the Acquisition Centre puts new challenging requirements that have to be taken into account.

First, data acquired by the Temporary Seismic Stations should be transmitted in real-time to the Acquisition Centre. This feature has several advantages:

- scientists can analyze in real-time current volcano status and activate any action;
- the problem related to the finite storage capacity of the Temporary Seismic Stations is eliminated;
- scientists do not move to reach all the Temporary Seismic Stations to download collected data spending useful time.

Moreover, the need to collect seismic data in real-time requires a wide wireless area coverage together with broadband features, even in NLOS (Non Line Of Sight). Finally, the need to support also voice and video communications, as they are needed during a volcanic crisis for the communication between scientists in the field and scientists in research centre, introduces Quality of Service (QoS) requirements. The WiMAX technology, thanks to its wide coverage area, its high capacity and the possibility to support Quality of Service, is the new broadband wireless access technology that allows to fits all the listed requirements.

WiMAX, based on OFDM/OFDMA (Orthogonal Frequency Division Multiple Access) technique, is the most promising Broadband Wireless Access (BWA) technology. In fact it makes possible to provide wireless data connections over long distances (up to 50 km) with high bit-rate (up to 75 Mbps). Thanks to this specific feature, WiMAX is able to guarantee requirements imposed by the considered emergency scenario (Guainella et al., 2007).

The WEIRD system design has been based on state-of-the-art technologies and the ongoing standardizations processes and aims to be a part of full multi-domain network architecture, allowing fixed and mobile access. The WEIRD system (Fig. 1), designed in order to offer solutions not only for volcano monitoring but also for other emergency scenarios like fire prevention and tele-medicine, aims at enhancing the WiMAX technology. It takes into account the guide lines of IEEE 802.16d, IEEE 802.16e and WiMAX Forum (WiMAX Forum, 2006) but adds important features, especially with respect to end-to-end Control Plane and QoS Resource Control and Management. In order to build heterogeneous network architecture and enhance the QoS management, WEIRD provides a convergence layer that manages the underlying technology to provide QoS features to upper layers.

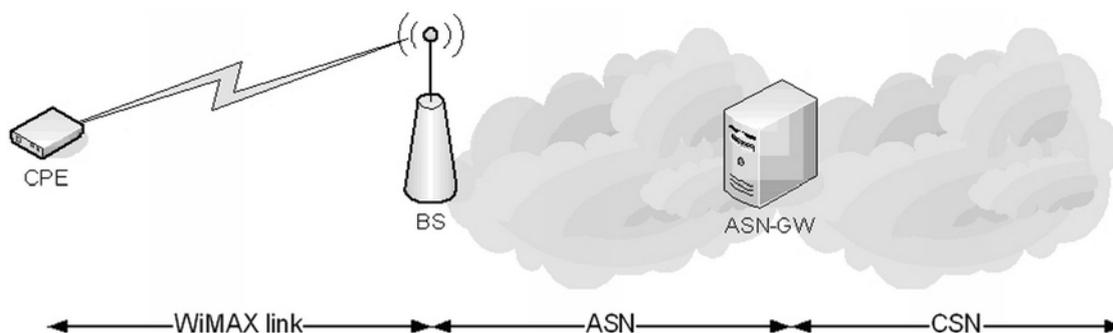


Fig. 1 - Simplified WEIRD Overall Network Infrastructure.

The WEIRD system includes three components: *Customer Premises Equipment (CPE)*, *Access Service Network (ASN)* and *Connectivity Service Network (CSN)*. The CPE can be composed of single-user IEEE 802.16 Subscriber Stations (SS) or multiple users SSs (MS), in case that a SS offers access to LANs/WLANs having several users/hosts. An ASN may control and aggregate several BSs, based on a wireline or wireless IP infrastructure. The ASN is linked through an *ASN Gateway (ASN-GW)* to the CSN. Connectivity with other networks may be realized via IP backbone. Application entities clients and/or servers can exist in the CPE side or in CSN networks.

Among several features provided by the WEIRD system, the most important one for volcano monitoring in emergency situations is related to the possibility to control and offer end-to-end QoS enabled services. WEIRD should achieve and control QoS in its scope: WiMAX segment and ASN. To this aim, it defines appropriate interfaces with CPE and CSN and runs QoS oriented signaling onto these interfaces. The WEIRD system offers different levels of QoS to the high level services/applications mapping them on appropriate IEEE 802.16 classes of services in WiMAX segment (Unsolicited Grant Service (UGS), real time Polling Service (rtPS), extended real time Polling Service (ertPS), non real time Polling Service (nrtPS) and Best Effort (BE)).

3. The application

When a volcanic alert occur, it is very important manage, as soon as possible, the data acquired by the temporary seismic stations. In this way, it will be possible to integrate the information of the entire seismic monitoring system to understand in detail the behavior of the seismic and volcanic activity.

Because the temporary seismic stations gather continuously the data on local storage media, the data are always available by means of the communication interfaces.

Some tests have been performed in order to compare different wireless access systems (GSM and WiMAX) to be used to send collected data from the temporary seismic stations to the Acquisition Centre. Tests have been realized at the Ivrea testbed of the WEIRD Project.

Through the serial output, it is possible to transfer the data using a GSM modem connection. This type of connection is very slow and it is not suitable during an emergency, when the quickness in the data transfer is very important. The best solution is represented by the LAN interface linked to a WiMAX transmission system. With this type of communication, based on TCP/IP protocol, it is possible to download the seismic signal stored in the temporary seismic stations directly from the Acquisition Center.

The temporary digital station used during the test was a Lennartz M24 device (Lennartz Electronic GmbH), characterized by the presence of a web-based interface. A downloadable time window can be selected from the Data Export menu. A WiMAX connection to retrieve the data stored on a Lennartz M24 seismic station has been tested. A time window of five minutes in ASCII compressed format has been selected. This time interval is enough to analyze the waveform of a local low-energy earthquake. The test shows that the download is complete in about six seconds, allowing a near real-time processing of the data and the fast integration with the Permanent Seismic Network data. Using the 9600 bps GSM connection the same file is transferred in more than fifteen minutes.

The WiMAX technology allows using the transmission both in LOS (Line Of Sight) and in NLOS (Non Line Of Sight) environments. A scenario has been developed for the Campi Flegrei volcanic area, where a Temporary Seismic Network has been deployed during the recent 2004-2006 emergency (Saccorotti et al., 2007, Fig. 2). In this situation, the NLOS transmission allows the link between each Temporary Seismic Station and the Acquisition Center. This configuration is very useful because it permits the best deployment of the Temporary Seismic Stations according to the seismicity behavior.

However, in LOS configuration, the link can be obtained also through a sequence of radio links (repeaters) in order to reach stations not directly visible. In Fig. 2, an example for the Campi Flegrei volcanic area is shown. With only three access points configured as repeaters, it is possible to cover the entire area and to link the Temporary Stations to the Acquisition Centre. Moreover, the support for QoS provided by the WEIRD system allows also establishing voice and video communications between people in field and scientists in research centre, which could not be realized through a GSM access system.

Finally, the WEIRD network connected with the GEANT Pan European network give the possibility to share data/voice in real time with all interested people to evaluate the risk effort during the emergencies.

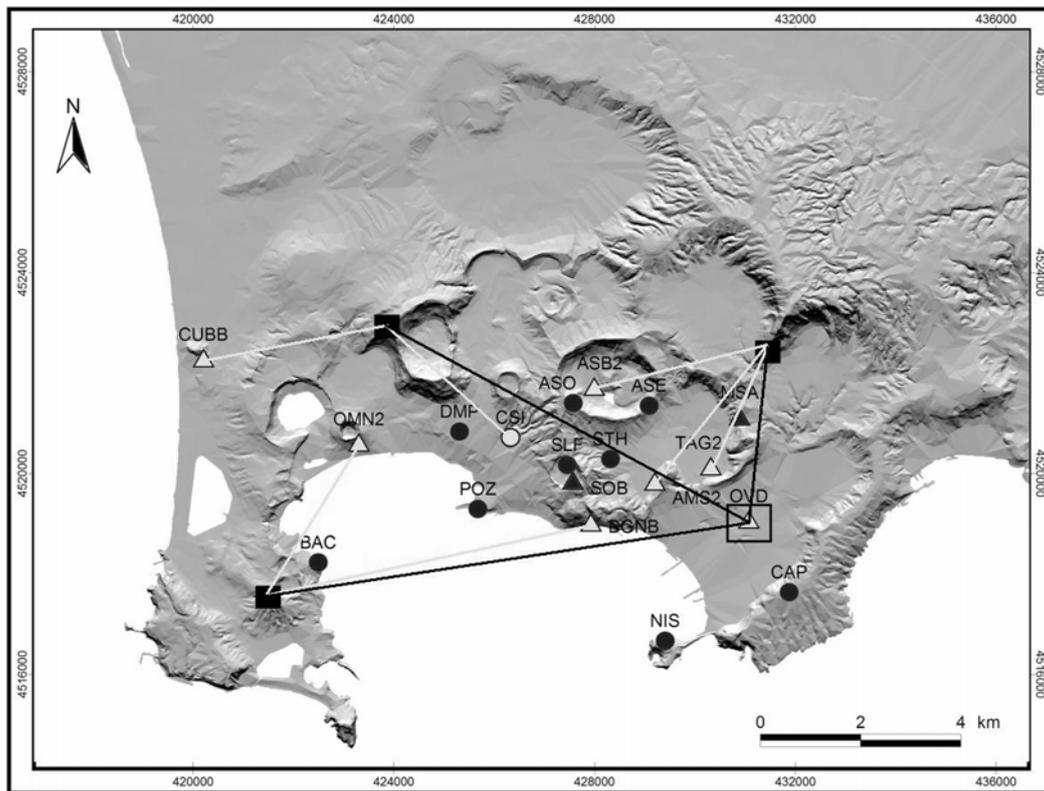


Fig. 2 - Example for the Campi Flegrei volcanic area. The seismic monitoring system deployed at the Campi Flegrei volcanic area during the 2004-2006 emergency. White symbols represent the Temporary Seismic Stations. Black symbols show the Permanent Seismic Network. Triangles and circles represent the broadband and the short period stations, respectively. White lines represent the link between Temporary Seismic Stations and an access point (filled black squares), black ones are the links with the Acquisition Centre (square). (DTM by: Geomatics and Cartography Lab., INGV-OV).

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