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A Customizable Middleware Framework for Accessing Mobile Sensors

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Ζήση Πλίτση

ως μέρος των Υποχρεώσεων για τη λήψη του

ΜΕΤΑΠΤΥΧΙΑΚΟΥ ΔΙΠΛΩΜΑΤΟΣ ΣΤΗΝ ΠΛΗΡΟΦΟΡΙΚΗ
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ΑΦΙΕΡΩΣΗ

Στην Ξανθίππη, στους γονείς μου και στον Randolph Carter..

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Zissis K. P.

ΠΑΝΕΠΙΣΤΗΜΙΑΚΗ ΒΙΒΛΙΟΘΗΚΗ ΙΩΑΝΝΙΝΩΝ

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ABSTRACT

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Sensing, monitoring and controlling devices have been used in industry for many years. The evolution of microcomputers and the increasing needs for sensing and controlling have led to new sensing devices being smaller, cheaper, capable of new applications and connected in wireless networks. This new area of research and development is known as sensor networks or Wireless Sensor Networks (WSN). WSN consist of hundreds of self-contained, battery-powered sensing devices that measure and communicate wirelessly environmental data. They are embedded in the environment, can act proactively, and can be presented as a new "tier in the Information Technology ecosystem". A global computing environment built on top of the Word-Wide Web can integrate sensors and provide the appropriate applications and interfaces to utilize different kinds of sensors. To handle such distributed, heterogeneous and oblique systems we shall adopt the approach of a "Middleware Framework", as the software layer between the operating system and the applications on each side of the system.

Our goal is to integrate a specific kind of sensor devices in a global computing environment. These are GSM-enabled sensor devices, that can communicate and be instructed through the GSM network, the network of cell phones. Specifically, we focus on sensors controlled by SMS messages that exchange information through SMS or MMS messages. We provide the means to integrate different mobile sensors in our computing environment by using the proprietary communication protocols (usually SMS messages) and the specific characteristics of the mobile sensor. Starting from GSM enabled devices we automate the process of integrating these devices in a global computing environment with the use of XML-based sensor descriptions. To this end we proposed a customizable middleware framework was proposed.

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Περιληψη

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Η εξέλιξη των μικροϋπολογιστών και οι αυξημένες ανάγκες για μέτρηση και έλεγχο οδήγησαν σε αισθητήρες που είναι πιο μικροί, φθηνοί, ικανοί για νέες εφαρμογές και ασύρματη σύνδεση. Αυτή η νέα περιοχή έρευνας και ανάπτυξης είναι γνωστή ως Δίκτυα Ασυρμάτων Αισθητήρων (Wireless Sensor Networks, WSN). Τα δίκτυα αυτά αποτελούνται από εκατοντάδες αυτόνομους, τροφοδοτούμενους με μπαταρία αισθητήρες που μετρούν και στέλνουν ασύρματα δεδομένα του περιβάλλοντος. Είναι ενσωματωμένοι στο περιβάλλον, μπορούν να δρουν προκαταβολικά και χαρακτηρίζονται ως νέο επίπεδο στο 'οικοσύστημα' της τεχνολογίας της πληροφορίας (a new "tier of IT ecosystem"). Ένα παγκόσμιο υπολογιστικό περιβάλλον (global computing environment) μπορεί να ενσωματώσει ασύρματους αισθητήρες πάνω από το παγκόσμιο δίκτυο, παρέχοντας τις κατάλληλες εφαρμογές και διεπαφές για την χρήση τους. Για να χειριστούμε την ανομοιογένεια αυτών των κατανεμημένων συστημάτων χρειαζόμαστε μία υποδομή ενδιάμεσου λογισμικού, που θα είναι το στρώμα λογισμικού ανάμεσα στο λειτουργικό σύστημα και στις εφαρμογές σε κάθε πλευρά.

Ο σκοπός είναι να ενσωματώσουμε ένα ειδικό τύπο από αισθητήρες σε ένα παγκόσμιο υπολογιστικό περιβάλλον. Αναφερόμαστε σε αισθητήρες που λειτουργούν με το δίκτυο των κινητών τηλεφώνων, το γνωστό GSM. Στην εργασία αυτή επικεντρωνόμαστε σε αισθητήρες που ελέγχονται από γραπτά μηνύματα (SMS μηνύματα) και μεταφέρουν πληροφορία μέσω γραπτών μηνυμάτων ή μηνυμάτων πολυμέσων (SMS ή MMS μηνύματα). Παρέχουμε τα μέσα για την ενσωμάτωση διαφορετικών GSM αισθητήρων στο σύστημα. Ξεκινώντας από τα ειδικά πρωτόκολλα και τα χαρακτηριστικά κάθε αισθητήρα αυτοματοποιούμε την διαδικασία κωδικοποιώντας την περιγραφή τους σε αρχεία γραμμένα σε XML και προτείνουμε μία προσαρμόσιμη υποδομή Ενδιάμεσου Λογισμικού για GSM αισθητήρες.

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Το κείμενο που ακολουθεί αποτελείται από 6 κεφάλαια. Μέτα από μια σύντομη εισαγωγή, στο 2ο Κεφάλαιο παρουσιάζονται ορισμένα στοιχεία για τα δίκτυα ασυρμάτων αισθητήρων και κάποια από τα θέματα που επικεντρώνεται το ενδιαφέρον: σχετικά με τις εφαρμογές των δικτύων, η τεχνολογία στην οποία βασίζονται -σε επίπεδο υλικού και συσκευών, οι διαδικασίες δικτύωσης και επεξεργασίας των ερωτήσεων για την εξαγωγή δεδομένων (query-processing) στα δίκτυα αυτά και κάποια θέματα ασφάλειας. Τα θέματα των ασυρμάτων δικτύων αντιπαραβάλλονται με την εργασία μας πάνω στο ενδιάμεσο λογισμικό (middleware) για τους GSM αισθητήρες. Το 2ο Κεφάλαιο συνεχίζει με παρουσίαση ορισμένων GSM αισθητήρες που μπορεί κανείς να προμηθευτεί και τελειώνει με στοιχεία για ενδιάμεσο λογισμικό, υπηρεσίες διαδικτύου (Web Services) και μηνυμάτων που χρησιμοποιούνται και είναι χρήσιμα και στη δικιά μας εργασία. Στο 3ο Κεφάλαιο παρουσιάζεται το ενδιάμεσο λογισμικό για τους GSM αισθητήρες, αναλύονται η αρχιτεκτονική του, όπως είναι το τμήμα της προσαρμογής (customization) στον κάθε αισθητήρα και οι διάφοροι εξυπηρετητές του συστήματος, και αναφέρονται ορισμένα στοιχεία τής υλοποίησης. Στο 4ο Κεφάλαιο δύο από τους αισθητήρες που παρουσιάστηκαν στο 2ο Κεφάλαιο χρησιμοποιούνται για να δοκιμαστεί το σύστημα. Οι αισθητήρες που δοκιμάζονται είναι μία ασύρματη κάμερα, που εκτός από λήψη εικόνων, μετρά θερμοκρασία και έχει ανιχνευτή κίνησης και ένας GSM μετεωρολογικός σταθμός. Στη συνέχεια στο 5ο Κεφάλαιο τα συστήματα για την κάμερα και τον μετεωρολογικό σταθμό αξιολογούνται και έχουμε τις μετρήσεις στα διάφορα πειράματα που έγιναν στο σύστημα. Τέλος, ακολουθούν ορισμένα συμπεράσματά και πιθανή μελλοντική εργασία στο 6ο Κεφάλαιο.

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CHAPTER 1

INTRODUCTION

This work addresses the issue of accessing transparently mobile sensors through a customizable middleware framework.

Sensing, monitoring and controlling devices and techniques have been used in industry for many years. The evolution of microcomputers along with Moore's law and the increasing needs for sensing and controlling in our complex environment have led to new sensing devices being smaller, cheaper and capable of applications that it was impossible to realize ten years ago. This new area of research and development is known as sensor networks or Wireless Sensor Networks (WSN), because is more useful and frequent to communicate with hundreds of those sensing devices wirelessly. Wireless sensor networks consist of hundreds of self-contained, battery-powered computers that measure and communicate wirelessly environmental data, They are embedded in the environment, can act proactively, and can be presented as a new "tier in the Information Technology ecosystem". Those abilities improve the "proactive computing" and "pervasive computing" (or "ubiquitous computing") paradigms. In proactive computing computers anticipate human needs and act on human's behalf. Pervasive computing refers to the next generation computing environments with information and communication technology everywhere, for everyone, at all times.

A global computing environment built on top of the Word-Wide Web can integrate sensing devices. A global computing environment should provide the appropriate applications and interfaces to utilize different kinds of sensors. This is the concept of embedded Internet, embedded deeper in any real environment using wireless sensor networks. Developing such

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distributed, extreme heterogeneous and embedded systems is a challenge. To handle such distributed, heterogeneous and oblique systems we shall adopt the approach of a "Middleware Framework". The ObjectWeb consortium gives the following definition of middleware:

> "In a distributed computing system, middleware is defined as the software layer that lies between the operating system and the applications on each side of the system."
>
> (middleware.objectweb.org, [1])

Thus, the term middleware is used to describe web servers, application servers, content management systems, proxies, wrappers and similar tools supporting the application development and delivery process. The middleware is central to modern information systems based on XML, SOAP, Web services, and service-oriented architectures.

Our goal is to integrate a specific kind of sensor devices in a global computing environment. These are GSM-enabled sensors, that can communicate and be instructed through the GSM network, the network that any cell phone uses. The term "mobile phone" is identical to the term "cell-phone", so the term "GSM-enabled sensor" is used alternatively with the term "mobile sensor", meaning the sensing device that wirelessly transfer data through the GSM network. Specifically, we focus on GSM-enabled sensor devices, controlled by SMS messages that exchange information through SMS or MMS messages. Besides using the proprietary communication protocols (usually SMS messages) and the specific characteristics of the mobile sensor, we provide the means to integrate different mobile sensors in our computing environment.

The work presented in this thesis proposes a middleware framework that enables uniform access to mobile sensors. We introduce a mobile sensor description that is used to configure the middleware according to the sensor specifications and to provide the interface for accessing the mobile sensor.

The remaining of this thesis is structured as follows. Chapter 2 provides a brief overview of Wireless Sensor Networks, a survey of mobile sensors for industrial and commercial use and discusses similarity to our work, from the middleware prespective. Chapter 3 describes our middleware framework, discusses the process of customization based on a proposed sensor description standard, the system architecture and finally presents implementation issues. Chapter 4 details the use cases of mobile sensors, Chapter 5 presents performance evaluation results and finally, Chapter 6 offers conclusions.

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CHAPTER 2

WIRELESS SENSORS AND SENSOR NETWORKS: AN OVERVIEW

2.1 Wireless Sensor Networks

Technology that is commercially available today gives rise to engineering efforts that have produced complete devices with processing, storage, sensing and communication functions,

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devices that are smaller and cost less. The last 50 years, a new class of computers has appeared about once a decade, modern computing is progressing through mainframes, microcomputers, personal computers and mobile computers. Each successive model relies upon technical advantages, to make computing available in a way not previously possible. Each has introduced new uses for computer technology and each succeeding generation is smaller, more plentiful and more intimately associated with personal activity than the generation that proceeded it. *Wireless Sensor Networks* (WSN) appear as a new class, they follow the same trends of size, number, and cost; but rather than being devoted to personal productivity tasks, they make it possible to perceive what takes place in the physical world in ways not previously possible. One can consider Wireless Sensor Networks as:

> "Thousands of tiny low-power devices spread over large physical spaces collaboratively monitoring the environment, guide vehicles and predict potential faults in buildings, bridges, roads and rails."
>
> Communications of ACM, June 2004/vol. 47, no. 6 [2]

Wireless Sensor Networks are new important tier in the IT ecosystem and a emerging domain of active research and development involving issues in hardware and system design, networking, distributed algorithms, programming models, data management, security and social factors. Through the use of Wireless Sensor Networks the vision of an *Embedded Internet* becomes reality; in this vision networks of interconnected computing devices deeply embedded into the physical environment transform whole fields of science, engineering and manufacturing by providing detailed instrumentation of many points over large spaces, both natural and artificial. As an example: the Global System for Mobile Communications (GSM), the most popular standard for mobile phones in the world, can be used in connecting observation cameras, weather stations and other kinds of sensors to transmit images, temperature information and other data. By doing so we implemented an embedded wireless sensor network over the common network of cellural phones.

The pervasive instrumentation that wireless sensors networks provide will be of great value in many applications, including understanding ecosystems dynamics, setting land-use policy, protecting property, efficiently operating and managing machinery and vehicles, establishing perimeter and building security, protecting packages and containers, monitoring supply chain management and helping deliver health care. Sensors networks can extend to monitoring interactions among many objects within these domains, ensuring asset management, ubiquitous computing environments and emergency response. Moreover, those networks help

feed information to autonomous distributed control devices. They may help in applications used for road safety, fire prevention, temperature control, precision agriculture systems and much more. By using a middleware framework to improve the communication and proactive capabilities those networks can have.

Realizing important aspects of the embedded Internet vision includes the design and development of applications, hardware needed to collect physical data, algorithms for gathering and analyzing this information and methods for robust and secure operation. These issues are discussed in the remainder of this section.

2.1.1 Applications Issues in Wireless Sensor Networks

The first aspect of the embedded Internet vision, as described before, has to do with the applications of Wireless Sensor Networks that have been designed and developed. There are several real-world deployments of *environmental monitoring* such as habitat monitoring with sensors networks which deliver to ecologists data on localized environmental conditions, about animals, plants and people. This is an example of the applications that make use of sensors networks. Nowadays the scale of the nodes in these sensor networks can be compared to the scale of the organisms under study, and these networks are ranging in size from tens to thousands of different sensors (nodes) within a habitat patch.

Several real-word deployments of "habitat monitoring applications" in the US and all over the world have leaded the development of a network architecture, that is flexible enough and multilevel. They make use of different kind of sensors grouped in patches networks involving nodes with heterogeneous sensing capabilities, processing power and storage.

Habitat monitoring applications require ways to specify and deliver data of interest, so they need routing and tasking service. The data of interest can be either streaming or triggers and the task service has to cope with a dynamic topology of poor-quality links, potentially arbitrary termini (sinks) of data form nodes with minimal resources. The low-power mode of the system is needed for the long-term operation and the current solution is duty cycling, or changing the amount of time the subsystem is active during any given period, at several levels. The percentage of time each node is awake is known as the node's *duty cycle*, and a variety of approaches are available for achieving low-duty-cycle operation. Finally networks health monitoring and management are necessary for networks users to both trust the incoming

measurements and ensure the network's performance and longevity. The health-monitoring system relies on explicit and implicit signals. Explicit signal can be the battery voltage of a sensor which provides information about the remaining capacity and implicit signal can be, for instance, out of range readings in the humidity that indicate a fault.

There are also many examples of *environmental monitoring systems* such as systems developed by Harvey Mudd College Harvey Mudd College Center for Environmental Studies with embedded networks that study issues in the relationship between human life and both natural and human-built environments [3] and [4] with distributing remote sensors that would provide habitat monitoring via a wireless network grid to understand how local conditions as temperature, light intensity, and noise affects lizard habitats. Other examples are NASA's Volcano 'sensorweb' project [5] and other autonomous observing sensorwebs ([6] and [7]) and UC Berkeley's habitat modeling at Great Duck Island, Maine ([8] and [9]). On a much larger scale there are Environmental Observations and Forecasting Systems, such as the EOFS project studying Oregon's Columbia River estuary (CORIE system) [10] and FloodNet intelligent sensor network, which is included in EOFS of the University of Southampton's Envisense Center [11], a Center for Pervasive Computing in the Environment, and is designed to provide more accurate flood warnings. Future projects include NASA's sensorwebs in New Mexico deserts and in Antarctica, and sensors networks on both Mars and Jupiter's moon, Europa as mentioned in [12] about sensrowebs. In addition researchers working on diverse projects have developed novel applications for sensor networks technology and projects. Projects like GlacsWeb, about sub-glacial bed deformation [12]; sensor networks for detecting vehicles transporting radioactive isotopes [13] and detecting location of a sniper in a complex urban terrain [14]; and "The Flock" in the core of the computer engineering curriculum in which "mote sensors sing" [15], are examples of this diversity of applications. Our work provides a complementary middleware solution for integrating different GSM-enabled sensors in a computing environment with heterogeneous components and distribution.

The long-term outdoor deployment of such environmental monitoring systems with Wireless Sensors Networks stress reliability, low-power operation, network protocols, data quality and new experimental processes. The future habitat monitoring networks and wireless sensor networks applications in general would be enhanced with robust localization, calibration, clock synchronization and data processing.

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2.1.2 Hardware Technology of Wireless Sensors Networks

The second aspect is the hardware technology. The *underlying hardware technology* for wireless sensors networks, consisting of perhaps thousands of integrated devices, with built-in processing, storage and sensor with RF transceiver, energy storage and antenna, is evolving quickly and a signature style of design is formulated. Wireless sensor networks combine processing, sensing and communications into tiny embedded devices. Peer-to-peer communication protocols then combine the individual devices into an interconnected mesh network where data is seamlessly routed among all the nodes. These networks require no external infrastructure and can scale to hundreds or even thousands of nodes. Critical to the operation of any sensor network device is the ability to satisfy harsh always-on power requirements and the periodic recharging is not possible for most cases. Special purpose sensor nodes are purposely designed to satisfy flexibility in order to be as small and inexpensive as possible. High-bandwidth sensors contain the built-in processing and communication capabilities needed to deal with complex sensor streams, including video and voice processing. Traditional network abstractions are generally not suitable for wireless sensors networks, for instance, unlike traditional operating systems, operating systems for wireless sensors networks must tightly integrate wireless connectivity, while gate-way-class and high-bandwidth nodes use more traditional operating systems.

There are *four main platform classes* that have emerged recently in wireless sensor networks, as Table 2.1 shows, which is mentioned in [2]. Initial deployment experience has show that sensor network systems require a hierarchy of nodes starting at low-level sensors and continuing up through high level data aggregation, analysis and storage nodes. This tiered architecture is common in virtually all sensors networks, it starts with the head, or gateway nodes, which provide an interface into many existing types of networks and then includes: acoustic, video or chemical sensors as examples of high-bandwidth nodes requiring more computational resources and communication, sensors placed on windows and doors for instruction detection as examples of generic sensing devices and finally "mini-motes" like low-cost security tags, attached and tiny for tracking mobile assets, as well as personnel. Moreover, the data produced by the sensor network gain scientific validity through a verification process and collaboration, in other words there is the need for frequent calibration and the data have to be compared to independent calibrated instruments. A verification network is the application component responsible for collecting these independent readings and has often fewer but more-established sensing devices, of the upper rows of Table 2.1. It needs to provide the data quickly so the function of a sensor patch can be adjusted, faulty sensors

Table 2.1: Sensors hierarchy in wireless sensor networks, each platform class handles different types of sensing.

Class / Level	# of Nodes	Examples
First	A few gateway nodes	Web interfaces, databases
Second	Dozens of high-bandwidth sensors	Cameras, microphones
Third	Hundreds of generic sensor nodes	Door, window, motion sensors
Forth	Thousands of special-purpose sensors	Asset tags

can be eliminated and help the maintenance of the network. In our middleware framework the sensors that we use are of the class of high bandwidth sensors and gateway nodes.

Once again, the operating system running on a particular platform must be matched to the platform's underlying hardware capabilities. For special-purposes and generic-sensor-class devices, a special operating system called TinyOS (developed at the University of California, Berkeley [16]) is designed to run on platforms with limited CPU power and memory space. Unlike many embedded operating systems, it provides tight integration between wireless connectivity and networking functions. However, as platform capabilities improve, for example in the case of the Stargate platform (a type of gateway node), more advanced operating system support is required to meet the demands of more complex applications. Multiprocessing, preemptive tasks switching and even virtual memory support become desirable when managing multiple system functions. The Stargate node runs an embedded version of Linux operating system and in addition to provide a range of system capabilities, Linux provides a suite of device drivers for enabling gateway nodes to bridge to legacy networks.

Despite significant differences in device capabilities, the overall architecture for the classes of sensor-networks platforms is remarkably similar. This similarity follows from the requirement that they seamlessly follow from the integrate wireless networking. Network support

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must be transparent and self-configuring to allow sensor networks to scale in size and complexity. The engineering decisions about the amount of on-board memory, the amount of CPU processing power, the type and bandwidth of wireless link determine the cost and power consumption which influence the final design of any given sensor node. Additionally, Moore's law and the development of advanced wireless sensor-networking platforms influence the age of ubiquitous sensing and actuation, and as capabilities are improving these systems will be able to automatically act on sensor data to manage our environment, for years at a time in potentially hostile environment without hope of human intervention.

Our work is orthogonal to communication and power considerations. The mobile sensors, in our work, are at an upper level to the typical micronodes, as those of the third and forth level of Table 2.1, according to their capabilities and they have additional computing power and storage capacity. They have specific functions and usually custom made operating systems, with the use of control SMS messages or with a serial port connection. There is no need for configuring duty cycle, as there have no power issues. Those are things that will be detailed later, when some mobile sensors will be presented.

2.1.3 Networking and Query-Processing in Wireless Sensors Networks

Moreover, *networking and query-processing issues* become deeply intertwined, as queries are continuously processed within the network, and this is *the third* aspect of the embedded Internet vision. Network and query processing must be co-designed to allow data self-organization for flexible but efficient in-network storage, access and processing. In fact sensors networks have the potential to support applications ranging from habitat and structural monitoring, to home and building automation, to supply chain management. Users are typically interested in continuous streams of information representing the evolving status of systems, combined with periodic statistical reports about specific phenomena and even, when some thresholds are used or alarm systems are triggered, those alarm messages and the data reports. Query processing systems, provide high-level interfaces that allow users to collect and process such continuous streams.

Speaking of stream data management, the Aurora system [17] is an experimental data stream management system with a fully functional prototype including both a graphical development environment and a runtime system. In the future plants of the Aurora system

there is a distributed stream processing system, called Borealis. Apart from dynamic revision of query results and dynamic query modification, the ability of Distributed Optimization makes Borealis useful in application of wireless sensor technology [18]. Moreover, Stanford Data Stream Management [19] (and [20]) is another system with a first version of prototype even available for public use.

Researchers are beginning to formulate languages and enumerate the type of queries needed by users of sensor networks. Distributed query processing is also needed as the data is stored and retrieved from nodes within the network. Several in-network query systems have been built for sensors networks. Diffusion is the pioneering work, developed by the Information Sciences Institute at the University of Southern California and presented in [21] as the directed diffusion paradigm for Wireless Sensor Networking and in [22] as the TinyDiffusion API implementation in TinyOS [16]. There is no specific query language in Diffusion; instead it allows application writers to choose a domain-specific query language, and focuses on query rooting mechanisms and flexible in-network processing. A family of routing algorithms is provided and queries in the network are described by interest messages. There is also TinyDB [23] which uses declarative queries that reflect their data processing needs, specifying the types of data, as well as the subset of nodes of interest, along with simple transformation over the data. Queries are written in a SQL-like language, they are the input on a PC that sends the query into the sensor network and a number of optimizations are might applied by the query processor. Common ground between TinyDB and Diffusion is a query language interface for network processing and in some cases tend to give users more control over the types of network topology and patterns of communication.

In our work, there two different networks involved the GSM network of the mobile sensors, including GPRS for communication based on packet switching, and the Internet, with the web interfaces and the servers of our customizable middleware. This middleware framework is responsible for the execution of any information request and the utilization of those different networks.

However, future systems will be more sophisticated than any of today's prototypes, and will involve many novel network requirements. The basic dimensions of design in terms of networking mechanisms are: scope, concerning the nodes involved in a query; volume, i.e. communication cost per unit time; complexity, concerning multiple concurrent queries; timeliness, having to do with delays between events and quality of the query response. The

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fact is that network aware for query processing is in its infancy, multiple complex queries must be supported beyond the basic tree-based data collection, more sophisticated topology-construction algorithms and facilities are needed for storage and correlation than the available in nowadays.

2.1.4 Security and Privacy in Wireless Sensors Networks

Finally, *effective security and meaningful privacy* is an other important aspect of the sensors networks, the technical aspects of these issues must be addressed from the start of any system's design process in the context and the applications. Sensors networks are susceptible to a variety of attacks, including node capture, physical tampering and denial of service, while prompting a range of fundamental research challenges.

Sensor network security should be properly addressed from the start because there are unique new challenges in the network of limited in energy, computational and communicational capabilities sensor devices. They are also deployed in accessible areas, presenting the added risk of physical attack and interact closely with their physical environment and with people, posing new security problems. It is crucial that security pervade every aspect of system design and be integrated into the system and every component of it. In this case of wireless sensor networks, for instance, the cryptographic key establishment of the network is very different than the well-studied same problem in previous networks that proposed a variety of protocols and solutions. We need a secure and efficient key-distribution mechanism allowing simple key establishment for large-scale sensor networks. Better random-key predistribution schemes and investigation of hardware support for public-key cryptography are useful. Protection against eavesdropping, injections and modification of packets are also important and recent research shows that software-only cryptography is indeed practical with today's sensor technology. Further research is needed is matters as privacy, robustness to communication denial of service attacks and resilience to node capture. And finally important network secure services such as secure group management, intrusion detection and secure data aggregation need improvement.

In our work again, we combine web-based interfaces and protocols with GSM-GPRS. When it cames to security and privacy the middleware can give the solutions, as those issues have been studied in the context of the World-wide web (e.g. the https with additional encryption/authentication layer between HTTP and TCP). In our work we don't treat security

issues, but there are implementations and ideas integrated into the mobile sensors and their functions that can be activated. The mobile sensors can distinguish among administrators and common users and assign privileges according to the access group they belong. Some examples will be detailed later on when some mobile sensors instances are presented.

2.2 Commercial Mobile Sensors

There are many examples of commercial *mobile sensors* or GSM-enabled sensors which are available and widely used today. These sensors are part of monitoring and alarm systems and they are useful in environmental measuring and logging. It is also common for the mobile sensors to have the communicational capacities in order to transmit data to different kind of networks and even to send alarm signals to the appropriate users.

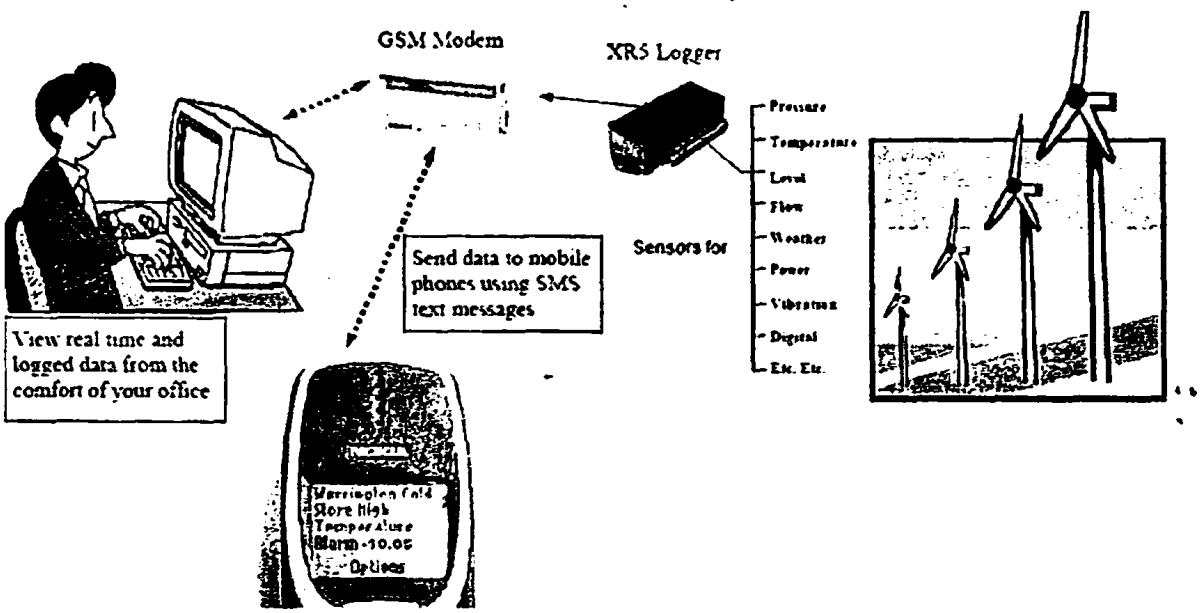

Figure 2.1: GSM Remote Monitoring and Alarm System, XR5 Data Logger for pressure, temperature, level, flow, weather, power, vibration, etc with the use of GSM Modem (Wavecom WCOD2 GSM modem).

In Figure 2.1 different parts of a remote monitoring system are shown. There are some sensors measuring environmental parameters like pressure, temperature, level, flow, weather, power, vibration etc, from the power system shown on the left. Those measurements are collected by a data logger and through a GSM modem are communicated to the administra-

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tor. These systems should be programmed remotely using any Windows terminal emulator and send data to mobile phone using SMS text messages. This is a typical example of the implementation of a monitoring system combining sensors, loggers, modems and terminals using their functionality and properties.

The power, storage, bandwidth, communication or other capacities of the devices used can lead to a variety of monitoring systems implementation. There are devices which include some or even all the capacities needed for this kind of systems in order to be used stand-alone and devices specifically designed for only one function needed in the system. There are, for example, mobile sensors that have also communication capacities, like mobile GSM thermometer and camera sensors, and data loggers with communication capacities that can store and send the data from connected sensors through GSM or computer networks. Of course the example of specifically designed devices-parts of the monitoring system is the above figure (Figure 2.1).

There is a vast variety of mobile sensors used in any kind of monitoring systems form industrial use to commercial use and of course in house monitoring. In addition to measuring and monitoring environmental parameters they should also communicate the data collected and sometimes set alarms. The sensors are designed in order to be connected and communicate their data and status, informing about their measurements and their normal or not normal functionality. There are sensors which need other communication devices, like any kind of modems or data loggers; and other sensors which include communication capacities and can be connected to many networks. For this kind of design, which integrate a monitoring and a communication system, typical examples are some mobile cameras: GTM module network and dedicated PC based software management from AxelProd [24], GSM alarm monitoring system and GPS vehicle locating system like the Patriot unit from Spy Equipment, Law Enforcement Systems [25], the TCS-CAM developed by DPS-Promatic, a reliable GSM digital camera for stand alone applications, which is used to take a pictures and send it over a GSM network [26], and Nokia Observation Camera (Figure 2.2) used to take pictures and more [27].

In addition, *Data loggers* have digital and analog inputs for the connection of devices with analog outputs (temperature sensors, pressure sensors etc) or digital outputs and signals from alarms. There are also data loggers with independents outputs of activation and deactivation of devices that are connected; and their communication capabilities might include commu-

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nication ports (RS-485 or RS-232 ports are common) or/and GSM - GPRS connection with included modems. These loggers have of course different methods of control, in a remote manner, used for activation and deactivation of the individual devices that are connected to them. These are some examples of the latter data loggers: AUTOTECH Irida/GSM, which offer remote control through GSM network [28], Ekopower Complete Data-Logger System EKO21[29] and GuardMagic SCT, GuardMagic SC2x2, GuardMagic SC4x4 devices [30].

Figure 2.2: Nokia Observation Camera sending MMS or e-mail messages with image and temperature data.

Continuing, some examples of mobile sensors, their specifications and capabilities will be presented, sensors that will be use in our middleware framework. Hence, details about Nokia Observation Camera, IRIDA, BieneRemote16 and Weather Station will conclude this introduction to commercial mobile sensors.

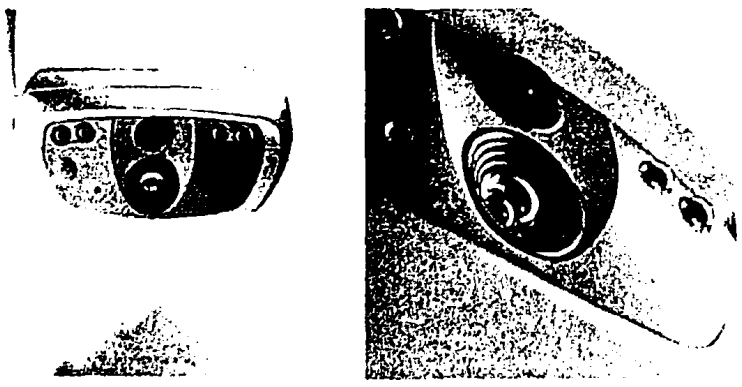

Figure 2.3: Nokia Observation Camera.

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2.2.1 Nokia Observation Camera

Nokia Observation Camera is shown in Figure 2.2 and Figure 2.3. This camera is a remote imaging stand alone device with a motion detector, thermometer and microphone. Images can be captured and sent to any multimedia messaging (MMS) enable mobile phone with color display, or to an e-mail address. Temperature can be sent, after user request, or if the temperature goes out of a set range; the camera can be also programmable to take images automatically at a designated time interval, or when the motion detector is triggered. Finally, the microphone can be used to listen to the environment that the camera is installed into. The site for the Observation Camera Support is [27] and the user manual can be found there.

Table 2.2: An example of Nokia Observation Camera instructions; note: the underline character (_) is used for space in the SMS message.

Task	SMS Command
Set a name for the camera	25_camera name
Capture an image and send it to your mobile phone	1 or image
Capture an image and send it to another phone number or e-mail address	1_phone number/e-mail address or image_phone number/e-mail address
Set the image resolution to high (1), normal (2), or compact (3)	11_number
Set motion detector off	2_off or detection_off
Request the current temperature	3 or temp
Set temperature alarm off	15_off
Set the sending of current temperature with images on or off	13_on/off
Set the user name for the connection	41_user name
Set connection security on or off	45_on/off
Define the master user. The e-mail address is mandatory	8_security code_user name_phone number_e-mail address or master_security code_user name_phone number_e-mail address
Add a new use, and give the right to capture images and/or use the audio connection	5_security code_user name_user's phone number_on_on or add_security code_user name_user's phone number_on_on
Remove a use. The user can be removed based on either the user name or the phone number	6_security code_user name/ phone number or remove_security code_user name/ phone number
Set the PIN code request on or off	22_PIN code_on/off

Someone can control and configure the camera with short messages (SMS), and the PC Suite for Nokia Observation Camera software is provided for more advanced functions. This camera is approved for use on the GSM 900/1800 network and besides GSM network coverage, a GPRS enabled mobile subscription with a SIM card and MMS service will be needed for its function. As mentioned above an MMS and SMS enable mobile phone with color

display can be used to control the device and deliver the data. In our work we make use of a GSM modem for control and an e-mail address for receiving images. Some of the specific instructions and requests with SMS messages to the camera are gathered in Table 2.2 and through that table more camera specifications can be discussed. Please note that in the SMS Command column of Table 2.2 the underline character (_) is used for spaces and that those commands can be sent in one SMS separated by a comma. There are commands about getting information (image or/and temperature), setting the camera parameters, the automatic imaging and the connection, and finally, user and security commands.

2.2.2 IRIDA GSM

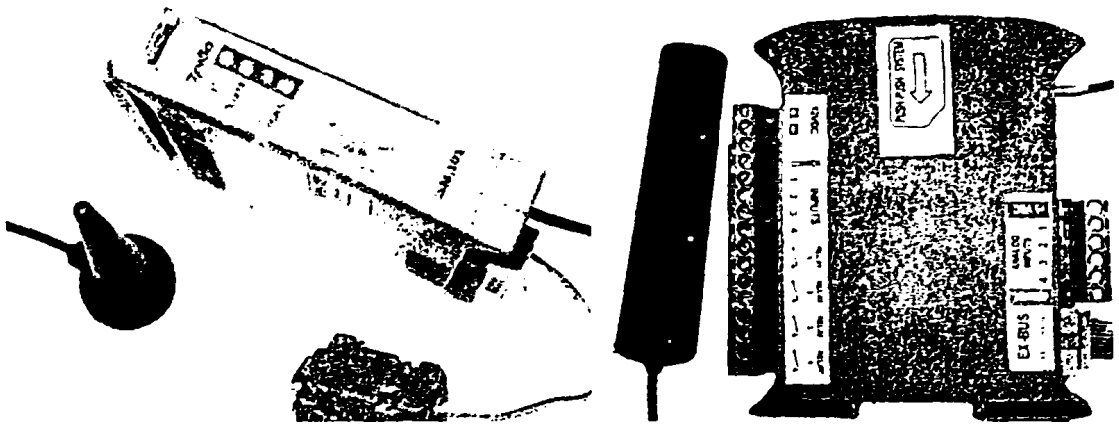

Figure 2.4: IRIDA GSM from Autotech

Irida GSM logger from Autotech is shown in Figure 2.4. This logger allows wireless remote control through cell phone and can be useful in remote paging, telemetry and alarm applications. It has been programmed on a "user friendly" philosophy, by SMS messages or by a PC through a serial port.

IRIDA GSM has :

- 4 independent outputs for activation or deactivation (with or without time delay) of devices that have been connected to these outputs either at home or in the factory. Examples of such devices are: various household electric or electronic devices.

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- 4 digital inputs for the connection of devices with N.O. - N.C. outputs or signals coming from alarms or directly from gas, motion, fire detectors etc.

Table 2.3: Some of Irida GSM instructions.

Task Description	SMS Command	Syntax/Examples
Programming Commands		
Enter access code	**PASS**	**PASS=1111#**
Store the Supervisor phone number in memory	**SUPERVISOR**	**SUPERVISION=6970333330#** PASS=1111# (the 1st time)
Replace the current code (default: 1111) with a new one	**CHPASS**	**CHPASS=1111.1234 #**
Store the phone number from which the system will receive commands and the sequence of commands to be executed	**SETCALLx**	**SETCALL1=6970333330 OUT=ON-MIN052 OUT2=OFF OUT3=XOR OUT4 =OFF-SEC035 CALLBACK1 REPORT#**
Store a keyword and the sequence of tasks to be executed	**SETMACROx**	**SETMACRO1=*IRIDA* OUT1=ON-MIN052 OUT2=OFF OUT3=XOR OUT4 =OFF-SEC035 CALLBACK1 REPORT#**
Store programming values for alarms 1 to 4	**SETMALARMx**	**SETALARM1=6977763000 IN1=ON IN2=OFF AN1>80 AN2>55 AN2<35 AN3<10 OUT1=0N-MIN052 OUT2=OFF CALLBACK1 REPORT #**
Store in one of the memory locations the predefined SMS that the user will receive in case of alarm	**SETSMSx**	**SETSMS1=<A BURGLARY IS CURRENTLY IN PROGRESS AT THE SHOP IN 34 AEOLOY ST.> #**
Set and store the time and date in the GSM module	**SETDATE**	**SETDATE#**
Indicates if a notification SMS will be sent to the user's phone	**REPORT**	SETCALL1=6970333330 OUT1=ON-MIN052 OUT2=OFF OUT3=XOR OUT4=OFF-SEC060 REPORT # or SETALARM1=6557763000 IN1=ON AN1>80 AN3<10 OUT1=ON-MIN052 SMS CALLBACK1 REPORT #
Indicates if a user-defined SMS message will be sent to the phone number that has been programmed in memory	**SMS**	
Output Functions		
Output activation and deactivation	**ON** and **OFF**	
Output activation for the time indicated by parameter xxx (000 to 999 minutes or seconds) Then the output is deactivated	**ON-MINxxx** and **ON-SECxxx**	
Output deactivation for the time indicated by parameter xxx (min. or sec.) Then the output is activated	**OFF-MINxxx** and **OFF-SECxxx**	
Remote Control Commands		
Direct outputs management	**COMMAND** or **COM**	**COMMAND OUT1=ON** OUT3=XOR OUT4=ON-SEC035 #
Request for a notification SMS to supervisor phone number	**STATUS**	**STATUS #**

- 4 analog inputs for the connection of temperature sensors, pressure sensors, humidity sensors etc., or any other system that provides readings through analog outputs (Alternatively, the analog inputs may be used as additional digital inputs).
- 4 independent timers for each Relay output with time function. (1sec - 999min)

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- RS-485 & RS-232 ports communication.
- And additionally the capability to expand the outputs and inputs by multiplying their number is provided.

The activation or deactivation of all individual devices that are connected can be remotely controlled by:

1 commands through SMS that the device receives from a predefined telephone number (supervisor) or from any telephone number with a password.

2 non-answered, toll-free calls to the device (utilizing the calling number identification service)

3 keywords sent by the user in an SMS (the user can program up to 8 different keywords).

There are also 8 different programmable combinations of alarm signals, the device can provide information in regular time intervals about the inputs-outputs status or information regarding the overall status of the device by an SMS or even by a non-answered call.

More information can be found at the site for the Irida GSM [28] and the user manual can be downloaded there. This logger is approved for use on the GSM 900/1800 network and besides GSM network coverage, communicate/transfer data with the use of GPRS service. Some of the specific instructions and requests with SMS messages to Irida are gathered in Table 2.3. Those commands must always be terminated with the sharp character (#), and there are commands about programming, remote control, and output functions.

2.2.3 GSM/SMS Remote Control Module BieneRemote16GM

BieneRemote16GM logger, from Biene Electronics, is shown in Figure 2.5, it's a GSM/SMS remote control module that can be applicable in cases of remote monitoring in different kind of stations, as transformer and wastewater; remote control and alarm systems. There are four different versions of this module: BieneRemote16GM-S for digital signal monitoring and alarming, BieneRemote16GM-2A, BieneRemote16GM-4A both for analog and digital signal monitoring, and BieneRemote16GM-2SMT for temperature monitoring. The user can receive an SMS message at occurrence of a certain event, send a SMS message for managing of various equipment, or requesting information about the target system status. Independent monitoring up to 14 inputs and local control up to 6 outputs is possible. The site for the

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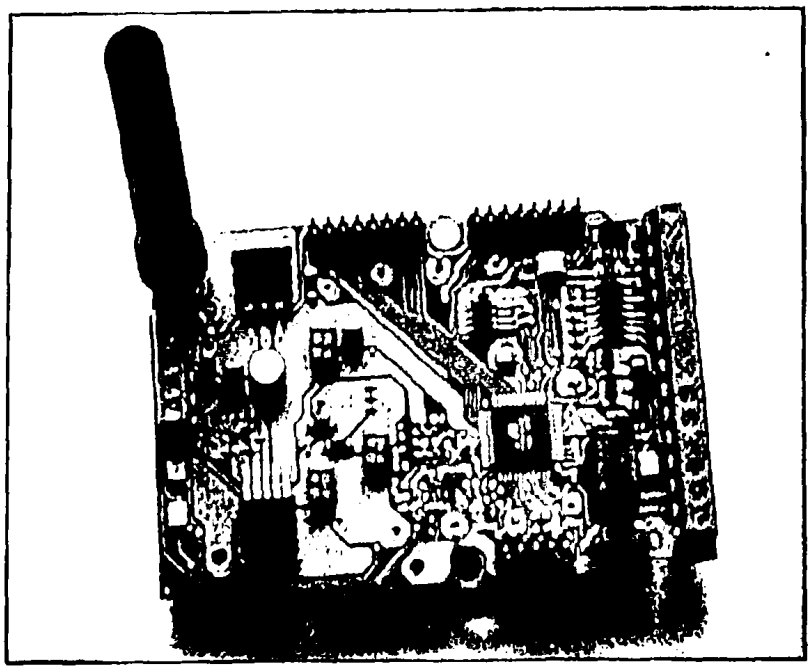

Figure 2.5: GSM/SMS Remote Control Module BieneRemote16GM

GSM/SMS Remote Control Module BieneRemote16GM is [31] and the user manual, demos and other information can be found there.

Someone can control, be informed and configure this remote control module with short messages (SMS). It has a built-in two-band (900/1800) or tri-band (900/1800/1900) Telit GM862 GSM Modem, programmable via SMS embedded software and on board power supply voltage regulator in a small size package. Some of the specific controls commands for the standard version (BieneRemote16GM-S) are shown in Table 2.4. The user can get the current status, set or reset the outputs and the notification, set the logger ON-LINE, and enable or disable switch active /passive answer SMS.

2.2.4 TCS-AWS: GSM Autonomous Weather Station

In the case of the TCS-AWS weather stations, from Telecom Control Systems, we have a reliable GSM based autonomous Weather stations, and there are available various versions to measure parameters like wind speed and direction, temperature, relative humidity, precipitation. Figure 2.6 illustrates installed weather stations. Real time data can be requested with an SMS or listened through a voice synthesizer, placing a call to the unit; data can be logged on a 4 Mbit logger or can be sent directly to a server via GPRS UDP packets.

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Table 2.4: An example of GSM/SMS Remote Control Module BieneRemote16 (standard version) control commands.

Task	SMS Command	Description
Get Status	jjjj0	Get input state, output state, charge status and reference source (for ADC) for instance: I=111111111111 O=10000000 CH=100%
Set Output 1	jjjj1	Set Output 1 to '1' (to '0' on terminal block)
Set Output 2	jjjj2	Set Output 2 to '1' (to '0' on terminal block)
	...	...
Set Output 7	jjjj7	Set Output 7 to '1'
Event notification enable	jjjj8	Set active mode - Event notification enable
Set ON-LINE	jjjj9	Set ON-LINE (BieneRemote dial to first in phone book number)
Reset Output 1	Nnnn1	Set Output 1 to '0' (to '1' on terminal block)
Reset Output 2	Nnnn2	Set Output 1 to '0' (to '1' on terminal block)
	...	...
Reset Output 7	Nnnn7	Set Output 1 to '0'
Event notification disable	Nnnn8	Set passive mode - Event notification disable
Enable/Disable answer SMS	Nnnn9	Enable /disable switch active /passive answer SMS (for alarm mode only). Default - disable

TCS-AWS (Telecom Control Systems for Autonomous Weather Station) control electronics has the following features:

- Built in Dual Band modem model Siemens TC35
- Wide power supply range: 12VDC to 35VDC or 12VAC to 24VAC and a lead battery constant voltage charger on board
- Solar panel power management on board
- Speech synthesizer to speak weather data upon call
- SMS handling to receive commands and send Weather status and alarms
- Alarms: wind speed and temperature with programmable thresholds. Rainfall alarm available on versions with rain collector.
- Automatic message every 30 or 60 minutes in CSV format
- Optional
  - DTMF decoder to allow access only upon touch tone password

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Table 2.5: TCS-AWS: GSM Autonomous Weather Station, some of the commands in SMS messages.

Task	SMS Command
Enable or disable the generation of an ALeRt SMS	#ALR
Store and read text for programmable Alarm MeSsages	#AMS
Auto Reset gsm Modem daily at 3:00 am	#ARM
Change Admin Password	#CAP
CalL Back the tel data number indicated	#CLB
Check gsm rf Signal Quality (0-32)	#CSQ
Change User Password	#CUP
DeBuG: send a copy of all incoming messages to TELephone Nr.8	#DBG
Get LoG: read a LOG string by SMS with comma separated variables	#GLG?
Request an SMS with weather data	#GTM
INItialize: Initialize all parameters to the INIT default value	#INI
Set LoGtoGPRS parameters	#LGG
Define period for weather data sampling and averaging	#LGV
NO Acknowledgment: inhibit SMS acknowledgment	#NOA
Set PIN for the SIM card	#PIN
Set PPP parameters for GPRS connection	#PPP
Give PassWorD to enable any following command by SMS	#PWD
Read/Write PoWeR variables	#PWR
Software RESet the board	#RES
Read/write Real Time Clock in YYYYMMDD HHMMSS format	#RTC
Read/Write the Service Center Address	#SCA
Receive and sent SMs Counters: read/write sms counters	#SMC
Set Rain alarm	#SRA
Set Rain Units	#SRU
Set low Temperature Alarm	#STA
Set Temperature Units	#STU
Set strong Wind Alarm	#SWA
Set Wind speed Units	#SWU
Set the GSM TELephone numbers (up to 8) to which alarms will be sent	#TEL
Voice Call Functions	#VCF
Software Version	#VER
Read Wind direction (to align wind vane)	#WDC

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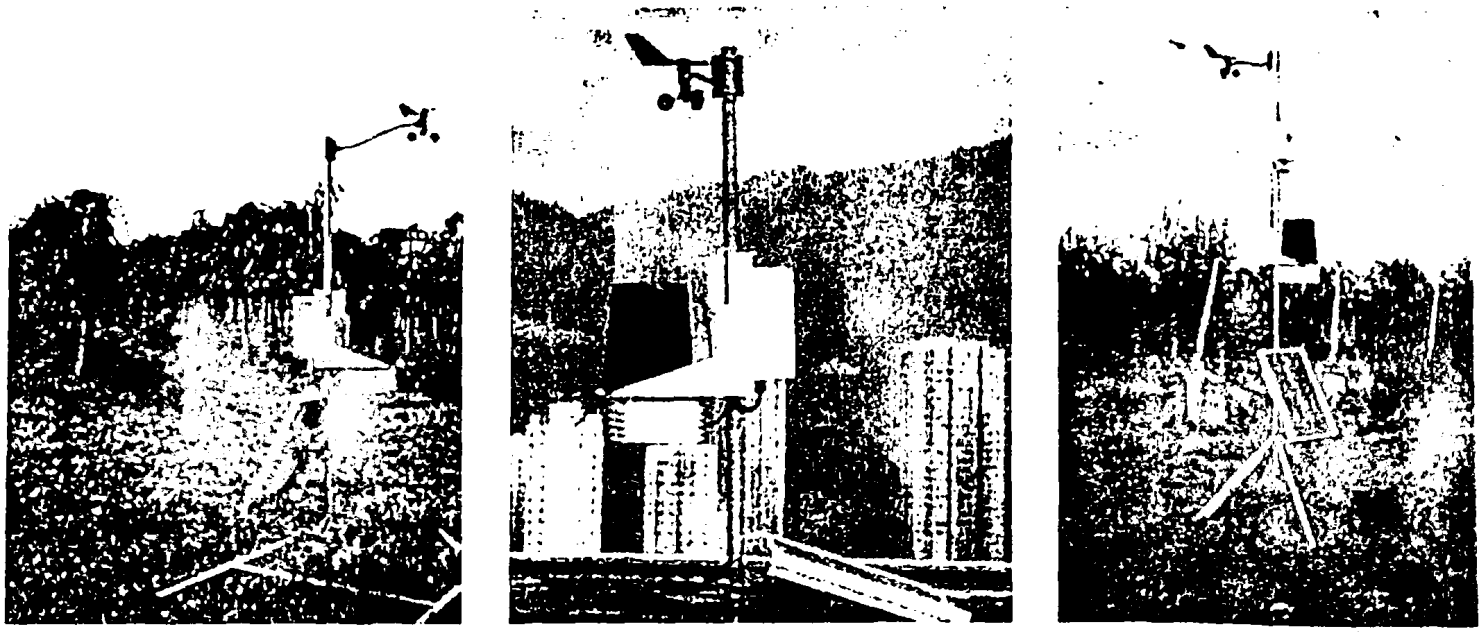

Figure 2.6: Installed GSM Autonomous Weather Stations

- GPRS modem and PPP software to send UDP packets to a WEB server (special skills required to be able to use this option)

- Operating temperature range (inside the box) : 0-50 degrees centigrade

The station can be managed with the TCS OS (Telecom Control Systems Operating System) with system commands given via SMS or via Command Line, when a terminal utility (i.e. Hyperterminal) is used or a PC with a serial cable to RS232 port (for specific products) is connected. More details can be found in [32] and some of the commands for this weather station are in Table 2.5.

In Table 2.6 details and characteristics of the above four sensors are combined. Firstly, this table provides information about the type and the appropriate network for those sensors. Nokia Observation Camera is a GSM/GPRS sensor, Irida and BieneRemote16GT are GSM data loggers and TCS Autonomous Weather Station supporting GPRS optionally. Software and connection need for programming the devices with a computer is custom made for the devices, with serial port connection, except from the BieneRemote16GT which supports only SMS programming. The sensing types that the devices can measure are depending on the devices, the mobile camera can capture images and get current temperature, the data loggers have analog and digital inputs and the weather station can measure wind direction and speed, temperature, humidity and rainfall. Of course, the number of outputs for activation

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Table 2.6: Classification of the above four sensors.

	Observation Camera	IRIDA GSM	BieneRemote16GM	TCS-AWS
sensor or data logger	sensor	data logger	data logger	full system: sensors and data logger
networks	GSM-GPRS	GSM-GPRS	GSM (SMS)	GSM (GPRS opt.)
PC - connection and programming	Custom-made software serial port	Custom-made software serial port and SMS programmable	only SMS programmable	PC Software TCS-OS (RS-232)
sensing types	image and temperature	analog/digital signals	analog/digital signals and temperature (for 16GM-2SMT ver.)	weather measurements (wind, temp., rainfall etc)
alarm	motion detection, temperature alarm	alarm messages	event notification	wind, temperature, rainfall alarms and alarm messages
users	master user, users with privileges and security code	supervisor, users and access code	-	administrator and users - use of passwords
power	external power supply	external power supply	external power supply	wide power supply range and battery (on board)

or deactivation of the data loggers is an other specification characteristic depending on the logger, and this was mentioned in the earlier descriptions of Irida and BieneRemote16GT. Finally, those devices have specific alarming, user management and power capabilities. For instance, BieneRemote16GT does not support different user, privileges or access code in its programming and use; and the autonomous weather station supports a wide power supply range (12V to 35V DC or 12V to 24V AC), an external solar power supply or a lead battery on board.

2.3 Middleware, Web Services and Messaging

The work presented here generally relates to the integration of devices that communicate through SMS and MMS in a global computing environment. Short Messaging Services or Short Message Sending (SMS) [33] is widely supported in mobile phones in most countries. It allows users to compose short textual messages using the telephone handset, and transmit them asynchronously. Thus, it is natural to bind together the pertinent telephony and computing protocols so that computers can originate and perhaps receive such messages. In that respect Short Messaging Services are offered by various cellular telephony providers through WEB interfaces.

In general, XML has been used for sending SMS messages over HTTP [34]. However,

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each vendor created its own implementation leading to interoperability problems. To solve such problems the SMS Forum [35] developed two relating standards: Short Messaging Application Part (SMAP), an XML format for the messages themselves, and Mobile Messaging Access Protocol (MMAP), a SOAP-based protocol for sending those messages. Simple Object Access Protocol (SOAP) is a simple XML protocol for exchanging structured information over the Internet and is amongst the core standards that formulate the overall Web Services architecture [36]. SOAP lies on top of a variety of transport protocols such as HTTP and SMTP.

The aforementioned standards constitute a foundation for communicating with mobile sensors using SOAP. An approach that actually realizes such communication capabilities is detailed in [37]. In particular, the authors propose a bi-directional SOAP/SMS gateway service. This approach bears some similarity with our framework. The gateway service gets SOAP requests from the client application, makes use of a database and a GSM modem to access mobile sensors and sends SOAP responses. The service described in this context runs as a common gateway interface (CGI) script on an Apache WEB server. Implementation-wise there are several common points between this approach and our framework. However, a major difference is that our approach unifies access to different types of mobile sensors through WEB-based interfaces generated automatically. The implementations of these interfaces translate client requests to sensor-specific sequences of SMS control messages. Our system further provides compatibility with approaches for accessing mobile devices through WAP [38]. WAP allows low-end devices with limited CPU power, memory and storage to access the wireless WEB, which further suffers from frequent outages, high latency and low bandwidth. In addition to dealing with these constraints, WAP was designed as an open standard (like HTTP), which significantly reduces compatibility problems across different vendor's implementations. Besides being operating-system independent, WAP is also network-independent and thus capable of operating seamlessly on top of any wireless transmission protocol.

The middleware framework developed in this work is reflective as it self-customizes its interfaces with respect to constraints imposed by each particular sensor. A middleware is said to support *reflection* if it is capable of (1) reasoning about both the application's requirements over the middleware and (2) self-customizing its properties or functionality to cope with the application's requirements. This follows the very first definition of reflection given by Smith in [39]. There are several middleware frameworks that expose the properties provided by the middleware services for introspection and change. An example of such a

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framework is Flexinet, presented in [40]. In Flexinet, it is possible to modify the behavior of the middleware by adding and removing the reified request processing layers of the communication infrastructure, defined by the framework. Other examples are reflective frameworks presented in [41, 42, 43]. To our knowledge, none of the aforementioned particularly deals with the provision of WEB-based access transparency over mobile sensors.

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CHAPTER 3

A MIDDLEWARE FRAMEWORK FOR ACCESSING MOBILE SENSORS

In this chapter, we propose a middleware framework that unifies access to GSM-enabled sensor devices in a global computing environment. Typically, communication with mobile sensors relies on their own protocols, involving the exchange of SMS and MMS messages. In the proposed framework we use XML-based control descriptions that abstractly specify these protocols to generate proxies and corresponding WEB-based (HTML, WAP and WEB services) interfaces that realize them. Thus, we provide WEB-based access transparency over different kinds of mobile sensors. This chapter is structured as follows: after the introduction and the detailed system architecture in Section 3.1, mobile sensor customizer, and server and WEB page proxies will be described in Section 3.2 and 3.3 and finally Section 3.4 implementation issues of the middleware will be discussed.

3.1 Introduction and System Architecture

The World-Wide Web has evolved into the major data structure for providing and accessing computer applications and other resources though well defined WEB-enabled interfaces.

Several emerging technologies exist for the development of such interfaces. In practice, in our work, we meet HTML-based interfaces that facilitate the communication between devices like personal computers and laptops and WAP-based interfaces that support the communication in environments involving hand-held devices like PDAs and pocket PCs. Nowadays, we further have the ability to use programmable interfaces, such as the CGI scripts, and rely on the standard Web Services architecture [36, 44].

In this chapter, we specifically focus on incorporating in such global computing environments (as in [45]) small GSM-enabled sensor devices, controlled by SMS messages. Typically, information gathering from mobile sensors is performed through either SMS messages (e.g. temperature, atmospheric pressure or humidity) or MMS messages (e.g. images, video or time varying signals of seismic or electromagnetic activity). SMS messages are traditionally used as means not only for controlling GSM-enabled devices and logging data regarding their operation (e.g. the status), but also for requesting information (e.g. temperature or wind speed). A sensor-specific proxy server collects client requests for control, logging or information and submits them to the sensor. Then, it collects the specified response and information and makes it available in client-compatible formats. The interaction between the proxy server and the mobile sensor is determined by the manufacturer's specifications regarding command sequences for initializing the sensor and for selecting amongst alternative delivery methods and data contents.

The framework that is introduced is the Middleware Framework layer (as shown in Figure 3.1) between different kind of GSM-enabled sensors and data loggers, which communicate data, and the user interfaces. From the variety of sensors and data loggers in front of sensors, our middleware framework uses GSM/GPRS technology to communicate with those GSM-enabled devices. This framework can be based on Web Services, simple CGI scripts from html pages, e-mail servers or other proxy servers and in the implementation one of the above architectures or a combination between them can be chosen. For instance, we may use Web Services and an e-mail server in cooperation. The middleware will control and access the sensors/loggers through the GSM/GPRS network, as shown at the bottom of Figure 3.1 and the interfaces of the users, based in WEB or WAP, in the top of that figure, will access the middleware through the API that is provided. Of course, other applications industrial and domestic can access the GSM-enable sensors through the user interface or the API of the middleware framework, as an example: with SOAP messages when a Web Services architecture was selected for the implementation of the middleware framework.

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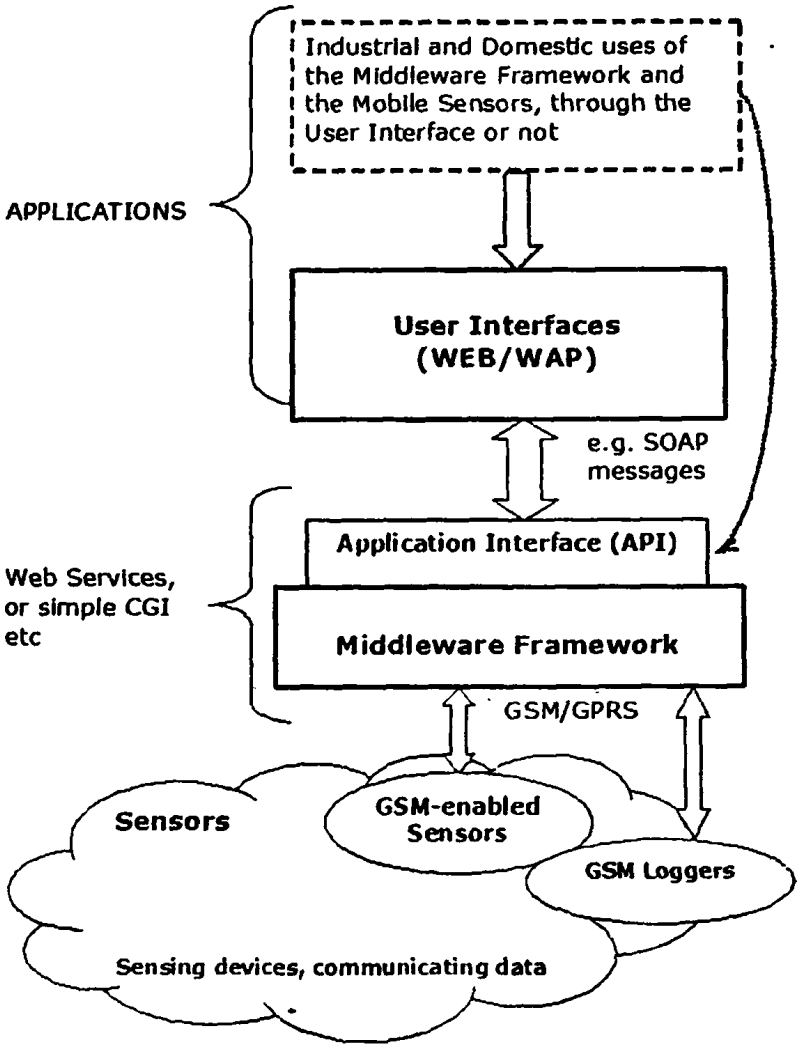

Figure 3.1: Architecture Layers

Hence, the initialization and the gathering of information provided by mobile sensors varies depending on the type of the sensor. In principle, a global computing environment, such as the ones we examine [45], shall comprise many different types of sensors. Consequently, the aim of this work is to propose *a middleware framework that enables a uniform WEB-based access to mobile sensors.* To this end, each mobile sensor is accompanied by a description called *Mobile Sensor Control Description (MSCD)* that serves as input to the proposed framework and will be discussed later. Based on the MSCD, we generate sensor-specific proxy servers and corresponding WEB interfaces. The generated proxy servers realize the necessary procedures for the sensor initialization and the gathering of information accord-

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ing to several sensor-specific parameters that can be customized by the clients through the WEB interfaces. The clients may use different devices such as personal computers, laptops or PDAs with Internet access.

Depending on the client preferences, the sensor-acquired information may be delivered to an e-mail address, to a mobile phone or to a WEB page, because, in the case of a Web page, when we know the format of the delivered information we can automatically generate this page. In a sense the proposed middleware framework is *reflective* [46] since it self-customizes its interfaces with respect to constraints imposed by each particular sensor that participates in the global computing environment.

An overview of our architecture is illustrated in Figure 3.2. Figure 3.2 intoduces the concept of middleware customization with a mobile sensor description, shown in the right side. The global computing environment we consider comprises clients, using different WEB-enabled devices such as personal computers, laptops and PDAs to access available resources. Mobile sensors communicating through GSM and GPRS are a particular kind of such resources. Our framework consists of three main components, namely a *mobile sensor customizer*, and different kinds of *server* and *WEB page proxies*. The server and the WEB page proxies are sensor-specific and establish communication between the clients and the sensors. On the other hand, the mobile sensor customizer serves for generating the aforementioned sensor-specific components, given the specification of *Mobile Sensor Control Descriptions (MSCDs)*. The rest of this chapter further discusses the main responsibilities of the components that constitute the proposed framework.

To demonstrate our overall approach for unifying access to mobile sensors in global computing environments, we provide a specific instances of our architecture that allows accessing a mobile camera, described in Section 2.2.1, through multiple WEB-based interfaces and the GSM autonomous weather station, as described in Section 2.2.4. Those are the use cases that will be described and evaluated in the next chapters. First we present in details the different parts of our framework.

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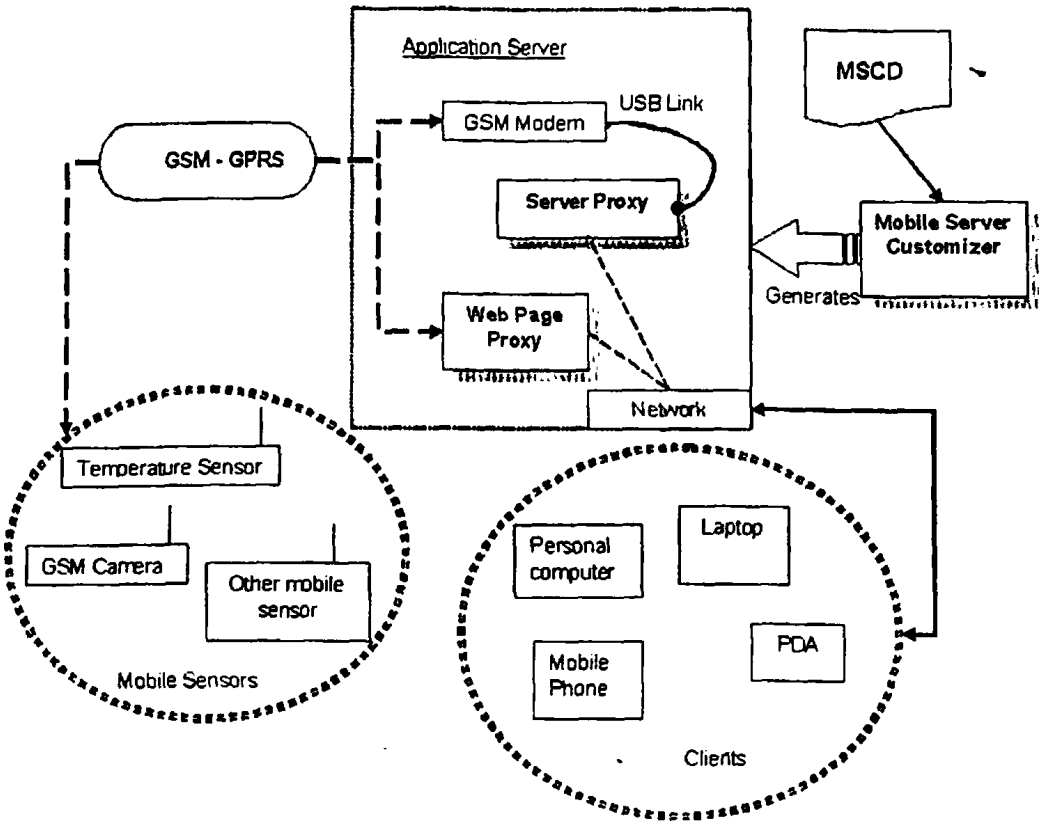

Figure 3.2: System Architecture

3.2 Mobile Sensor Customizer

As we discussed in Section 3.1, the interaction between clients and mobile sensors is determined by the manufacturers' specifications regarding command sequences for initializing a sensor, and for selecting delivery methods and data contents. Unifying the communication between clients and mobile sensors by providing appropriate WEB-based interfaces is a major issue in this context. Addressing this issue is the main responsibility of the mobile sensor customizer. The customizer accepts as input a MSCD, provided by means of an XML file. Roughly, the Mobile Sensor Control Description (MSCD) specifies, besides control messages as for instance initiation commands for installing the sensor, the type of information that can be delivered by the sensor and alternative delivery methods.

Following, the customizer generates appropriate WEB-based interfaces and corresponding implementations of server and WEB page proxies that mediate the interaction between clients and mobile servers. Different kinds of sensors have different descriptions and capabilities and so the behavior of the server and the WEB page specific proxies can vary. For instance, let us assume that a mobile sensor can send image, temperature or both, and this information can be delivered with an SMS or an MMS. The SMS control sequences that

```
<?xml version="1.0" encoding="UTF-8" ?>
<!-- edited with XMLSpy v2006 U (http://www.altova.com) by Zissis (-)  -->
- <xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema" elementFormDefault="qualified"
  attributeFormDefault="unqualified">
  - <xs:element name="sensor">
    - <xs:annotation>
        <xs:documentation>Sensor description</xs:documentation>
      </xs:annotation>
    - <xs:complexType>
      - <xs:all>
          <xs:element name="html_info" type="xs:string" minOccurs="0" />
        + <xs:element name="init" minOccurs="0">
        - <xs:element name="info">
          - <xs:complexType>
            - <xs:choice maxOccurs="unbounded">
                <xs:element ref="infoRequest" />
              </xs:choice>
            </xs:complexType>
          </xs:element>
        + <xs:element name="end-user" minOccurs="0">
        </xs:all>
        <xs:attribute name="sensorName" type="xs:string" use="required" />
        <xs:attribute name="sensorPhone" type="xs:string" use="required" />
      </xs:complexType>
    </xs:element>
  + <xs:element name="message">
  + <xs:element name="delivery">
  + <xs:element name="initialization">
  + <xs:element name="end-user_description">
  + <xs:element name="subType">
  - <xs:element name="infoRequest">
    - <xs:annotation>
        <xs:documentation>Requesting for information</xs:documentation>
      </xs:annotation>
    - <xs:complexType>
      - <xs:all>
          <xs:element ref="message" />
          <xs:element ref="delivery" minOccurs="0" />
          <xs:element name="html_info" type="xs:string" minOccurs="0" />
          <xs:element ref="subType" minOccurs="0" />
        </xs:all>
        <xs:attribute name="inOneMessage" type="xs:boolean" use="optional" />
        <xs:attribute name="isOptional" type="xs:boolean" use="optional" />
      </xs:complexType>
    </xs:element>
  + <xs:element name="SMS">
  + <xs:element name="MMS">
  + <xs:element name="messageVar">
</xs:schema>
```

Figure 3.3: The XML schema for MSCDs.

perform these operations on the mobile sensor is the information that the customizer wants to acquire from the MSCD, to generate a server proxy that actually realizes the operations which are exported by the server proxy in terms of a well-defined WEB interface. Specifically, the mobile sensor customizer supports the generation of two different types of server proxies: (1) servlets providing HTML or WAP based interfaces, and (2) Web Services, providing WSDL compliant interfaces.

Figure 3.3 gives the XML schema for the MSCDs used by the mobile sensor customizer. In detail, the MSCD of a mobile sensor consists of the following elements:

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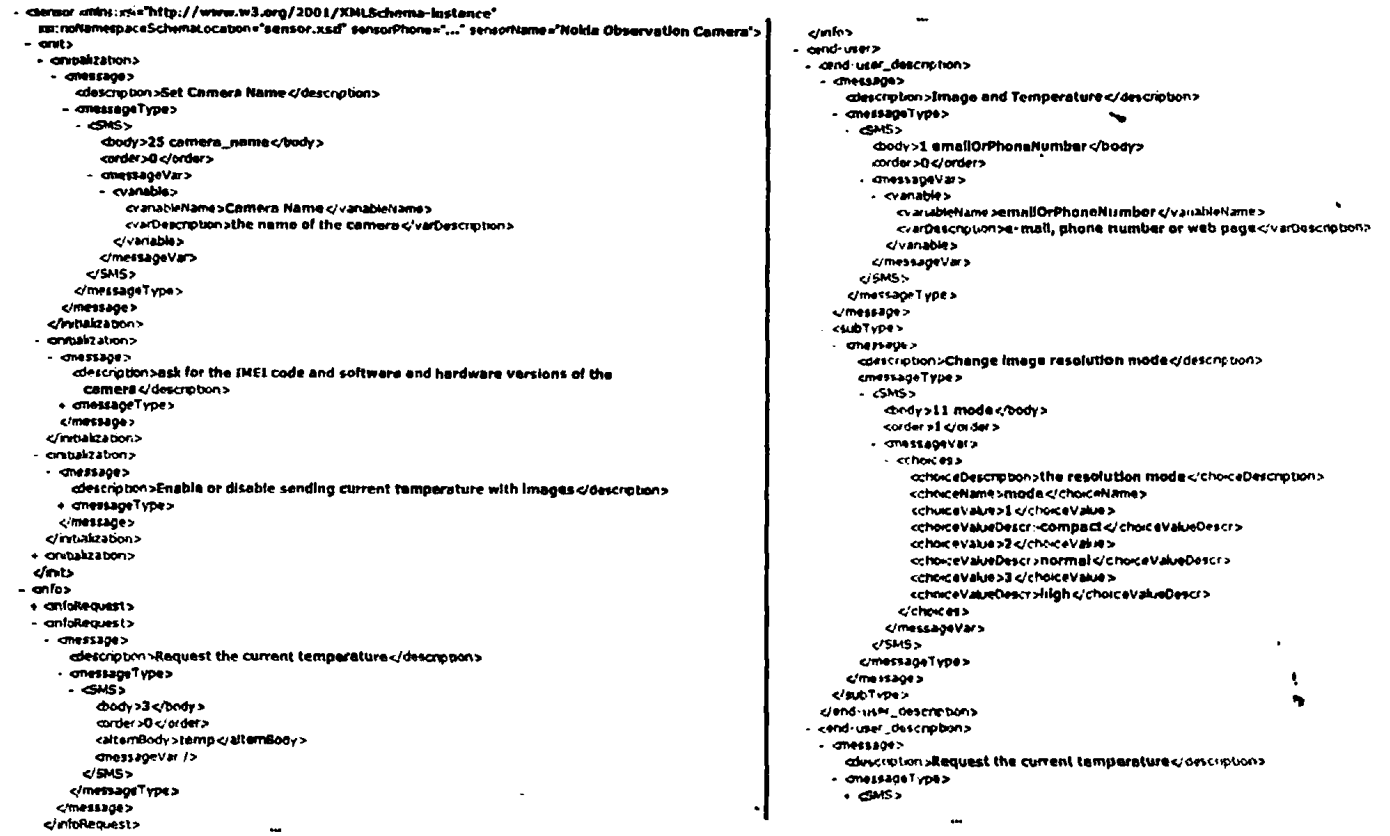

Figure 3.4: Example of a MSCD specification for a mobile camera.

- *Initialization information* (`initialization` tag in Figure 3.3), consisting of a set of alternative initialization protocols for the mobile sensor. An initialization protocol specifies an ordered collection of request and response messages that must be exchanged between the proxy server and the sensor toward the sensor's initialization.

- *Query delivery information* (`infoRequest` tag in Figure 3.3), comprising a set of alternative query protocols for the mobile sensor. Those query protocol prescribes an ordered collection of request and response messages that must be exchanged between the proxy server and the sensor to obtain the information provided by the sensor. The query protocols represent possible user requests and use case in general, when someone can chose what, where and how information will be delivered. It is also possible those protocols to involve the exchange of more that one commands or SMS messages to the sensor configuring the selected parameters.

The initialization and the query protocols customize the content type provided by the mobile sensor and several other content-dependent quality attributes that specify characteristics of the data type that will be delivered (`infoRequest` tag in Figure 3.3). For instance, the content types may be image, video or text and the attributes may specify characteristics such

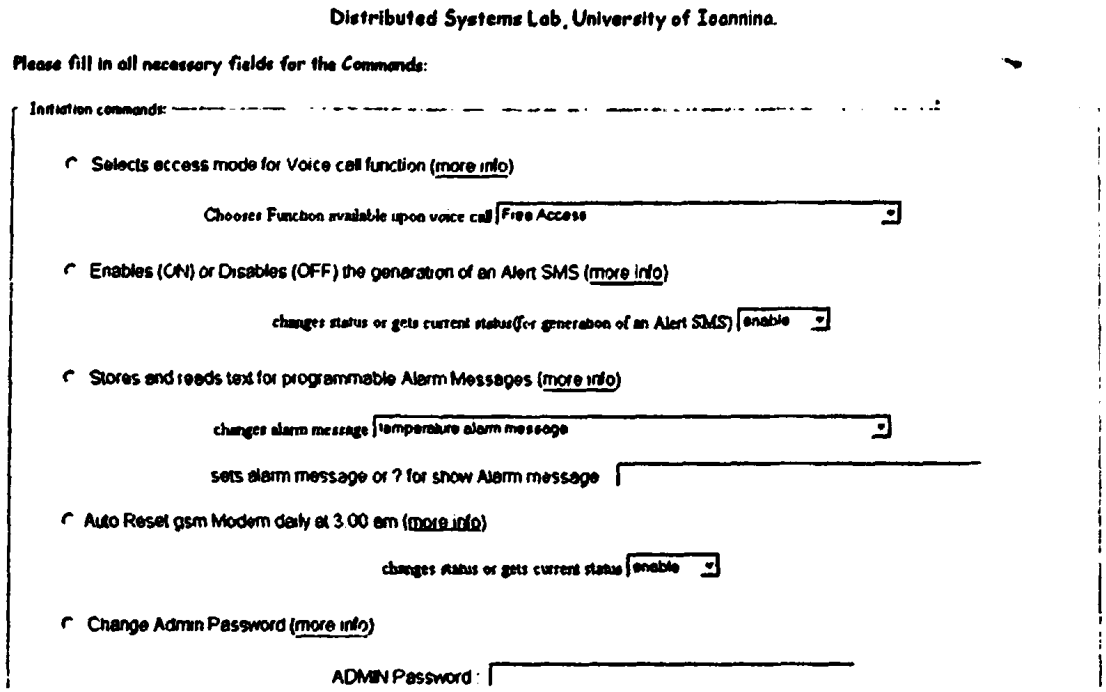

Figure 3.5: Web-based Interface for the Autonomous Weather Station, part of the initiation commands.

as image resolution, video compression or image format. The WEB interfaces generated by the customizer facilitate the selection between alternative initialization and query protocols, as they allow the clients to set their preferences regarding the various content types and attributes either graphically through HTML or WAP based pages, or though a programmable WSDL interface. Then, the client preferences are properly handled by the corresponding proxy servers. Finally, there are also common and useful interactions with the sensors. Those interactions are consisting of a number of initiation and information query requests (of SMS messages) described in case of the "end-user" protocols (`end-user_description` tag in Figure 3.3) and can provide different and simple interfaces. What is why those protocols are called "end-user protocols" and provide "end-user interfaces".

Hence, to integrate a mobile sensor in our global computing environment we define an XML scheme that describes the structure of MSCDs. We can then describe all mobile sensors by providing MSCDs that comply to this scheme. A representative MSCD example is given in Figure 3.4, which is further detailed later in Section 3.4 and in the use cases given in detail in next Chapter.

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3.3 Server and WEB Page Proxies

The behavior of proxy servers is rather typical as it materializes the alternative initialization and query protocols, specified in the MSCDs that were used for generating the servers. In particular, a proxy server collects requests for information issued by clients and translates them into sequences of sensor-specific requests such as SMS messages. For the requests to the proxy there are the appropriate interfaces customized according to the MSCD of the sensor. The interfaces include the forms of choices that are available, in the case of initiation and requesting information as shown in Figure 3.5, for the initiation process of the weather station, and in Figure 3.6 for the observation camera. Following, the proxy server receives the specified information and makes it available in client-compatible formats. The proxy server uses GSM to communicate with the mobile sensor and the mobile sensor responds by submitting appropriate SMS or MMS messages using GSM or GPRS, respectively.

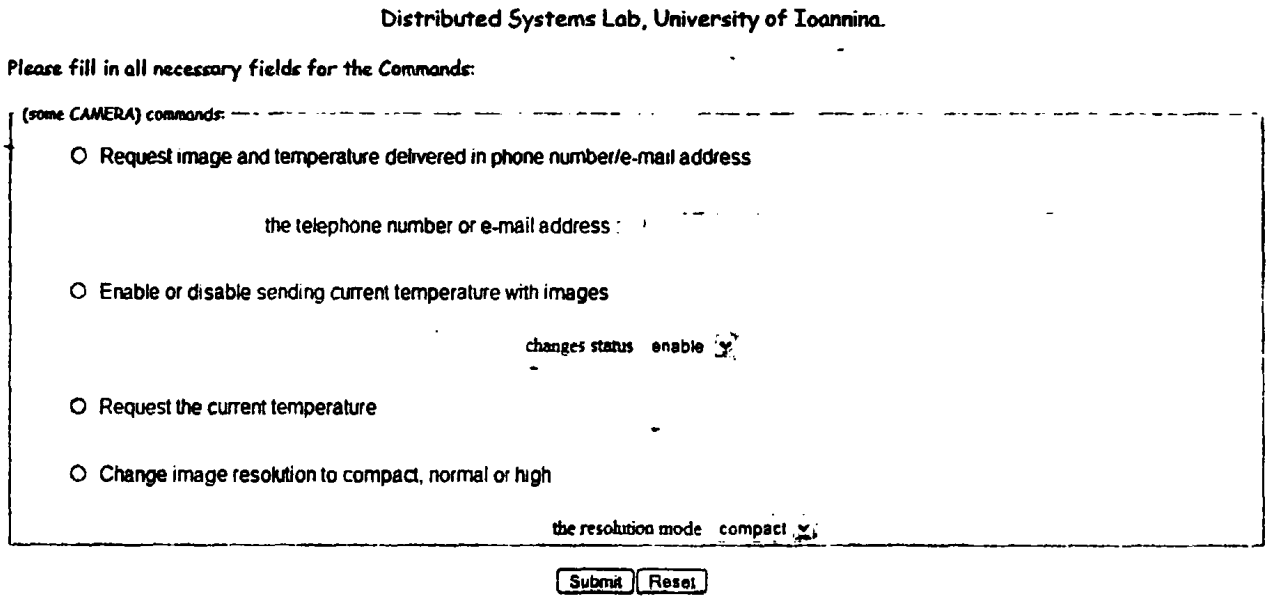
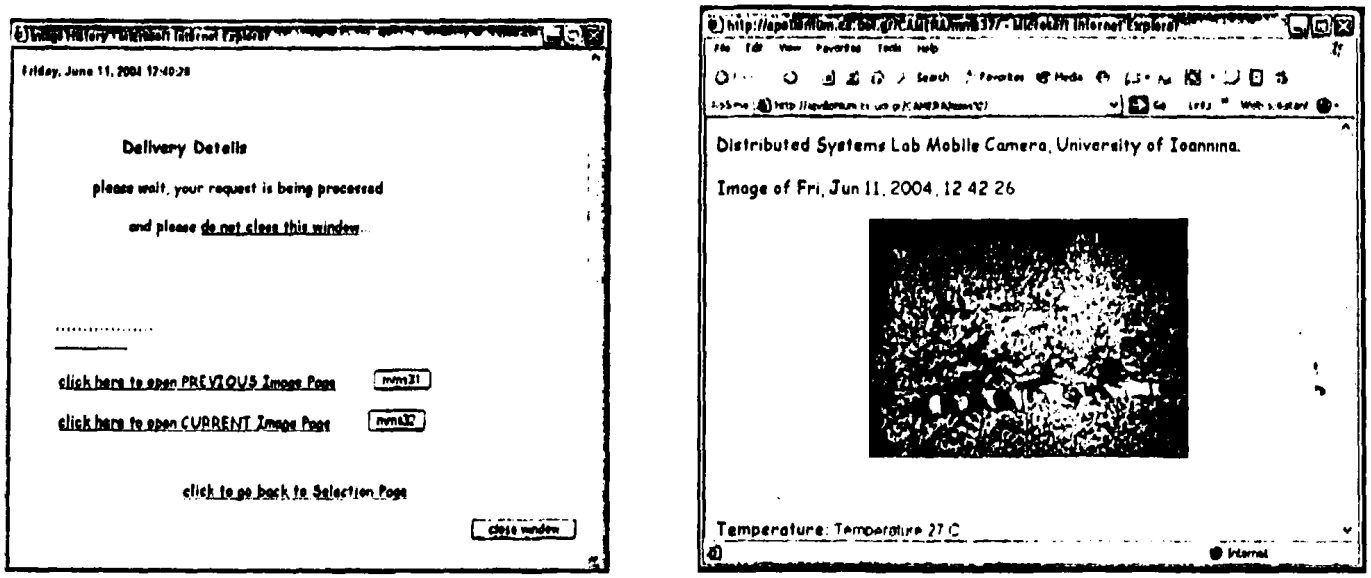


Figure 3.6: Web-based Interface for the Nokia Observation Camera, some of the commands of the mobile camera that be selected.

The construction of this WEB page, when it is requested, is a responsibility of the WEB page proxy component, which receives the MMS sent by the sensor in place of the client. The result page has a unique id assigned incrementally by the framework. The WEB page is created upon the arrival of the email message that contains the MMS built by the sensor, as in the instance that Figure 3.7(b) shows. Synchronizing the client and the WEB page proxy is an issue, tackled by the proxy server. During the processing of a client request the proxy

server waits for the creation of the result page at the WEB page proxy and then notifies the client. The proxy server uses polling to realize the previous task. While the client request is being processed a popup window is open at the client's browser, highlighting the progress of the client's request; as in Figure 3.7(a) for the case of the observation camera.



(a) Popup window. (b) Results page.

Figure 3.7: "End-user" case for mobile camera.

Finally, it worths discussing a very common scenario where a client executes on a low-end device with limited power, processing and storage capabilities. This is the case for the use of WAP-based interfaces and if such kind of devices do not support the reception of MMS messages efficiently the option of building a WEB page that contains the results obtained by the sensor is the solution. And those WAP-based interfaces are generated by the customizer as well.

3.4 Implementation Issues

Speaking of our prototype implementation we can focus on three basic matters: the XML Schema, the proxy server and the GSM/GPRS communication.

Firstly, any MSCD file about a mobile sensor is base on the XML Schema mentioned above. So the description of a mobile sensor has mandatory an optional fields of data. Name

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and phone number for this senor are optional but useful when they are known, then any specific function - command of the sensor must be detailed. Some functions can be executed alone, sending only the command messages for those and not with any other in the same SMS messages, and some other can be sent together in the same SMS messages. That's why it is specified for every function if this command would be sent in one SMS. Those function - commands are collected in groups of initiation, requesting information protocols and "end user" description in the xml file (in different tags as `initialization` and `infoRequest`), and some of the functions can be in more than one of those groups. Apart from the name and the description of those functions there must be specified the variables or parameters of the commands for the functions. A parameter can be, for instance, the 'on', 'off' or question mark ('?') (usually when the status is requested) and a variable can be an e-mail address or a mobile phone number for delivering information, and so on. The commands are SMS messages with a generic message body and then the variables or and the parameters, those are things specified for any function in the description. The XML Schema that is used in our work is shown in Figure 3.3, some instances of the MCSD XML files for the Nokia Observation Camera and the Autonomous Weather Station are in Figure 3.4 and Figure 4.3(a). In the later the instances of functions that require parameters or variables are detailed. For any function there is also the information about the delivery, the request can be a control SMS message but the response from the sensor can vary. In the description of the function can included the type of the response (e.g. SMS, or MMS message), the sender and receiver for those messages can be specified (when it is needed) and maybe a description of the body of those messages can be helpful, in the case of unpacking the messages for receive the information.

Moreover, there are functions (or commands) that can be used together, in the sense that one function can change a parameter, a mode in the sensor and effect somehow an other function. For instance, a function can change the delivery parameters of the sensor, e.g. change the resolution of the images delivered or that temperature will not be sent along with image, and when an other function will have different effect when it will be executed, maybe the delivered information will be different and in the case of resolution the delivered image will not be in default resolution. This example is for the case of the observation camera but can easy lead to many interaction protocols in the use of the sensors for delivering data, after modifying the delivery with changes as above. This case is further detailed in the use case of the camera and is shown in the camera description file (Figure 3.4). Of course, for the same sensor there can be different description files when some one can add those interaction

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protocols, with the additional functions that can be used together. Despite the formal description of the sensor that will be just like the manual of the function - commands in an XML file, those interaction protocols can be add a user perspective. This fact will give a user friendly interface that will group together the functions and request form the sensor, along with the use of popup windows in case of user requests, as shown in Figure 3.7(a), with links to the result pages, as in Figure 3.7(b). This part of the MSCD is called (simple) "end-user description" and will be discussed in details again in the next Chapter.

Finally, for every mobile sensor that will be used a web server is customized. This is the server proxy that uses the Web Service of the sensor. In the parsing process every function, that the sensor has, was mapped in a method of the .jws file, which is in fact a Java file and those methods send the SMS messages to the sensor and wait the response when needed. In the case of many commands in the same SMS there are two different types of implementation. These implementations are different in the inner communication of the proxy server. The Web Service caller (WS-Caller) is the part of the proxy that communicates with the Web Service for the commands and gets the response. When multiple commands are selected to be sent, the number of commands that can be submitted from the WS-Caller can be one by one or all of them. The '*first type*' of implementation is the simple type that the customizer creates. The WS-Caller is connected to the GSM modem and the commands have to be submitted to the Web Service proxy only to be translated to SMS messages. In that case we selected that the caller will send one command at the time, and therefore there will be multiple calls of web services. Then this program, the WS-Caller, will collect the response and send the SMS message with all the requested commands. As mentioned the 'first type', of implementation is given by the customizer by default. When the Web Service proxy is connected to the GMS modem and has the responsibility to send the SMS messages, the WS-Caller will sent all the requested commands and their variables. We call this the '*second type*' of implementation and it is easy for the 'first type' to transformed to the 'second type' of implementation. This fact leads to different choices in the final architecture of the middleware and the middleware framework can even be distributed; as the components of the frameworks, such as the proxy server or the GSM modem and the connection with that, can be, for instance, in different servers in a local network.

In Chapter 5 we evaluated those different implementations for the cases of the commands that can be submitted through the user interface (the Web page with the Html form), connected locally or through an Internet connection; and with Web Service calls, with the

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WS-Caller in command prompt mode. Moreover, we make use of a mobile phone for the GMS modem connected in the USB port of the PC, for sending and receiving messages through the COM port that it was dedicated. There is also an other server, the Web page server, that makes use of an e-mail account and with unpacking the e-mail messages (in fact the MMS messages to e-mail addresses) with the information can generate the new Web page that includes the requested information.

In next chapter, use cases will be examined before the evaluation of our prototype. Those use cases have to do with accessing the mobile camera and the GSM autonomous weather station through WEB-based and WAP-based interfaces.

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CHAPTER 4

USE CASES

In this chapter, the proposed middleware framework is used for two mobile sensors that were described earlier. First the middleware framework instance for an Autonomous Weather Station is presented; the resulting architecture is discussed along with the specific implementation issues of the servers and the interfaces that this middleware uses. This GSM based Autonomous Weather Station was presented in Section 2.2.4. In Section 4.1 we outline the customization of the middleware framework to utilize its functions of sensing, controlling and submitting data in general. And in Section 2.2.1 a mobile camera was described. In Section 4.2 we describe the resulting architecture, the interaction protocols for this camera, the Web-based and WAP-based interfaces.

4.1 A Framework Instance for a GSM-enabled Autonomous Weather Station

In the case of the TCS-AWS weather station from Telecom Control Systems the GSM based autonomous Weather station there are various parameters: wind speed and direction, tem-

perature, relative humidity, precipitation. Real time information can be requested with an SMS or listened through a voice synthesizer by placing a call to the unit. The Weather Station is supported by the TCS OS (Telecom Control Systems Operating System) with system commands given via SMS or via Command Line for managing the station; some of the commands and the corresponding SMS messages for this weather station are in Table 2.5. For instance, we present three TCS OS commands of the Weather station:

- For enabling or disabling the generation of an alert SMS someone can use *#ALR<status>*, where <status> is ON or OFF for enable or disable. In this case the body of the message is #ALR and has the parameter <status>. Some examples of use are: "#ALRON", "#ALR OFF" (space between ALR and value is optional), or "#ALR?" (requesting the status for alert messages).

- For setting telephone numbers to weather station there is *#TEL* command. Sets the GSM Telephone numbers (up to 8) to which alarms will be sent. There are three types of syntax for this command "#TEL?" returns all Telephone numbers (up to 8), "#TEL<xx>?" returns the <xx> Telephone number, with <xx> the Telephone position (from 01 to 08), and #TEL<xx>[=]<ttttttttttttttt> sets <xx> telephone number to <ttttttttttttttt>, with <ttttttttttttttt> the telephone number (maximum 15 digits including a '+') and '=' is optional equal sign, to improve readability. Using a V in front of the number, example: #TEL01=V34822334xxx, will cause the TCS unit to place a call (for 20 seconds) and not send an SMS. This is a command that has a parameter for the position of the telephone number with values form 01 to 08 and a variable that is the telephone number, as mentioned above with or with out V. Note that the 'V' can also be a parameter, an option given to the user in the case of placing a call (for 20 seconds).

- A command that can be the end of a SMS command string is *#NOA*, meaning "NO Acknowledgment", and with using this there will be no return SMS acknowledgment. In the case of #NOA there are no parameters or variables.

Those examples will help us understand the customization of the middleware in the case of the autonomous weather station, and the process that will map the described commands of a sensor in the MSCD file to the corresponding user interface options and server functions.

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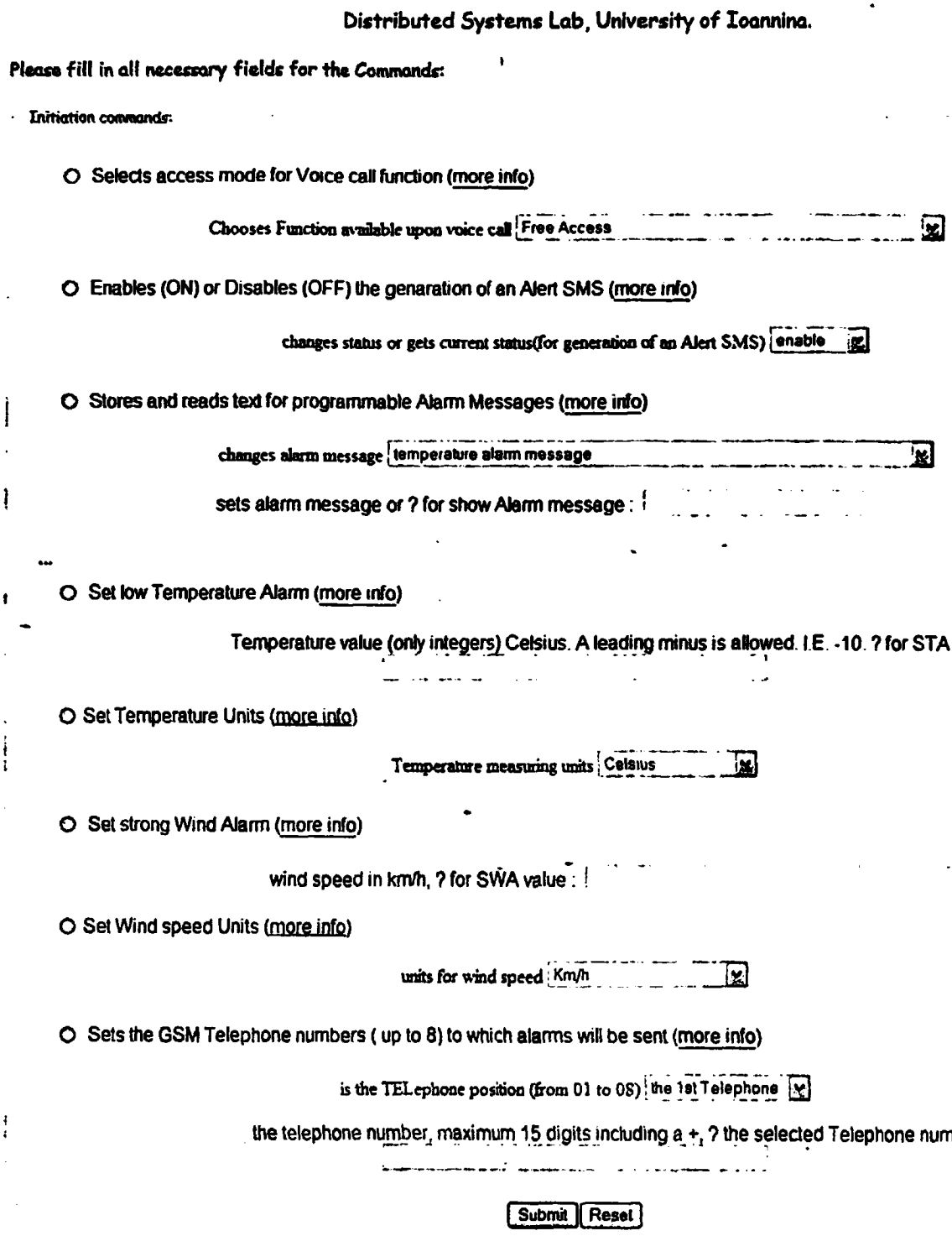


Figure 4.1: Web-based Interface for the Autonomous Weather Station.

ΠΑΝΕΠΙΣΤΗΜΙΑΚΗ ΒΙΒΛΙΟΘΗΚΗ ΙΩΑΝΝΙΝΩΝ

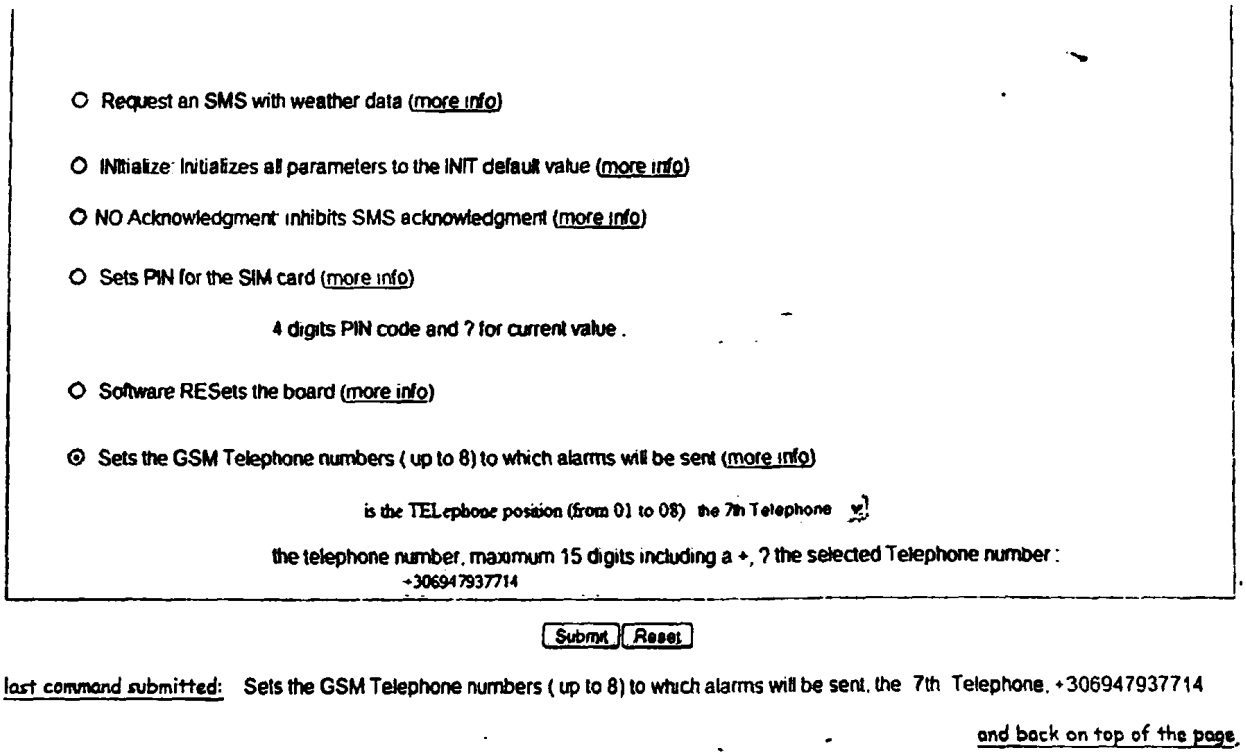


Figure 4.2: Web-based Interface for the Autonomous Weather Station, after submitting one command to the sensor.

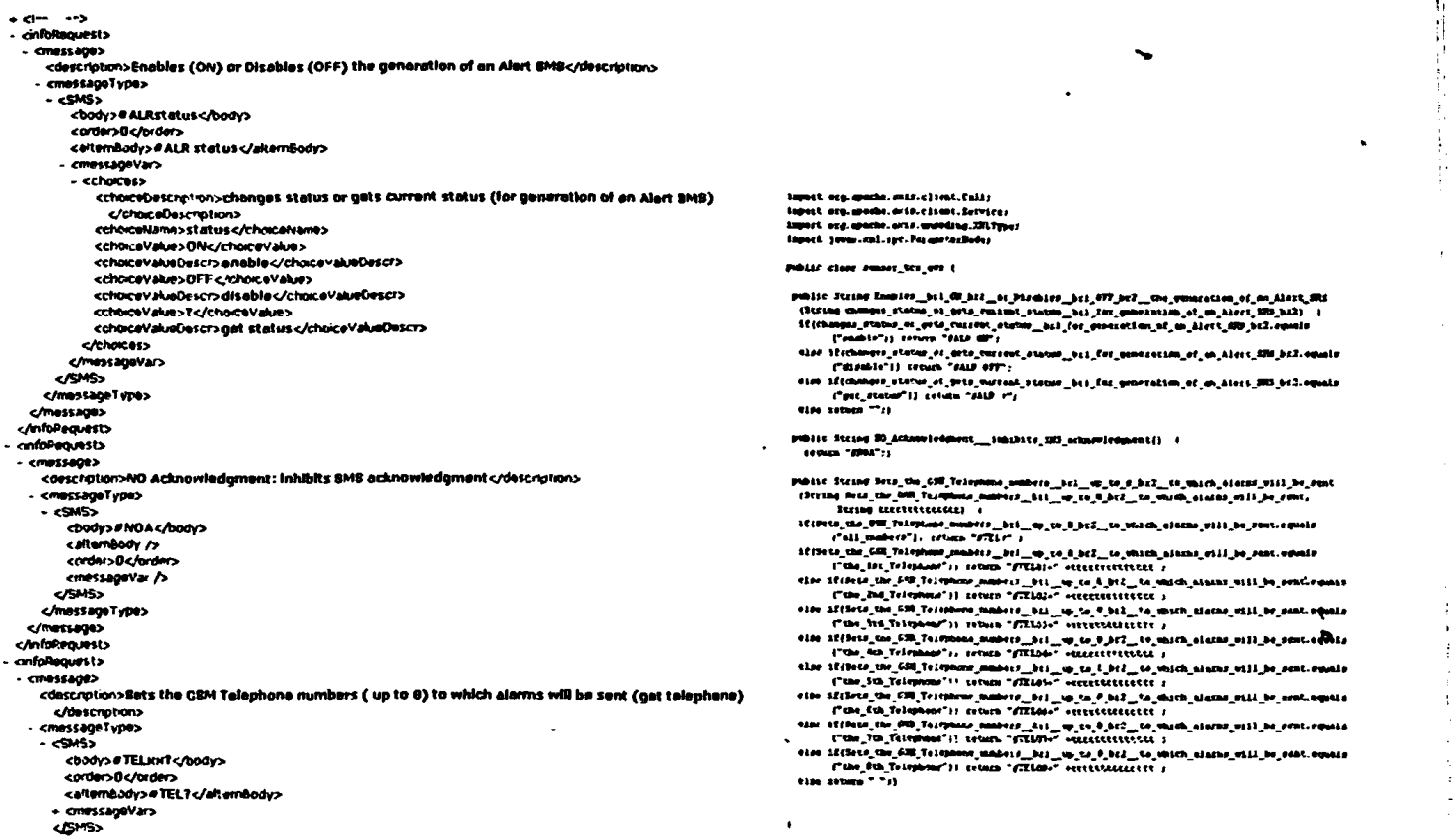
4.1.1 Interface and Implementation Details

The Web-based interface that includes those functions is shown in Figure 4.1 where the functions can be selected and the parameters or variables of the functions can be specified. In this case those functions can be executed alone in one SMS, that's why there option buttons, in type of "radio", and the user can choose only one of the functions. In other case checkboxes will be useful for multiple selections. This Web-based interface is an HTML Form with a "Submit" and a "Reset" push buttons and any submission through this form executes a servlet that informs about our selection (Figure 4.2) and calls the appropriate method of the Web service.

Those three functions in the case of the weather stations have led to three different methods in the proxy server that can be called. The methods in the Java file (.jws, Figure 4.3(b)[1]) have as input the parameters or /and variables for the function and combine the SMS message body that have to be sent, they use the GSM modem to send the SMS messages for the requests. When a function is selected and submitted the servlet calls the appropriate

[1]Details for the XML file of the sensor description (MCSD file) can be found in the Appendix.

ΠΑΝΕΠΙΣΤΗΜΙΑΚΗ ΒΙΒΛΙΟΘΗΚΗ ΙΩΑΝΝΙΝΩΝ



(a) XML. (b) JWS.

Figure 4.3: Autonomous Weather Station.

method with the parameters or variables specified and waits the response when there is one.

4.2 A Framework Instance for a Mobile Observation Camera

The Nokia Observation Camera will be showed in a different way. We make use of a simple end-user interface that can be described in the general MSCD file and has only some of the functions of the mobile sensor.

The MSCD file in the case of that camera is showed in Figure 3.4. But there is a part of this description that has some common and more useful commands, e.g. for the camera the request for image and temperature are frequent. This part of the description is simple and called "(simple) end-user description", and includes three or four commands and the delivery options (to phone number, to e-mail and maybe to a new web page). There is also possible

to add additional options-commands determining information type and mode, image resolution, enabling or disabling the additional delivery of temperature information when someone requests image and so on.

To take a look in some commands of Nokia Observation Camera (the full list of commands is in Table 2.2), let's examine four of the commands that will be in the simple end-user interface:

- *image* or *1* and *image phone number/e-mail address* or *1 phone number/e-mail address*, captures an image and send it the phone number requesting or to another phone number or to an e-mail address, if phone number/e-mail address is added in the command (e.g. *1 6900123xxx*, sends image and temperature in an MMS message to the phone number 6900123xxx).
- *13 on/off* enables (on) or disables (off) sending current temperature with images, e.g. when an image is requested by the "image" SMS.
- *3* requests the current temperature with an SMS message to the phone that send this message.
- *11 1*, *11 2* , and *11 3* changes image resolution to compact, normal or high. This is the case of changing resolution mode that was mentioned earlier.

4.2.1 Interface and Implementation Details

In the case of customizing the middleware for the observation camera the process is as described for the weather station and the WEB-Based interface is shown in Figure 3.6, for some of the camera functions-commands. Every function lead to different method in the proxy server and the interface is used for selecting and submitting the user requests. But there is also the "(simple) end-user description" of the sensor that has a different approach (as shown in Figure 4.4). In the case of this description only frequently used functions are described and there are additional functions. So the interface has the HTML Form for selecting the function, the additional specification functions and then the delivery options (Figure 4.4). There are, in other words, two parts in the interface the first includes the functions that the user has to select and the additional functions selecting, for instance, different resolution in the delivered images (Figure 4.5); and the second part about the delivery information, where the user selects the method of delivery, with an e-mail, to a mobile phone (Figure 4.6), and so on. The customization process gather the functions for the first part and uses the standard

ΠΑΝΕΠΙΣΤΗΜΙΑΚΗ ΒΙΒΛΙΟΘΗΚΗ ΙΩΑΝΝΙΝΩΝ

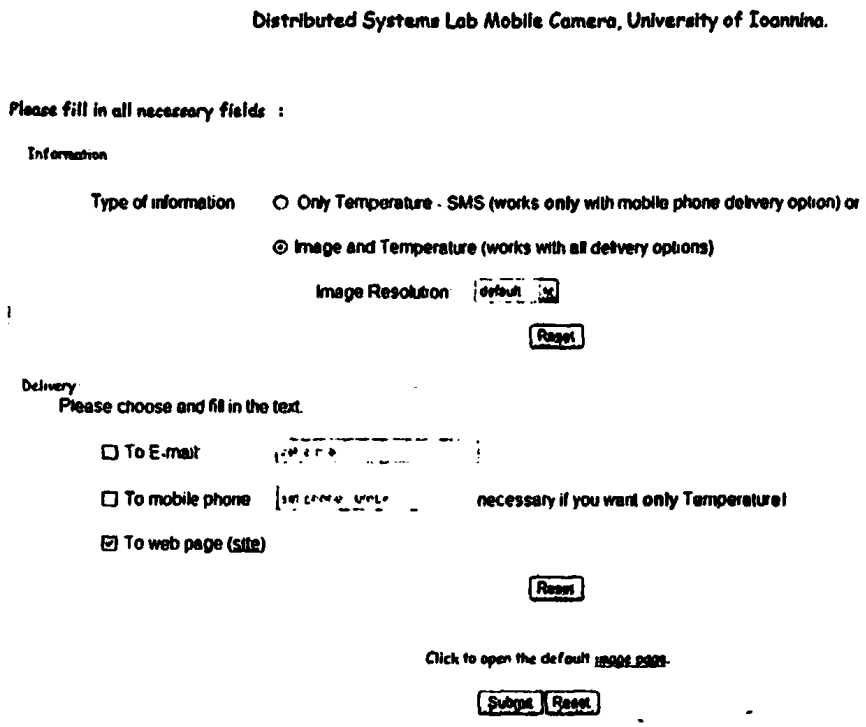


Figure 4.4: Web-based Interface for the Nokia Observation Camera, in the "End-user" (simple) case.

second part deactivated, and has to activate the appropriate methods of delivery when a function is selected because some functions many not use all the given delivery methods.

The basic idea in creating the WAP-based interface is the use of the first WAP card for choosing the function that the user want and then every function has its own different card for setting the appropriate parameters and or variables that this function needs. Some examples are shown in Figures 4.9, about the Nokia Observation Camera in the case of simple end-user interface, the same that was described above for the Web-based interface.

The behavior of proxy servers is rather typical as it materializes the alternative initialization and query protocols, specified in the MSCDs that were used for generating the servers. In particular, the proxy server collects requests for information issued by clients and translates them into sequences of sensor-specific requests such as SMS messages. Following, the proxy server receives the specified information and makes it available in client-compatible formats. At this point it worths discussing a very common scenario, the client has the option of building a WEB page that contains the results obtained by the sensor. The construction of this WEB page is a responsibility of the WEB page proxy component, which receives the

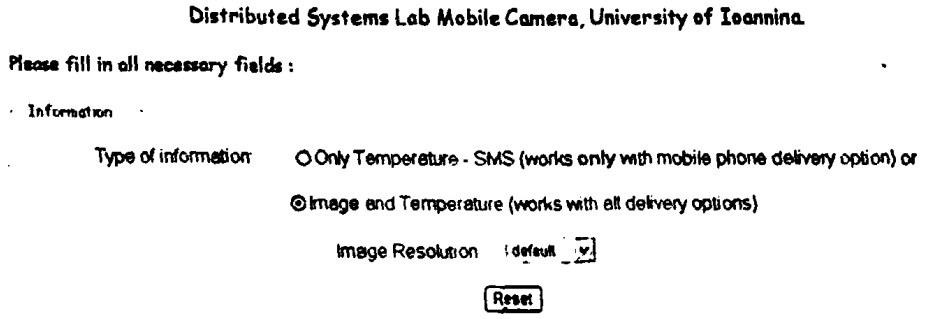


Figure 4.5: Filling delivery information.

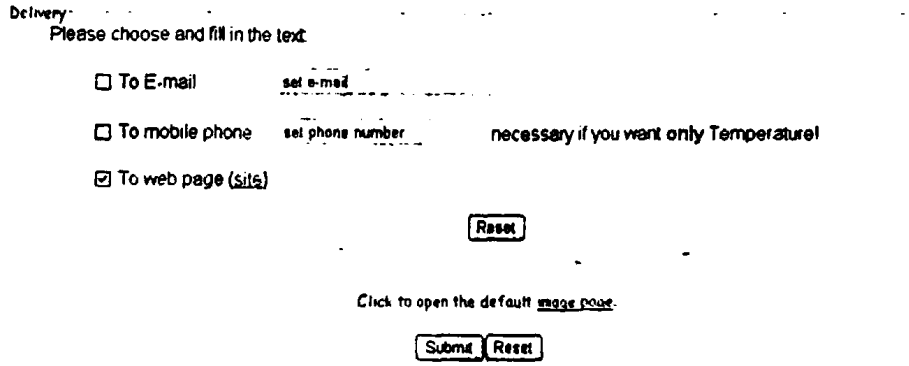


Figure 4.6: Setting up delivery destination.

MMS sent by the sensor in place of the client. The result page has a unique id assigned incrementally by the framework. The WEB page is created upon the arrival of the email message that contains the MMS built by the sensor. Synchronizing the client and the WEB page proxy is an issue, tackled by the proxy server. During the processing of a client request the proxy server waits for the creation of the result page at the WEB page proxy and then notifies the client. The proxy server uses polling to realize the previous task. While the client request is being processed a popup window is open at the client's browser (Figure 4.7), highlighting the progress of the client's request.

4.2.2 Protocols

The clients of our application may then execute several query scenarios involving information provided by the mobile camera simply through the use of the generated interfaces and without any particular knowledge of technicalities that relate to the particular camera. All the required expertise on using the mobile camera is encapsulated in the logic of the server and the WEB page proxies, generated by the mobile sensor customizer. Following we examine

possible scenarios which are further evaluated in next Chapter.

1. A client uses the HTML interface of the camera to obtain image and temperature, delivered through a new page.

2. A client uses the HTML interface of the camera to obtain image and temperature, delivered to an e-mail address. Changing the image resolution mode to high or compact.

3. A client uses the HTML interface of the camera to obtain temperature, delivered to a mobile phone.

4. A client uses the WAP interface to acquire image and temperature, delivered through an e-mail message.

To realize the first scenario, the client has to fill up the options of the HTML forms given in Figure 4.5 and Figure 4.6.

In particular, the scenario proceeds as follows:

a The client selects "Image and Temperature", a resolution (in this case default resolution mode) and "To web page" in the delivery options (Figure 4.5, Figure 4.6).

b After submitting the query a popup window appears and displays date and time asking the user to wait. At the same time the server proxy sends the client request to the camera and waits until the results web page is created (Figure 4.7).

c The camera receives the SMS message that encapsulates the client request and sends image and temperature data to the WEB page proxy through an MMS message.

d Upon the reception of the MMS, the WEB page proxy uses a script to extract the data and creates the results page (Figure 4.8).

e After polling the WEB page proxy, the server proxy gets the notification that the results page is ready. Following, the server updates the popup window with the final form that displays the link to the results page (Figure 4.7).

Similarly, to realize the second scenario the client has to use the HTML forms (as above: Figure 4.5 and Figure 4.6). Specifically, the scenario executes as detailed below:

ΠΑΝΕΠΙΣΤΗΜΙΑΚΗ ΒΙΒΛΙΟΘΗΚΗ ΙΩΑΝΝΙΝΩΝ

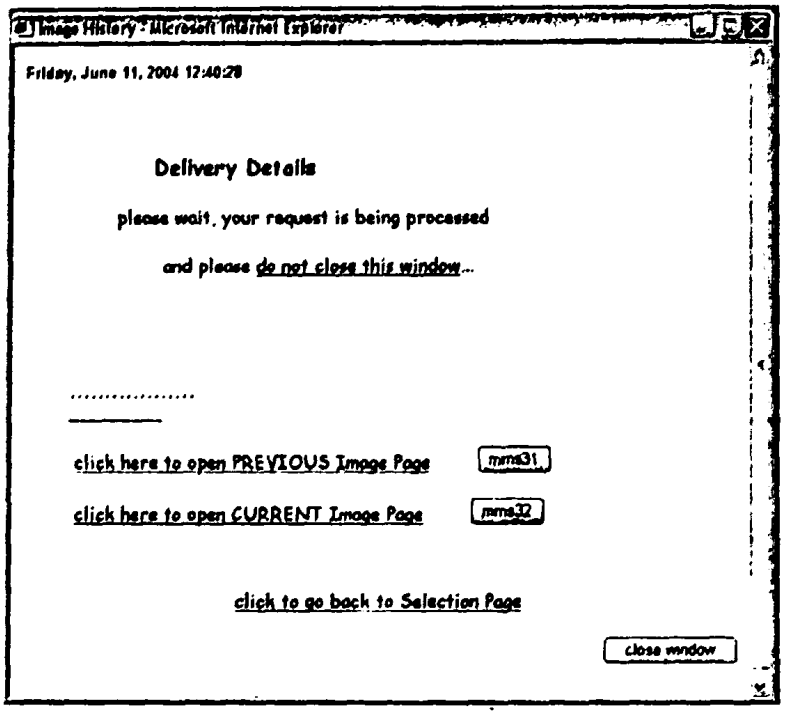


Figure 4.7: Popup window.

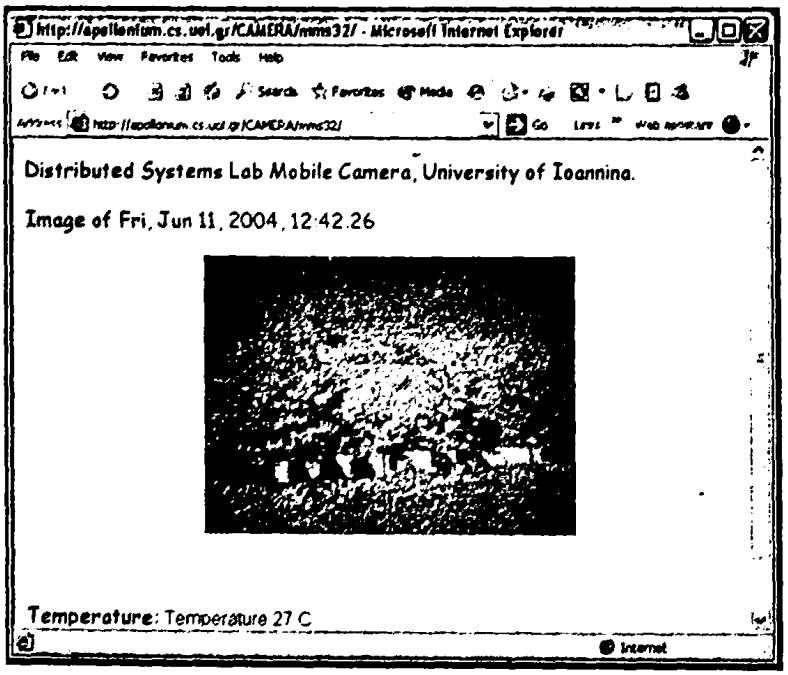


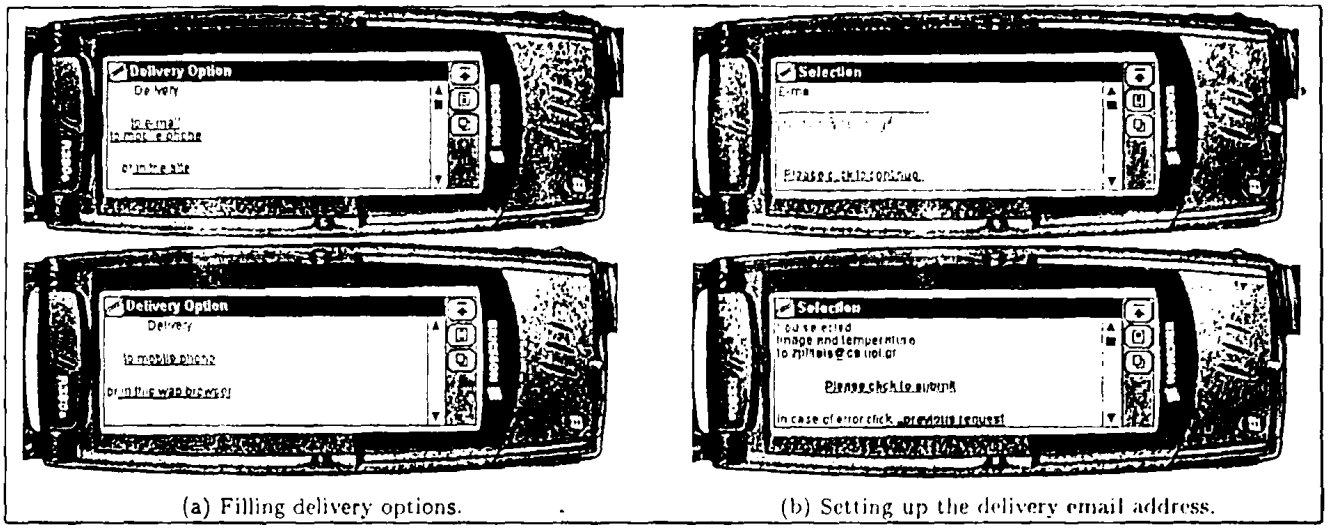
Figure 4.8: Results page.

ΠΑΝΕΠΙΣΤΗΜΙΑΚΗ ΒΙΒΛΙΟΘΗΚΗ ΙΩΑΝΝΙΝΩΝ

a The client selects "Image and Temperature", a resolution, in this case the client changes the default resolution mode to high or compact, and "To E-mail" in the delivery options. This textfield is activated and instead of "set e-mail" the client has to white the necessary e-mail address (Figure 4.6).

b After submitting the query a popup window appears and displays date and time asking the user to wait. At the same time the server proxy sends the client request to the camera and waits until the results are delivered, and

c The camera receives the SMS message that encapsulates the client request and sends image and temperature data to the e-mail address specified through an MMS message.



(a) Filling delivery options. (b) Setting up the delivery email address.

Figure 4.9: Using the WAP interface in the forth scenario.

In the third case, to realize this scenario the client has to use the HTML forms and then:

a The client selects "Temperature Only" and "To mobile phone" in the delivery options. This textfield is activated and instead of "set phone number" the client has to white the necessary phone number (e.g. +306907937xxx) (Figure 4.6).

b After submitting the query a popup window appears and displays date and time asking the user to wait. At the same time the server proxy sends the client request to the camera and waits until the results are delivered,

c The camera receives the SMS message with the client request and sends image and temperature data to the e-mail address specified through an MMS message.

ΠΑΝΕΠΙΣΤΗΜΙΑΚΗ ΒΙΒΛΙΟΘΗΚΗ ΙΩΑΝΝΙΝΩΝ

d Upon the reception of the MMS, the WEB page proxy uses a script to extract the data and creates the results page (Figure 4.8), and then the current temperature has to be delivered.

e After polling the WEB page proxy, the server proxy gets the notification that the results page is ready. Following, the temperature from this page is extracted and delivered to the specified phone number.

Finally, to realize the last scenario the client has to use the WAP interface given in Figure 4.9. Specifically, the scenario executes as detailed below:

a The client selects "Image and Temperature" and the preferred resolution (Figure 4.9(a)).

b Then, the client selects "To E-mail" as as delivery mode and fills in the e-mail address field (Figure 4.9(b)).

c After receiving the query, the proxy server sends a control SMS message to the camera.

d Upon the reception of this message, the camera sends image and temperature as mail attachment to the specified e-mail address.

This last scenario combined with the first three scenarios can give the other use cases for the WAP interface. Figure 4.10, about the first and last scenarios. The above interfaces can be tested for the HTML-based interface at: `http://sensor-proxy.cs.uoi.gr/index_ds.htm`, and for the WAP-based interface at: `http://sensor-proxy.cs.uoi.gr/index_ds.wml`. The last created page, with image and temperature information is stored in the Web Page Proxy, at: `http://apollonium.cs.uoi.gr/CAMERA/camera.html` and another page may be: `http://apollonium.cs.uoi.gr/CAMERA/mms166/`.

ΠΑΝΕΠΙΣΤΗΜΙΑΚΗ ΒΙΒΛΙΟΘΗΚΗ ΙΩΑΝΝΙΝΩΝ

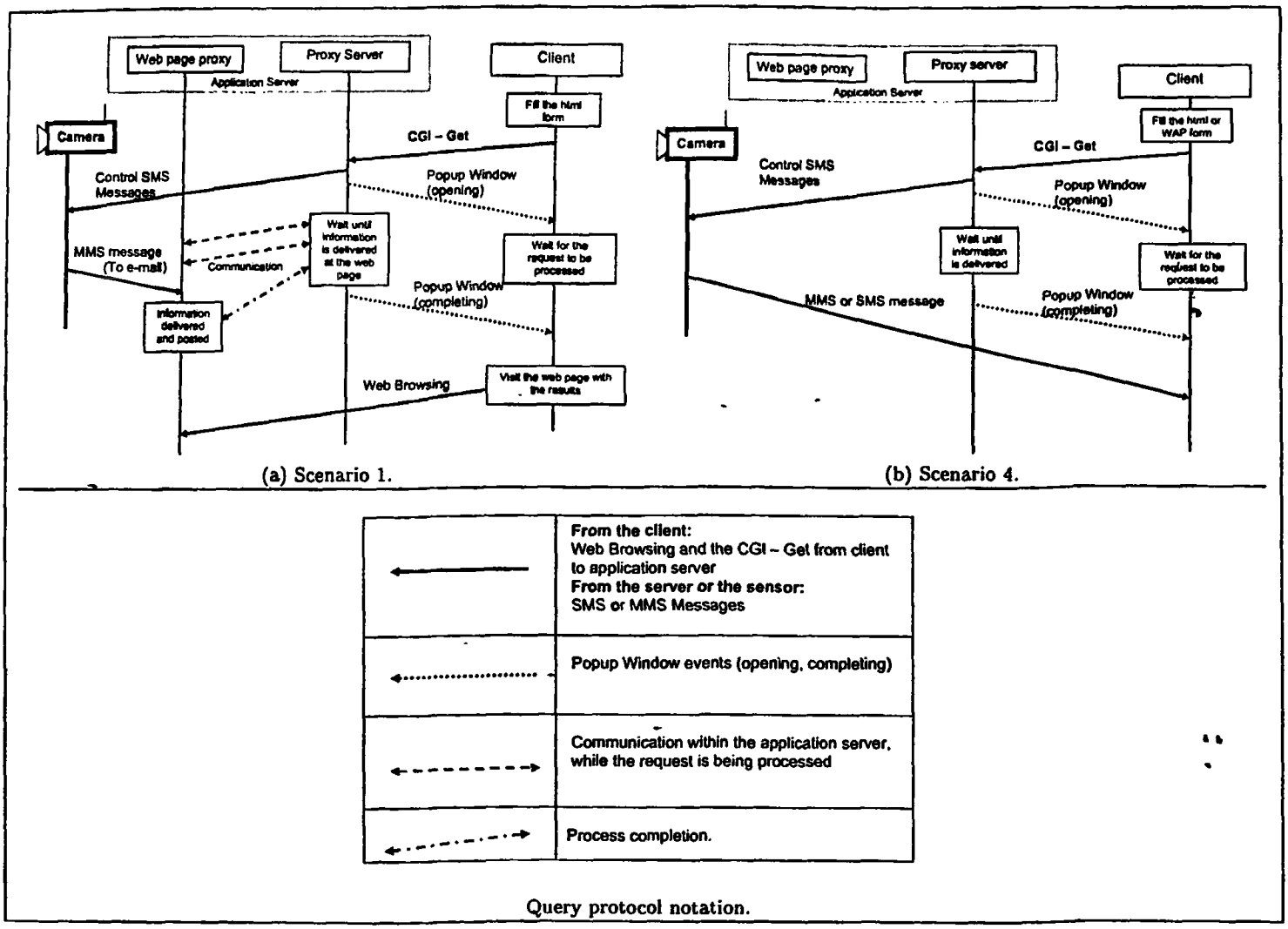


Figure 4.10: Query protocols for the two scenarios.

ΠΑΝΕΠΙΣΤΗΜΙΑΚΗ ΒΙΒΛΙΟΘΗΚΗ ΙΩΑΝΝΙΝΩΝ

CHAPTER 5

PERFORMANCE EVALUATION

In this chapter we evaluate the prototype middleware framework that accesses GSM-enabled sensors. In Section 5.1 we measure the middleware customization time. In Section 5.2 we evaluate the time overhead that the middleware introduces in the case of a mobile weather station. Finally, in Section 5.3 we evaluate the middleware time overhead in the case of the mobile camera.

5.1 Customization Overhead

The customization process is performed once for each sensor type, according to the customization (MSCD) file. Every subsequent change in this description file leads to different services and interfaces. The process of customization has two parts: the creation of the proxy server and the creation of the corresponding user interfaces. Every different command of the sensor results in a different method in the server that can be invoked by the client. The customization file describes three different user interfaces: initialization, information exchange and end-user interface. The proxy server in all these cases is the same.

In the evaluation we used three different files of sensor descriptions, files with small, medium and large number of commands in the cases of the initialization and information

Table 5.1: Customization time for the middleware framework in four cases, according to the size of the sensor description file in number of commands described.

Customization process (in sec)	5 Commands Description File	10 Commands Description File	20 Commands Description File	50 Commands Description File
Proxy Server:				
(i) Web service proxy	0.39	0.55	0.65	0.98
(ii) Calling Interface creation	0.4	0.56	0.65	1.03
User Interface Web page and Servlet	0.6	0.84	1.03	1.62
Total time of creation	**1.39**	**1.95**	**2.33**	**3.63**

exchange interfaces. We used descriptions with 10, 20 and 50 commands. The corresponding proxy server is the same for these interfaces. In addition, a selection of the most used commands leads to end user descriptions with 5 commands. We have measured the time for the customization of the server. Table 5.1 includes all the customization measurement in the cases of the different description files. The first row in the Table 5.1 has the results for the case of the server customization and the second row of this table has the results for the interfaces customization.The average time, of course, is affected not only by the number of commands described, but also by the complexity of these commands, concerning the parameters and variables that they might have. The selection of the commands in the descriptions used was not random, but the different kinds of commands had the same ratio in the cases of the descriptions with small, medium and large number of commands. The 'test set' in the evaluation of 10 commands description file included three commands without any parameter or variable, two commands with a parameter, three commands with a variable and two commands with a parameter and a variable. The same ratio was used in the other cases of the sensor description files.

The average times for the creation are: 1.95 sec for the '10-commands description file', 2.33 sec for the '20-commands description file' and 3.63 sec '50-commands description file'. For the creation of the interfaces (initialization and information exchange) the average time is: 0.56 sec for the '10-commands description file', 0.65 sec for the '20-commands description file' and 1.03 sec '50-commands description file'. In the case of the 5-function end user we measure 0.39 sec, in average, and in '5-commands description file' the initialization interface

ΠΑΝΕΠΙΣΤΗΜΙΑΚΗ ΒΙΒΛΙΟΘΗΚΗ ΙΩΑΝΝΙΝΩΝ

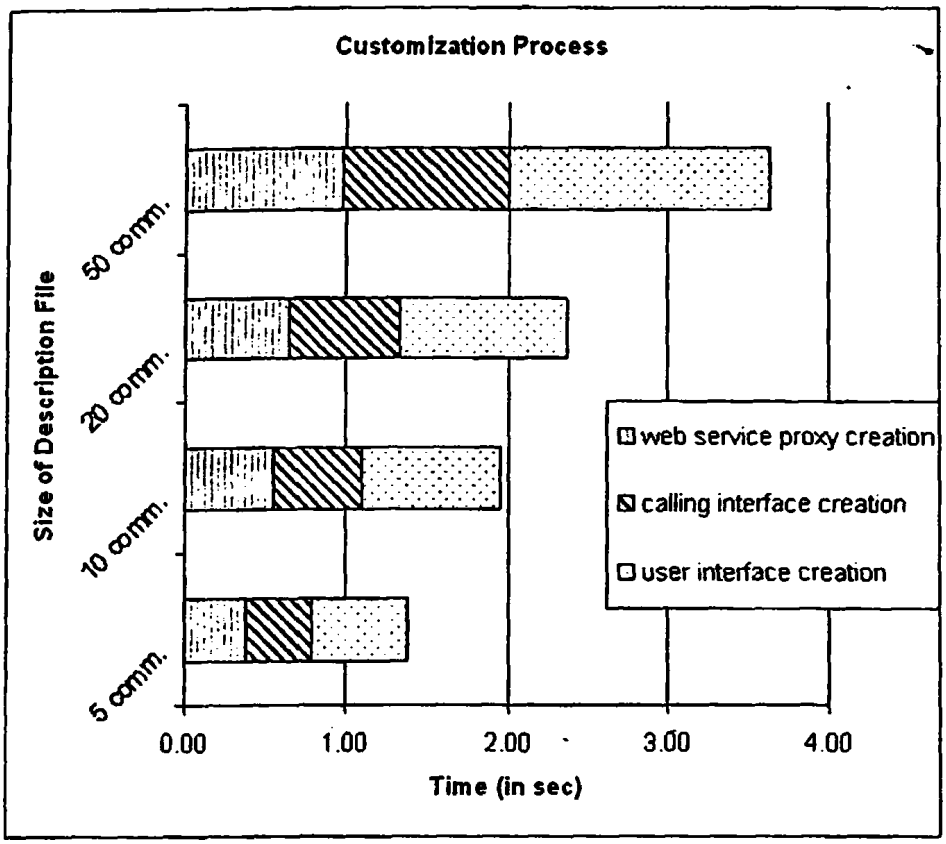


Figure 5.1: Customization Process of different description files

was created in 0.41 sec, in average. The third row of the Table 5.1 has the time for the customization of the Java files needed for the proxy server (the Web Service caller Java file) and the interfaces (the servlet file). Those measurements were added to total creation time. Figure 5.1 also shows the customization process for four cases according to the size of the sensor description file in number of commands. In this figure the process time is divided into three parts, the time for creation of: the proxy server, the web interface and both the WS-Caller and the servlet.

Summarizing, as it is shown in the related table and figure (Table 5.1 and Figure 5.1), someone can provide the interfaces and the proxy server within some seconds, depending on the number commands, which are described in the MSCD file. The files created can be used after compilation and copy in the directories of the server that is used. Tomcat server for the servlets and Axis for the Web Services need some configurations and then service and user interface will be ready.

ΠΑΝΕΠΙΣΤΗΜΙΑΚΗ ΒΙΒΛΙΟΘΗΚΗ ΙΩΑΝΝΙΝΩΝ

5.2 Middleware Overhead in the Weather Station Use Case

After customizing the middleware for the case of the autonomous weather station, we can measure the time overhead that the middleware introduces in different cases of accessing this sensor. This overhead depends on:

- The complexity of the requested commands, as there are commands without parameters or variables, commands with parameters or variables and commands with parameters and variables. For instance, there are:
  - commands without parameters or variables e.g. #GTM or #NOA (as in Section 4.1);
  - commands with one parameter, e.g. #ALR, to enable or disable the generation of an alert SMS, with the parameter status to be: enable, disable or ?;
  - commands with one variable, e.g. #CUP, for changing a user password, with the password as a variable; and
  - commands with a parameter and a variable, e.g. #TEL as described in Section 4.1.
- The number of requested commands to sent in the same SMS message to the sensor.
- The means that will be used to select and translate the commands to SMS message(s), as it is possible that the user can utilize the middleware with Web Services calls or through the Web Interface. Moreover there are two different implementations, that were detailed in Section 3.4, and each of them introduces different delays in the system.
- The number of commands described in the MSCD file for the middleware customization, as it will be detailed in the last set of experiments.

The overhead form the above parameters has to do with latency depending on the CPU time needed, e.g. in one of the server of the system, and network communication time between different parts of the system. Table 5.2 summarizes those latencies according to the parameter of the system that we can chose and shows the parameters that will be used in the experiments.

Specifically, for the first set of experiments (Table 5.3):

ΠΑΝΕΠΙΣΤΗΜΙΑΚΗ ΒΙΒΛΙΟΘΗΚΗ ΙΩΑΝΝΙΝΩΝ

Table 5.2: Parameters that effect Middleware overhead in the Weather Station use case and description of the following sets of experiments.

Parameter name	Latency introduced by:	First set of experiments.	Second set of experiments.	Third set of experiments.
Complexity of the Command	CPU time and Network time	Different types of Commands	Different types of Commands	Different types of Commands
Number of Commands in the same SMS message	Network time	One Command in one SMS message	One, two, three or four Comm. in one SMS mes.	One, two, three or five Comm. in one SMS mes.
Two implementation types	Network time	Different implementations	Different implementations	Different implementations
The means used for request	CPU time (server and client)	Different means are used	Different means are used	Different means are used
Number of Commands described in the MSCD file	CPU time (server)	25 Commands described in the MSCD file	25 Commands described in the MSCD file	10 and 50 Comm. described in the MSCD file

i The number of requested commands is the same in all the experiments of this set, we requested one command in one SMS message.

ii The complexity of the command varies as described. There are four types of commands and in our measurements we included these different types of commands.

iii For this configuration of commands the two implementations have the same results, as in both ones there is only one Web Service call.

iv We make use Web Services calls, the Web Interface locally and the Web Interface through Internet connection.

v The MSCD file that were used described 25 commands.

For the second set of experiments (Table 5.4 and Table 5.5):

i The number of requested commands in one SMS message varies as follows:

- Requesting a simple command to be sent in one SMS message, with leads to four cases according to the commands complexity.
- Requesting two commands to be sent in one SMS message, which leads to 16 cases (four cases for the first command combined with four for the second one).
- Requesting three commands to be sent in one SMS message, which leads to 64 cases.

ΠΑΝΕΠΙΣΤΗΜΙΑΚΗ ΒΙΒΛΙΟΘΗΚΗ ΙΩΑΝΝΙΝΩΝ

Table 5.3: Middleware overhead measurements in the case of one command in one SMS message, in the Weather Station use case .

1st set of Experiments	Web Service calls locally Average time in sec	Web Interface, Web page - locally Average time in sec	Web Interface, Internet connection Average time in sec
Command without parameter or variable	1.05	1.57	1.58
Command with a variable.	1.06	1.59	1.59
Command with a parameter.	1.07	1.6	1.6
Commands with a parameter and a variable.	1.07	1.62	1.63

- Requesting four commands to be sent in one SMS message, which leads to 256 cases.

Selecting only commands of a different type in the same SMS, is a decision that leads to more simple experiments (4, 6, 4 and one cases). This decision will not effect the general idea of the selection of multiple commands in one SMS message.

ii The complexity of the command varies as in the first set and in our measurement we have the average time.

iii We used both the two implementations.

iv Finally, same as in the first set of experiments: we make use Web Services calls, the Web Interface (locally and through Internet connection) and the MSCD file described 25 commands.

We performed the experiments with two different types of implementation, that were different in the inner communication of the proxy server. The Web Service caller (WS-Caller) is the part of the proxy that communicates with the Web Service for the commands and gets the response. When multiple commands are selected to be sent, the number of commands that can be submitted from the WS-Caller can be one by one or all of them. The '*first type*' of implementation is the simple type that the customizer creates. In that implementation

ΠΑΝΕΠΙΣΤΗΜΙΑΚΗ ΒΙΒΛΙΟΘΗΚΗ ΙΩΑΝΝΙΝΩΝ

Table 5.4: Middleware overhead measurements in different case of requests, in the Weather Station use case (for the *first type* of our implementation).

2nd set of Experiments (first implementation)	**Web Service calls locally** Average time in sec	**Web Interface, Web page - locally** Average time in sec	**Web Interface, Internet connection** Average time in sec
Simple Command in one SMS message	1.06	1.59	1.59
Two Commands in one SMS mess.	2.12	3.1	3.3
Three Commands in one SMS mess.	3.30	4.7	4.8
Four Commands in one SMS mess.	4.28	6.4	6.6

we selected that the caller will send one command at the time, and therefore there will be multiple calls of web services. Then this program, the WS-Caller, will collect the responses and send the SMS message with all the requested commands. As mentioned the 'first type' of implementation is given by the customizer by default, and this type of customization was measured in Table 5.4. In the 'second type' of implementation the Web Service proxy has the responsibility to send the SMS messages. The WS-Caller will sent all the requested commands and their variables to the Web Service proxy and then waits. We also evaluated this implementation for the same cases with the first implementation and the measurements are shown in Table 5.5.

Without having installed the weather station, the evaluation of the framework was based on the time needed from submitting the selected command(s) to be sent to the station, until the indication that the commands were translated into SMS messages and were ready to be sent. When the web service caller was used the total time of all the calls needed to the web service was measured. If the Web interfaces, the Html Form, was used, the page with the information about the submitted command(s) has that indication of completion. This was shown in Figure 4.1, but in our measurement we omitted getting all the Html Form again, as in Figure 4.2.

The average time of the middleware overhead in the different kinds of commands when we choose one command in one SMS message is given in Table 5.3. The average time in the cases of one, two, three and four commands in one SMS message to the sensor is given in

Table 5.5: Middleware overhead measurements in different case of requests, in the Weather Station use case (for the *second type* of our implementation).

2nd set of Experiments (second implementation)	**Web Service calls locally** Average time in sec	**Web Interface, Web page - locally** Average time in sec	**Web Interface, Internet connection** Average time in sec
Simple Command in one SMS message	1.06	1.59	1.6
Two Commands in one SMS mess.	1.1	1.63	1.64
Three Commands in one SMS mess.	1.12	1.66	1.68
Four Commands in one SMS mess.	1.13	1.69	1.71

Table 5.4, for the first implementation. Moreover, there is the distinction in two columns in order to measure the total time when the user interfaces were used. These interfaces can be used though the Web page and the use of the servlet calling the Web Service or when the middleware was accessed without the interface. Without the interface means through command prompt, using a Java file that has the role of a client that calls the Web Service (the WS-Caller). So, there are two columns of the average time in the Table 5.3 and Table 5.4 for the cases of accessing through the user interface and simple Web Service call and also a third column with the measurements of the overhead when the use of the user interface is made through a different client - computer connecting the proxy server via an Internet connection. These are the measurements in our first implementation type and those multiple web service calls lead to interaction time from 1 to 4.3 seconds, in simple web service calls; and 1.5 to 6.5 seconds, through the Web User interface (locally). Using the second implementation type the average time in the different case are summarized in Table 5.5. The average time for web service call, in this implementation, is 1.1 seconds; and through the Web User interface from 1.59 to 1.72 seconds are needed.

For the third set of experiments (Table 5.6):

i The number of requested commands in one SMS message varies as follows:

- Requesting a simple command to be sent in one SMS message.
- Requesting two commands to be sent in one SMS message.

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Table 5.6: Middleware overhead measurements in different case of requests, in the Weather Station use case, for our implementations with different sizes of description files (10 commands and 50 commands).

3rd set of Experiments	**Web Service call** Average time in sec 1st / 2nd implementation	**User Interface, locally** Average time in sec 1st / 2nd implementation
Simple Command in one SMS message		
10 Comm. Description:	1.12 / 1.13	1.64 / 1.64
50 Comm. Description:	1.15 / 1.16	1.67 / 1.68
Two Commands in one SMS message		
10 Comm. Description:	2.23 / 1.16	3.3 / 1.65
50 Comm. Description:	2.29 / 1.16	3.25 / 1.70
Three Commands in one SMS message		
10 Comm. Description:	3.35 / 1.18	4.93 / 1.67
50 Comm. Description:	3.4 / 1.19	4.9 / 1.73
Five Commands in one SMS message		
10 Comm. Description:	5.6 / 1.2	8.14 / 1.72
50 Comm. Description:	5.61 / 1.22	8.1 / 1.79

- Requesting three commands to be sent in one SMS message.
- Requesting five commands to be sent in one SMS message.

ii The complexity of the command varies as in the first set and in our measurement we have the average time of the different cases.

iii Same as in the second set of experiments: we used both the two implementations, we make use Web Services calls, the Web Interface (locally).

iv We used two MSCD files, one with 10 commands and one with 50 commands described.

In the last set of experiments we compare our two implementations with the number of commands described in the MSCD file. Table 5.6 shows the average times. In this table four cases of experiments in our implementations are measured for the 10-commands description

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file and the 50-commands description file. The different approach in the types of implementation, as described, is mapped in the code of the WS-Caller as cases of 'if' statements. In the first type of implementation it is one 'if else-if' case that stops when the suitable command is found, then the web service call can be made. In the second type there are many 'if' cases checking each command in the set of commands that was requested. In both implementations there are 10 or 50 clauses (if cases) for the 10-command or 50-command descriptions given. When the requested command is found in the first type of implementation one call is made and the execution continues. In the second implementation, where a set of commands is requested, we have to pass through all of them and call the web service when we have a match. That's why in the first type of implementation we have many calls with preparation time that varies for call to call (finding one case) and in the second type we have one call with preparation time that is about the same (checking all the cases).

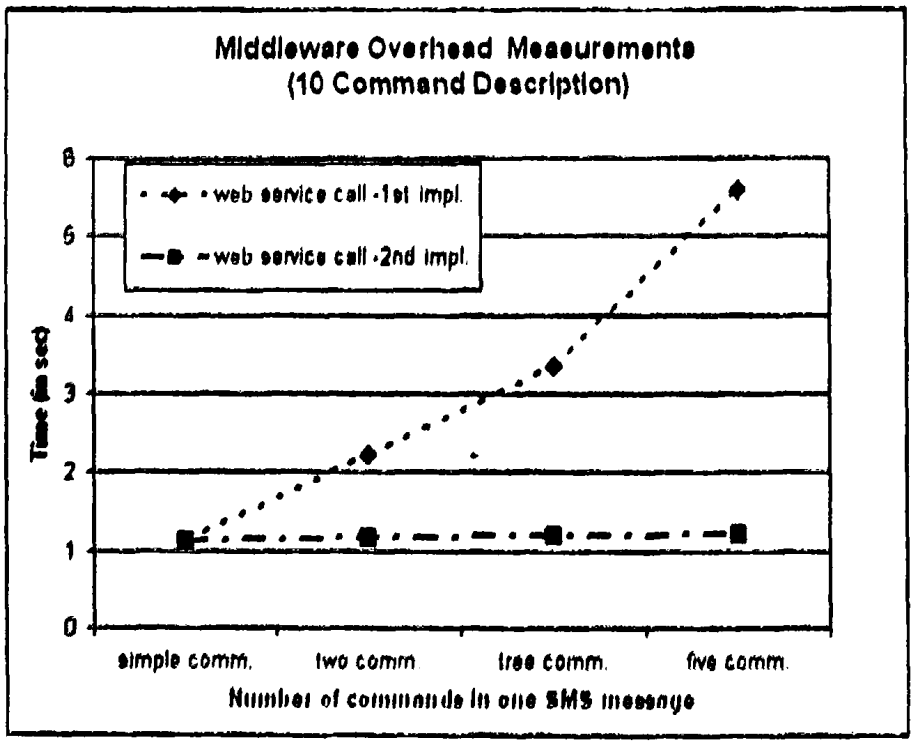

Figure 5.2: Middleware Overhead Measurements, for 10 Commands description file

Table 5.6 shows how parameters like the type of implementation, the number of commands in the description file, the number of requested commands in the same SMS message and the use of Web Service call or the user interface affects the measured middleware overhead. In particular, the Web interfaces costs half a second for every web service call, approximately. In the case of simple commands it is the same for the implementations and in the other cases

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the first type of implementation has two, tree and five web service calls which add 1, 1.5 and 2.5 seconds, in average, to the user interface overhead. In the second implementation, with only one web service call, there is only half a second additional overhead time. This amount of time can be increased in cases of slower connects, when for instance, we measured the time through an Internet connection. Moreover, between the first and the second implementation the cases of two, tree and five commands in one SMS message the needed time doubles, triples and is almost multiplied by five in the first implementation. In the second one some additional milliseconds are added. The amount of these milliseconds depends on the connection of the machine running the web service caller and the proxy server. In our measurements, this amount is 20 to 30 msec because they are running in the same computer. The case of 50 commands description file follows the same rule, doubles, triples and multiples by five (in average, in the first type) and has some additional milliseconds (in the second type). There is also additional time between 10 commands description and 50 commands description case and hence, the time that is multiplied in the first type is increased. Finally, we can assume the differences in the overhead in the two types of implementation would become smaller as the number of commands described in the customization file increases and the commands became more complex. In other words, as the number of commands and the complexity of them increases the overhead for the second type of implementation will be similar with the overhead for the first one. A faster connection will decrease the overhead of the web service calls, needed in the first implementation, even more. This is shown in Table 5.6 comparing 10 to 50 commands description files and would be even clear in 10 to 100 commands comparison and more complex in terms of parameters and variables.

Figure 5.2 shows the middleware overhead measurements for 10 command description file when web service calls are used. In the figure we measure the first and second implementation in the cases of different number of commands in one SMS message. Figure 5.3 shows the same measurements for 50 command description file when the Web interface is used.

To conclude, in the case of the Autonomous Weather Station, someone can use the web interface or just call a web service requesting data or changing a sensor parameter (e.g. the wind speed measuring units) with a control message. The time for this use case and the overhead in the user requests was measured and detailed in the related tables and figures (from Table 5.3 to Table 5.6 and in Figure 5.2 and Figure 5.3) for two different implementations. Cases of different kind and number of commands requested was also measured. A couple of seconds are enough for the translation of the user requests into SMS messages. The overhead

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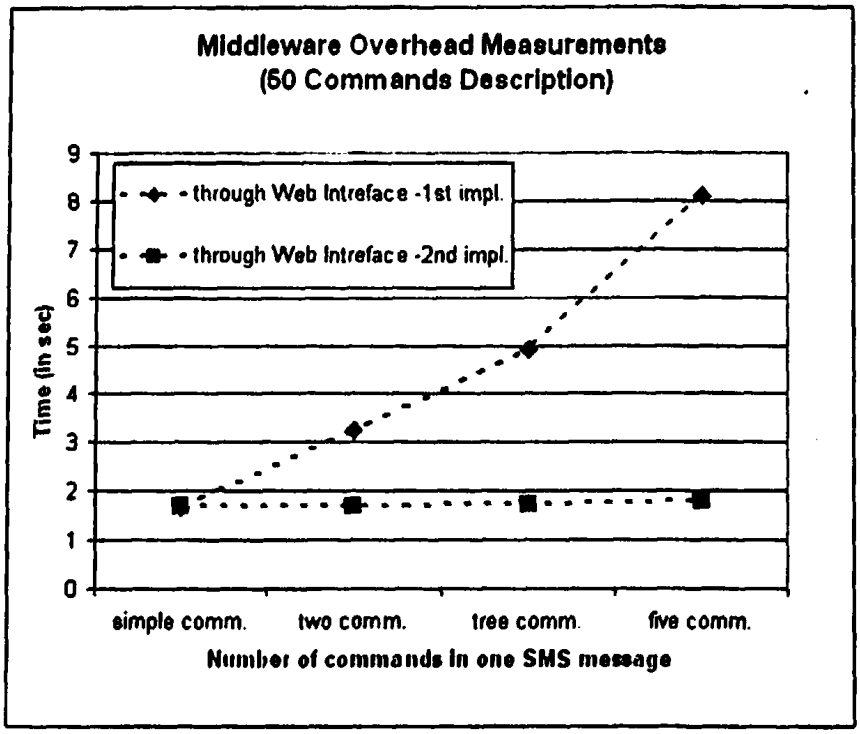

Figure 5.3: Middleware Overhead Measurements, for 50 Commands description file

increases only with less than a second, approximately, for a Web Service call when the user interface is used, with the web page and the servlet. In addition, the two implementations can lead to different overhead when multiple commands are sent to the station. Future work with distribution in the middleware would lead to the use of the first implementation, because of the great overhead in the tested system architecture.

5.3 Middleware Overhead in the Camera Use Case

We performed experiments for determining the average response time for the framework instance of Section 4.2 for common query requests in various configurations. The query experiments performed were the following:

(i) Requesting image and temperature with image resolution (a) default (b) high and (c) compact. The request is issued through the WEB-based interface and the results are delivered on a Web page. Those are the first two protocols that were described in Section 4.2.2, with the only difference that in the second one, with change of the resolution mode, an e-mail address was used for delivery. In this case for the evaluation

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Table 5.7: Response time and middleware overhead for experiment (i).

Type of experiment	Average preparation time for sending message(s) (in sec)	Overall response time average (in sec)
Image with default resolution and temperature at web page	15.6	66.1
Image with high resolution and temperature at web page (two SMS messages)	13.3 (1st SMS) 22.7 (2nd SMS)	150.6
Image with compact resolution and temperature at web page (two SMS messages)	14 (1st SMS) 25.4 (2nd SMS)	77.2

an e-mail address is also used, but then the message is unpacked and a new page is created, as requested.

(ii) Requesting temperature only through the WEB-based interface. The results are delivered by SMS to a mobile phone (note that even in that case a WEB page is created). This is the third protocol of the Section 4.2.2.

(iii) The queries of experiment (i) and (ii) submitted through the WAP-based interface. Here the request of image and temperature as in (i) though the Wap interfaces is similar to the forth scenario of Section 4.2.2.

Specifically, for the above scenarios we measured the average preparation time required by the server proxy for sending the SMS messages to the camera and the overall response time (measured from the moment that the user presses the submit button in the HTML or the WAP form, until the moment that he/she receives the corresponding results). Roughly, the average preparation time is the overhead introduced by the proposed middleware framework.

For the first experiment the results are shown in Table 5.7. For the default resolution the query protocol comprises a single SMS request message. The average response time was 66.1 sec with a standard deviation of 18 sec. When the resolution is set to high or compact an additional SMS request message is required in the query protocol so as to appropriately set up the corresponding quality attribute of the mobile camera. The need for this additional message almost doubles the overall response time. For the second experiment the results are illustrated in Table 5.8. In this case, a results page is created with image and temperature info. Subsequently, the temperature info is extracted from the page and an SMS message is

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Table 5.8: Response time and middleware overhead for experiment (ii).

Type of experiment	Average preparation time for message sending (in sec)	Overall response time average (in sec)
Getting temperature at the mobile phone	14.2	107.6

sent to the user's mobile phone with the temperature info only. The average time is 107.6 sec with 15 sec standard deviation. Here, it is important to mention a detail in the middleware that affects the overhead and the above deviation, this detail has to do with a log file that is accessed and update when a request is submitted. This is an add-on feature in the middleware and the size of this file can vary as it is updated or deleted manually. The deviation can be effected not only by the load on the server, but also from keeping this log file updated.

Table 5.9: Response time and middleware overhead for experiment (iii).

Type of experiments	Average response time for WAP access (in sec)
Getting image and temperature at the web page	42.5
Getting temperature at a mobile phone	71
Getting temperature at the same mobile phone (in the Wap Browser)	68

Finally, Table 5.9 presents the results for the last experiment, i.e. accessing the camera from the WAP interface to get (a) image and temperature (with default resolution), delivered in a WEB page, (b) just temperature, delivered to a mobile phone and an extra experiment (c) get temperature to the same Wap Browser.

Figure 5.4 and Figure 5.5 summarize our results. Specifically, the overall response time is divided into the time required for the preparation of the SMS request messages at the proxy server (vertical lines)and the time required for the preparation and the delivery of the MMS reply from the camera to the client or to the WEB page proxy (gray). Observe that the processing time introduced by our framework at the proxy server is almost the same in every experiment. The remaining overhead depends on the network latency. The large standard

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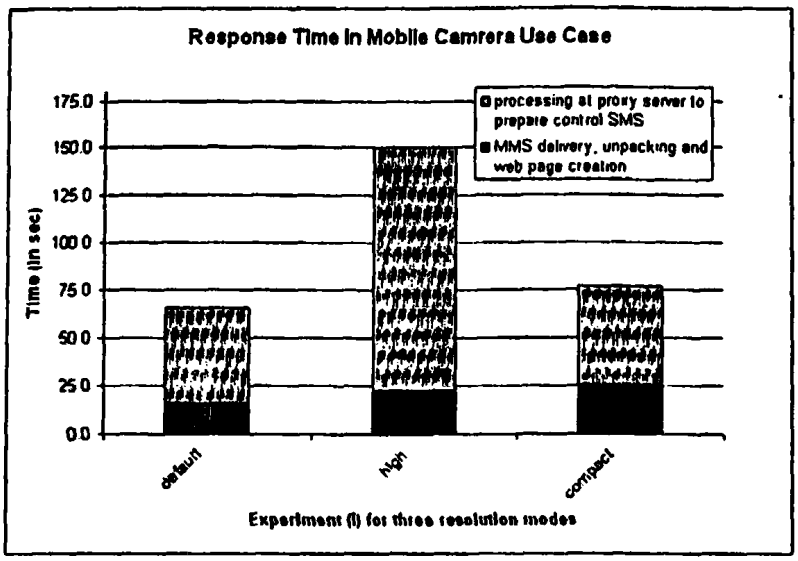

Figure 5.4: Breakdown of overall response time for experiment (i)

deviation is due to the GSM/GPRS network traffic and communication parameters. In the case of multiple user requests at the same proxy server the response time could increase significantly. To resolve this bottleneck we may use more than one proxy servers and/or multiple sensors at the same point.

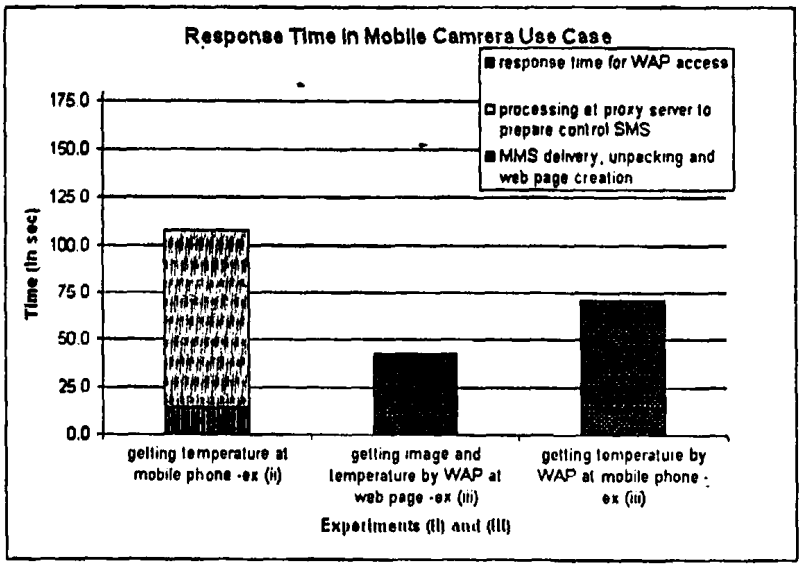

Figure 5.5: Breakdown of overall response time for experiment (ii) and (iii)

To conclude, the mobile camera can deliver the requested data to an e-mail address, a mobile phone number or to a new web page, created for this case. The overhead that was

measured from 15 to 25 seconds depending on the number of control SMS messages needed for user request (in our case one or two messages were needed). The information was delivered after a little more that a minute after the submission of a request with the exception of the request of a high resolution image that could double the time.

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CHAPTER 6

CONCLUSIONS AND FUTURE WORK

Wireless Sensor Networks is a new area of research and development. Wireless sensor networks consist of hundreds of sensing devices embedded into the environment that measure and communicate wirelessly environmental data. Through the use of Wireless Sensor Networks the vision of Embedded Internet becomes reality and different aspects of this vision can be focused. Translating this vision into reality includes design and development of applications, hardware and software systems, algorithms for gathering and analyzing information and methods for robust and secure operations. Moreover, in a distributed and heterogeneous system of sensors middleware framework is needed among the operating system and the applications or devices on each side of the system. Our goal in this thesis was to integrate a specific category of sensors -GSM enabled sensors- in a global computing environment built on top of the World-Wide Web. We proposed a customizable middleware framework that enables uniform access to mobile sensors.

According to the sensor protocols, which involve the exchange of SMS and MMS messages, we introduced a mobile sensor description to configure the middleware. Starting from a general XML Schema for the description, we demonstrated examples of mobile sensor customization using a proposed Mobile Sensor Control Description (MSCD) XML file. The customization process is based on creating the proxy servers and the interfaces of the middleware according to MSCD files.

We have detailed two sensors: a GSM-based Autonomous Weather Station and a Mobile Observation Camera. We have performance experiments for determining the customization time of the framework from different MSCD files and the middleware time overhead in the

cases of the weather station and the mobile camera. In the case of the weather station we evaluated different cases of requests in two implementations and for the mobile camera we measured the whole process of requesting and delivering data (image and temperature) according to the interaction protocols that were detailed.

Future work may include different kinds of sensors, for example sensors that use different communication protocols (like WiFi based on the IEEE 802.11) and sensors that send streams of data. The middleware can be made more distributed, as different parts of the architecture can be in a local network. There are many choices regarding the implementation and the position of the proxy servers, the web interfaces This fact leads to a variety of solutions and latencies, and this is the reason that different implementation and distribution can be an interesting aspect to be discussed, materialized and evaluated in future work. Finally, we can evaluate the performance of the middleware in more complex scenarios where multiple users simultaneously request data from sensors.

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APPENDIX

Description of the basic tags in the MSCD XML file

The basic elements of an XML file that describes a mobile sensor are:

i `init`, a group of `initialization` elements that describes different cases of initialization processes for the mobile sensor, for instance when we select a name for the sensor device or we set the phone number of the administration user,

ii `info`, a group of `infoRequest` elements that describes different cases of requesting information from the sensor, for instance when we request weather measurements from the weather station, and

iii `end-user`, a group of `end-user_description` elements that includes different cases of frequently used interactions with the sensor (as shown in the case of the mobile camera).

The first two elements include `initialization` and `infoRequest` tags specifying messages that will be sent. For this case we use the tag `message` which contains a `messageType` tag. The messageType contains SMS or MMS tag (usually SMS for the requests) with the `body` and the `messageVar` (with choices or variables) elements and optionally, when it is needed, a sender and a receiver. In the `messageVar` there can be different choices or variables. For each `choice`, the `choiceDescription`, the `choiceValue`, and the `choiceValueDescr` elements can be specified. For each `variable`, the `variableName` and the `variableDescription` elements can be used. An example is shown in Figure 1 of the Appendix. Additionally, there can be further information about the delivery message, an alternative body of the message, a url link with helping information, etc.

In the case of end-user the frequently used interactions are specified using the above tags. In addition within the `infoRequest` elements there may be `subtypes` elements, for the cases

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```
+ <!--  -->
- <infoRequest>
  - <message>
      <description>Enables (ON) or Disables (OFF) the generation of an Alert SMS</description>
    - <messageType>
      - <SMS>
          <body>#ALRstatus</body>
          <order>0</order>
          <altemBody>#ALR status</altemBody>
        - <messageVar>
          - <choices>
              <choiceDescription>changes status or gets current status (for generation of an Alert SMS)
                </choiceDescription>
              <choiceName>status</choiceName>
              <choiceValue>ON</choiceValue>
              <choiceValueDescr>enable</choiceValueDescr>
              <choiceValue>OFF</choiceValue>
              <choiceValueDescr>disable</choiceValueDescr>
              <choiceValue>?</choiceValue>
              <choiceValueDescr>get status</choiceValueDescr>
            </choices>
          </messageVar>
        </SMS>
      </messageType>
    </message>
  </infoRequest>
- <infoRequest>
  - <message>
      <description>NO Acknowledgment: inhibits SMS acknowledgment</description>
    - <messageType>
      - <SMS>
          <body>#NOA</body>
          <altemBody />
          <order>0</order>
          <messageVar />
        </SMS>
      </messageType>
    </message>
  </infoRequest>
- <infoRequest>
  - <message>
      <description>Sets the GSM Telephone numbers ( up to 8) to which alarms will be sent (get telephone)
        </description>
    - <messageType>
      - <SMS>
          <body>#TELxttttttttttttttt</body>
          <order>0</order>
          <altemBody>#TEL?</altemBody>
        - <messageVar>
          + <choices>
          - <variable>
              <variableName>ttttttttttttt</variableName>
              <varDescription>the telephone number, maximum 15 digits including a +, ? the selected
                Telephone number</varDescription>
            </variable>
          </messageVar>
        </SMS>
      </messageType>
    </message>
    <html_info>http://www.dpspro.com/tcs_commands/tcs35_tel.html</html_info>
  </infoRequest>
```

Figure 1: Part of the GSM Autonomous Weather Station description file.

that the request for information has optional characteristics that can be chosen, for instance when we can select the resolution of an image and then request for the image from the camera.

Figure 1 shows a part of the MCSD file in the cases of the GSM Weather Station that was presented in Section 2.2.4.

ΠΑΝΕΠΙΣΤΗΜΙΑΚΗ ΒΙΒΛΙΟΘΗΚΗ ΙΩΑΝΝΙΝΩΝ

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SHORT CV

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Zissis K. Plitsis received his Diploma in Electrical and Computer Engineering from the Polytechnic School of Aristotle University of Thessaloniki, Greece in 2003. He has been a MSc degree student in the Department of Computer Science in the University of Ioannina since November 2003. He has worked in ITI (Informatics and Telematics Institute) in Thessaloniki during his thesis on Software Agent Techniques in Learning Environments under the supervision of Prof. Michael G. Strintzis and Prof. Demetrios Sampson. Zissis has been a student member of the IEEE (Aristotle University IEEE Student Branch) and he is a member of the Technical Chamber of Greece since 2004.

Recently, Zissis has joined the army and will be serving in the Hellenic Navy until August 2007.

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