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Early Warning Book

Development and testing of an advanced monitoring infrastructure (ISNet) for seismic early-warning applications in the Campania region of southern Italy

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Memorandum:	

INTRODUCTION

The Irpinia Seismic Network (ISNet) was designed in 2002 as an advanced research seismic network, and following its development, it is now in the phases of completion by the RISSC research group (a joint research group between the Physics Department of the "Federico II" University of Naples and the INGV-Osservatorio Vesuviano, Naples). It has been financially supported by the Campania Regional Center of Competence – Analysis and Monitoring of Environmental Risk. ISNet has a complete new communication and site infrastructure, and its fully digital and fast acquisition communication system renders it ideal for early-warning application studies.

ISNet is a highly dynamic, high density seismographic network under development in the southern Apennine chain. It is deployed across an area that has been struck by several destructive earthquakes over the last few centuries. The last of these occurred on November 23, 1980, with M=6.9, and it resulted in more than 3,000 casualties, and huge and widespread damage to the buildings and infrastructure of the whole regional territory. In its final configuration, the network will consist of more than forty highly dynamic seismic stations that are divided in physical sub-networks that are interconnected by a robust data transmission system.

In the early stages of the design of ISNet, it was conceived to monitor and analyze the background seismic activity that is produced by the regional fault system for purely research purposes. However, due to its high performance capabilities and within the framework of an ongoing project that is being financed by the Regional Department of Civil Protection, in 2006 the network will also become a prototype system for seismic early- and post-event warning that will be used for protecting public buildings and infrastructure of strategic relevance.

The implementation of a modern seismic network involves many different research and technology disciplines because of the sophisticated data management/processing and communication systems necessary to rapidly generate useful information. Due to this complexity, this paper provides a general technical overview of the ISNet architecture and implementation.

ISNet architecture and site installation

ISNet covers an area of approximately 100 km x 70 km along the Campania-Lucania Apennine chain, and is deployed around and over the known active seismic system faults generating the 1980 Irpinia earthquake. ISNet does not follow a central site communication model for the transmission of seismic waveforms from a remote site, but an extended star topology that is designed to ensure fast and robust data analysis. The signals are acquired and processed at different locations in the network, and this leads to four fundamental network elements: the seismic stations, the local control centers (LCC), the central network Control Center (RISSC), and the data communication systems. Figure 1 illustrates the locations that comprise ISNet.

The stations are positioned along two imaginary concentric ellipses, with the major axis parallel to the Apennine chain. The average distances between pairs of stations on the outer ellipse is about 20 km, while the distance between the two ellipses is around 10 km. The inner ellipse is also filled homogenously with seismic stations that have average inter-station distances of less than 10 km. Each seismic station is connected via radio bridge to a Local Control Center (LCC) (Figure 1), which is itself linked to the RISSC Control Center by an E1 digital broadband (HDSL) wire line over frame relay. Through the use of permanent virtual circuits (PVCs), the frame relay allows the central site to use a single phone circuit to communicate with the multiple remote sites (the LCCs). The whole data transmission system is fully digital over TCP/IP, from the data-logger, through the LCC, to the control room in Naples.

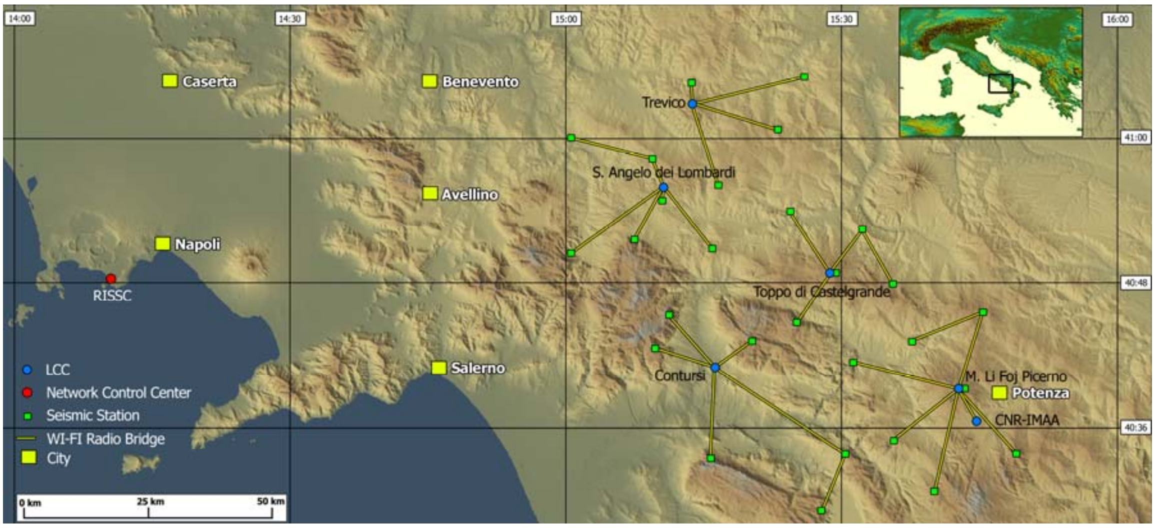

figure 1: Station map of Irpinia Seismic Network (ISNet). Symbols as given on the Figure.

Seismic Station and Local Control Center

ISNet is composed of 30 seismic stations, each of which is connected with real-time communication to a LCC that is generally located in an urban area with a major communication backbone. The seismic stations are placed in 2 m x 2 m x 2 m shelters that are located inside 6 m x 4 m fenced areas. Each station is supplied with two (120 W) solar panels, two 130 Ah gel cell batteries (which avoids freezing damage) and a custom switching circuit board between the batteries. With this configuration, a 72-h autonomy is ensured for the seismic and radio communication equipment. Each site is also equipped with a GSM/GPRS programmable control/alarm system connected to several environmental sensors (door forcing, solar panel controller, battery, fire, etc) and through which the site status is known in real time. This alarm system has standby power for at least three weeks. The GSM modem is connected to the data-logger and can be used as a backup data communication line. With an SMS (short message), and through the programmable GSM controller, the seismic equipment can be completely reset after a power shutdown/restart. The GSM also controls the device start/stop release procedure when the battery goes over/under a predefined level.

The six LCCs collect and store the incoming data from the seismic stations to which they are connected via digital radio. The LCCs are positioned near small towns (in a shelter) or in existing buildings with an AC power supply and fast communication connections. In some sites, the LCC is also a seismic station. In this case, the sensors are outside in a shallow well, at a depth of 1 m to 1.5 m. The data-logger and other equipment are locate inside an adjacent building. Each LCC has gel batteries for 320 Ah, a GSM remote-control system, a Cisco router, and an HP Proliant server with a 320 Gbyte hard-disk. All of the instruments are connected to the batteries and 72-h standby power is guaranteed. Today, all of the LCCs use the Earthworm (Johnson et al., 1995) linux version for data collection and processing, and event detection. The LCCs are connected to each other through the frame relay PVCs.

Sensors and data-logger

Inside each seismic site, all of the sensors are installed on a 1 m^3 reinforced concrete base at least 0.8 m inside the soil. To ensure a highly dynamic recording range, each station is equipped with two types of sensors: a strong-motion accelerometer and a velocimeter. Twenty-five sites are equipped with the Guralp CMG5-T and the short period (T_0 = 1 s) Geotech S13-J. The remaining five sites have Guralp CMG5-T and the broad-band Nanometrics Trillium (0.033-50 Hz band). After the first site installations, we noted a strong temperature dependency of the Guralp accelerometer. To minimize the thermal noise in the last sites to be built, a 30-cm hole was made in the concrete base. The hole contains the accelerometer and it is filled with sand to isolate the sensor. Before installation, the sensor/ data-logger pairs are fully calibrated for single-channel responses by an automated process. This covers the entire frequency spectrum using an originally developed LabVIEW/MatLab software package that provides the transfer function in graphical mode and in terms of poles and zero.

Data acquisition at the seismic stations is performed using Osiris-6 model data-loggers made by Agecodagis (www.agecodagis.com). Some of the specifics of the Osiris include a Σ-Δ 24 bit A/D converter, a 100 MHz ARM processor with embedded Linux and open source software, on-site data storage (through one removable 5 Gbyte microdrive), serial and TCP/IP connectivity, GPS time tagging, an integrated SeedLink server, and simple/ flexible configuration via a web interface (HTTP). The data-loggers have six physical and up to 24 logical channels, and each waveform can be analyzed with different sampling rates at the same time, for different purposes. An overview of the Osiris-6 data-logger has been provided by Romano and Martino (2005).

The external GPS receiver (NMEA/RS-232) guarantees a tagging accuracy that is better than 1 μs. A complete health status is available and helps in the diagnosis of station component failure or data-logger malfunction. The data-logger is remotely controlled from the IP configuration, sampling rate, gain, application of calibration signal to the resets of disks, GPS, etc. The data-loggers store the data locally on their microdrives or send it via SeedLink to Earthworm in the nearest LCC in 1 s packets. The real-time analysis system performs event detection and location based on triggers coming from the data-loggers, and parametric information provided by the other LCCs.

A *PostgreSQL* developed data-base tracks the network general configuration such as recorded channels, sampling rates for each channel, gain, sensor type, data-logger and other network devices IP addresses, station position and serial number for each installed device.

At present, ISNet records real-time data from 33 stations with six channels, and in the near future we plan to add another 10 seismic stations. Twenty-eight of the stations installed have an infrastructure as described above, two are located in affiliated university buildings, and one is outside near a dam in the southern part of the Campania region. All of the sites have the same sensors and data-loggers.

Current data communication configuration

ISNet has a distributed star topology and at present it uses several different transmission systems. The seismic stations are connected via spread spectrum radio bridges to the LCCs (Figure 1). To transmit waveforms in real time from the seismic sites to the LCCs, two outdoor 1310 G Cisco Wireless LAN bridges, operating in the 2.4-GHz ISM band, are used for each link. Each LCC is connected through different technology and media type to the Control Center in Naples, as shown in table 1.

The two primary backbone data communication systems of the central site use Symmetrical High-speed Digital Subscriber Line (SHDSL) technology over a frame-relay protocol. Frame relay offers a number of significant benefits over analog and digital point-to-point leased lines. With the latter, each LCC requires a dedicated circuit between the LCC and the RISSC Control Center. Instead, the SHDSL frame relay is a packet-switched network, which allows a site to use a single frame relay phone circuit to communicate with multiple remote sites through the use permanent virtual circuits. The frame-relay network uses digital phone circuits that can support up to 1.5 Mbit/second throughput for each single twisted-copper wire pair. In the present SHDSL configuration, two twisted-copper wire pairs are used to ensure 2 Mbps transfer. The monthly costs of long-distance digital packet-switched technology for fast data communication are much lower than for leased phone lines. With virtual circuits, each remote site is seen as part of a single private LAN, simplifying IP address scheme maintenance and station monitoring.

Several seismic sites, located well away from the earthquake source zone and out of the core of ISNet, use the internet to transmit data directly to the Control Center site (RISSC). These sites are located inside affiliated university buildings in the main city of the region.

The satellite and SHDSL backbone are provided by commercial service providers who, unfortunately, have little confidence in their interactions with research teams that are involved in network infrastructures that need high reliability and complete data communication line control. There are thus short daily outages that require troubleshooting by our technical staff for failure detection. In this initial phase of the ISNet startup, and for further development towards new, fast, real-time applications, we test mainly the backbone links. These tests include line delay, system latency, availability and reliability. After this initial development, we are confident that we can reach 99.99% (53 min outage per year) of network availability. To date, we have never had radio link failure due to adverse weather conditions. The snow and heavy rain that fall during the winter have only a small influence on the radio communication, without interrupting it.

Type	Frequency (GHz)	Bandwidth (Mbps)	# Number of		Comments
			Station	LCC	
Spread spectrum	2.45	54	29	—	Throughput around 20-24 Mbps for links between 10-15 km (based on Ethernet packets with an average size of 512 bytes).
Satellite	Ku band	0.512	1	—	From outside to nearest building through WI-FI bridge, then via satellite with a shared broadband internet solution to RISSC Center.
Internet	—	1.024	1	—	
SHDSL over Frame Relay	—	2.048	—	2	At the central site (RISSC) the CIR[1] is maximum 1.6 Mbps depending upon number of PVCs[2]. At the remote (LCC) site the bandwidth is 640/256 kbps with CIR of 64kbps in up and download, over ADSL with ATM ABR service class.
Microwave SDH	7	54	—	2	Nera Networks carrier-class microwave link. Connect two LCC. Truly full bandwidth available. Software upgradable until 155 Mbps (STM-1).
Microwave HyperLAN/2	5.7	54	—	1	The true usable maximum throughput of HiperLAN/2 is 42Mbps.
Satellite	Ku band	0.512	—	1	Shared broadband internet solution to RISSC Center (512/256 kbps).

table 1: Specification of data communication links between LCC and the control room in Naples. [1] CIR Commited Information Rate. [2] PVC permanent virtual circuit.

Each seismic site has a real-time data flow of 18.0 kbps (at 125 Hz sampling rate for each physical channel), and the overall data communication bandwidth that is needed is around 540 kbps for 30 stations. ISNet supports this throughput under the worst conditions and it has been designed to guarantee further developments, such as the adding of further seismic or environmental sensors, without needing a larger economic and technological investment. The currently used data transmission protocol is TCP/IP, but for early-warning-application data acquisition, we intend to adopt the connectionless UDP/IP protocol to avoid unwanted overheads and handshaking between sending and receiving transport-layer entities before sending data segments. In early-warning waveform analysis, where single-packet error/missing does not influence decisions in a critical manner, this protocol is much faster and simpler to handle than TCP/IP.

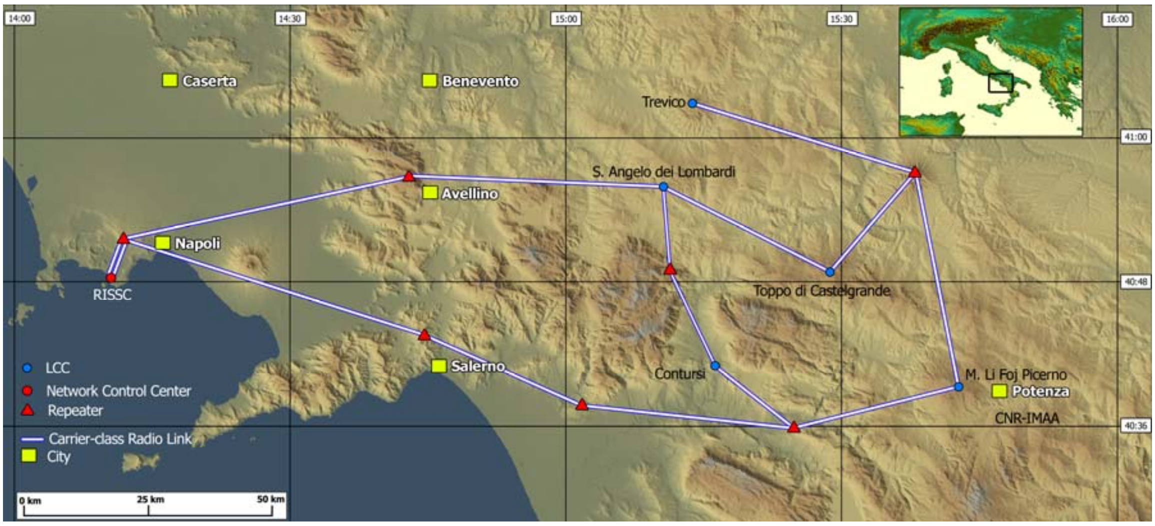

figure 2: Map showing the radio connections used in ISNet

RISSC Network Control Center

The seismic waveforms are stored locally on the data-logger and in real time at the nearest LCC. In its present condition, only selected signals are transmitted to the RISSC Control Center in Naples, and this is done manually and only for research purposes. We are developing a storage system at the Control Center that acts after the triggering of an LCC Earthworm or a station, which will have full automated capabilities. We are also considering the storage at the RISSC, for redundancy of the whole datasets coming from each station following a central site model. For this reason, we plan to install a large storage cluster at the Control Center on which all incoming waveforms can be loaded. The network Control Center tracks the seismic events and monitors the entire network, including the data-loggers and radio links, through commercial network and bandwidth monitoring software.

EARLY-WARNING PROTOTYPE

Increased data processing abilities and, above all, very fast and reliable data communication systems today allow the warning of parts of the region that strong ground motion has been measured in another part of the territory and that seismic waves may arrive shortly. The warnings include estimations of the earthquake origin and magnitude, and other source parameters, which must be continuously updated to improve data reliability while the earthquake is ongoing.

ISNet has been developed with modern communication, data acquisition and processing technology to be able to perform early warning and to have regional post-event capabilities, although it will need some infrastructure additions.

ISNet will have three new infrastructures integrated into it (figure 2):

1. an integrated seismic network which covers the Campania region outside of the source area;
2. a proprietary data communication system connecting the LCCs to each other;
3. a second proprietary data transmission system that connects some LCCs to the Control Center in Naples.

New seismic stations

The function of additional seismic network stations will be to supply the data necessary for rapid building of regional shaking maps after large earthquakes. These stations will be located in city and rural zones, but out of the earthquake source area (along the Apennine chain of southern Italy), and therefore they will not be used for real-time localization and magnitude estimations. The 10 new seismic installations will have the Osiris data-logger with a strong-motion accelerometer and velocimeter. They will be deployed in buildings that will cover, in a wide mesh structure, the remaining Campania region. The idea is also to record data close enough to urban conglomerations so that the waveforms observed can be correlated to eventual damage to structures. The data will be retrieved from these sites through a GPRS/UMTS communication system that will be provided by commercial service providers, and they will be automatically downloaded and processed only after triggering from ISNet.

Data comunication enhancements for early warning purposes

The data communications system for early-warning applications is one of the fundamental points of this whole system. Based on the troubleshooting and experience of ISNet development, we are convinced that the complete control and management of the telecommunication systems, from the data-loggers to the Control Center, is one of the goals that must be achieved during experimentation of early-warning applications. To understand latency, delay, failure and weak points in complex data communications structures gives quick answers, where essential time can be gained and indications can be given for the future technological evolution of the entire early-warning system.

To avoid losing the entire network in the case of failure of one or more of the links, and to control the whole communication system without the need for commercial service-provider links, ISNet will be upgraded during 2006 with a multiple radio-path data communication network. The redundancy in path determination and the percentage of unavailability acceptable for the system (outage) are fundamental parameters to be considered when the network enhancements are planned. Two rings have been created in the network: the first interconnects the six LCCs and the second connects the first to the Control Center in Naples. We are convinced that by selection of suitable technology and radio devices, we can reach an overall system availability of 99.99% in the first development step, and of 99.999% (five min outage/year) when the network is fully up and running. To reach this high availability rate, we have selected a carrier-class telecommunications device for the radio link. The first link is still being completed and will be used for the first main test purposes (figure 2). The radio device has the capability of an ethernet mapped over Synchronous Digital Hierarchy (SDH) device, with 54 Mbps (STM-0) throughput in a licensed 7 GHz frequency band.

Combining different technologies, such as satellite, radio and digital wire lines, will make it easier and faster to accomplish these high availability rates, and we will evaluate the use of this multiple communication technology in three LCCs. We have planned the new data communication system also taking in account the following constraints: System reliability and redundancy, low or no system damage during a strong earthquake, overall transmission delays less than 100-200 ms, and data security.

General overview of Network Management

As shown in figures 3 and 4, the ISNet data and information flow can be managed on three different levels:

- data-logger at the recording site;
- at the LCCs;
- at the network Control Center in Naples.

In particular, the data-loggers perform several functions: data acquisition, storage on hard disk, and transmission (data and trigs) over the network to the LCCs using the SeedLink protocol.
The LCCs run the Earthworm real-time seismic processing system and they each keep a complete local database of waveforms from the seismic stations directly connected to them. The real-time analysis system performs event detection and localization based on triggers coming from data-loggers and parametric information coming from the other LCCs. Once an event is detected, the system performs automatic magnitude and focal mechanism estimations. The results of these analyses are used to build a local event database, and at the same time, they are sent to the other LCCs and to the RISSC Control Center. In the immediate post-event period, the RISSC performs shaking map calculations using parameters from the LCCs and/or data from the event data-

base. The recorded earthquake data are stored into an event database, to be available for distribution and visualization for further off-line analyses.

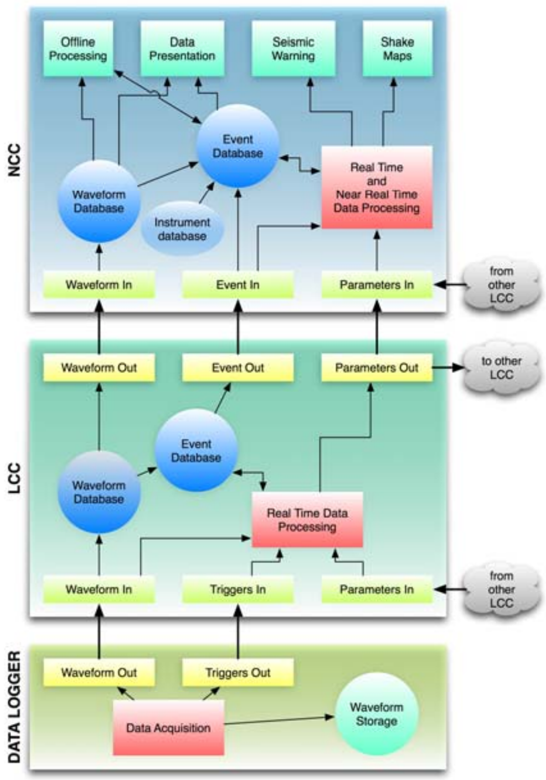

figure 3: In this figure the seismic data management architecture is depitecd.

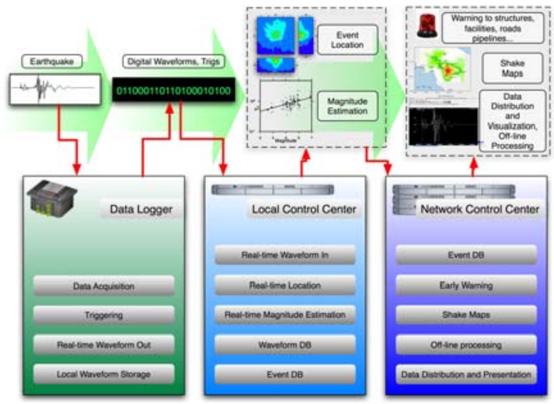

figure 4: Schematic representation of the information flow in ISNet.

As indicated in the previous section, ISNet has a complex infrastructure and needs to be accurately managed for proper real-time functionality. The most important information is the station and transmission network availability. To check the availability status of the network, a real-time cross-correlation between different information sources is needed. A large network is made up of many vendor devices for which the health status cannot necessarily be monitored by commercial software. To overcome these limitations, we are developing the ISNet Manager (ISNM). The ISNM will be a complete real-time monitoring suite with a notification system in the event of failure or critical status of any of the network elements (figure 5). The collected data from each device will be stored in a database. Considering the network complexity, various information sources will be used: SMS, E-mail, SMNP, ICMP (Ethernet), proprietary commands (Osiris), netflow (Cisco network flow-control protocol).

Today, in the first developing step, the network manager is only static and serves as devices data-base for the seismic network. It is made up of two fundamental design blocks:

- a database, managed by a server running PostgreSQL that is designed to store information related to sites, installed loggers, sensors, and generic and network hardware, along with their configuration and mutual connections.
- a user interface through a web application based on JavaServer Pages. The web server is powered by open-source standard Apache/Tomcat. A specific library of tags has been implemented to ease the interfacing of the web server with the database server.

The ISNM will have a server/client architecture. The data are collected at each of the LCCs and sent in parameterized form to the server, which analyzes the incoming information from all of the network elements.

Data- and network-security-related issues must be better investigated because of the sociological and psychological impacts of real-time alarms, especially if the general public is to have direct access to real-time shake maps. The network must be strongly protected against intrusion, which could intercept incomplete information that produce social panic, and/or generate false alarms.

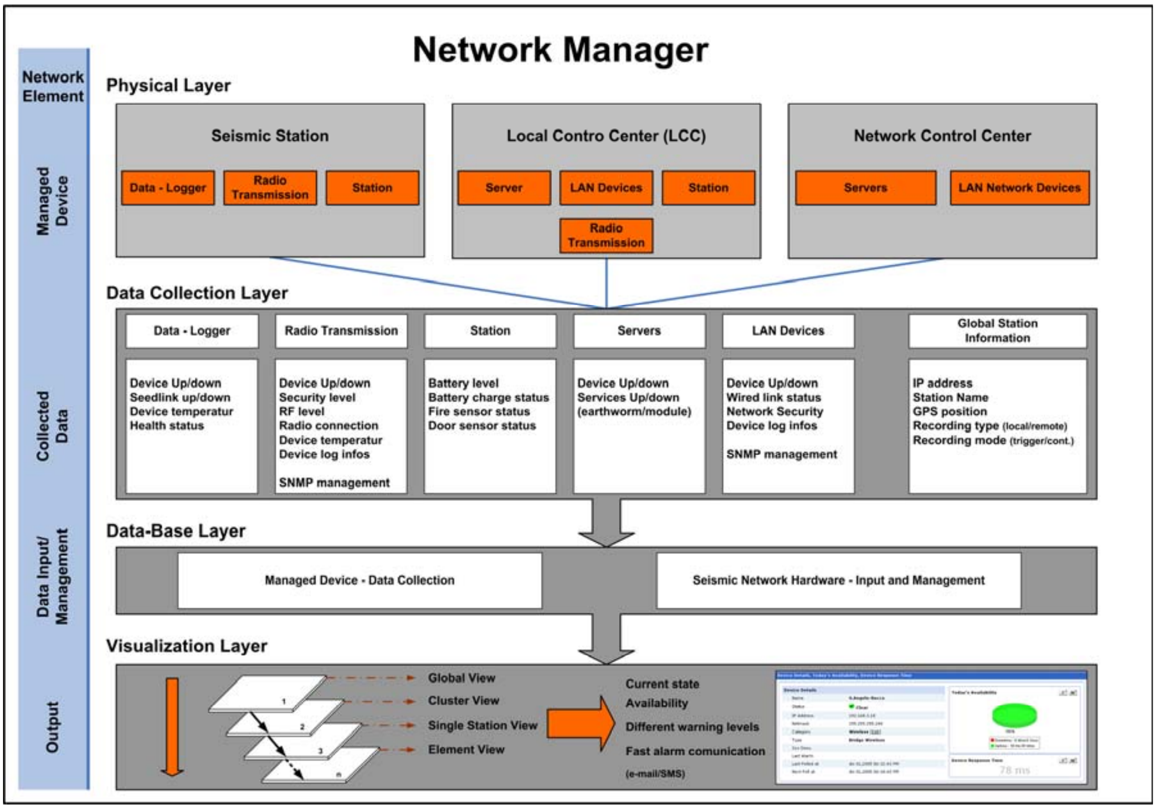

figure 5: Schematic representation of the ISNet Manager.

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