Gateway between sensor networks and an instant messaging system

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Abstract—This work is focused on sensor networks and aims to create a system able to monitor and command them through an Instant Messaging system. Currently there are multiple sensor technologies, developed by different manufacturers, which are incompatible at the application level. These networks are typically developed on low-resource platforms, leading to solutions designed specifically to each case, to provide the desired levels of functionality and performance. The lack of uniformity is a barrier to the development of this area and hinders the development of generic tools able to access and control any type of network.

This dissertation seeks to overcome the limitations described, by adopting the DomoBus model that hides the sensor networks’ peculiarities, and using a gateway that allows its integration with a system that exchanges text messages in real-time among multiple users (instant messaging).

The Domobus technology is based on a device’s type abstraction that allows the control of a generic sensor network and provides mechanisms flexible enough to enable an easy development of applications adaptable to the needs of each end-user. Using an instant messaging system allows a simple interaction with sensor and actuator networks. The adopted solution is based on the XMPP standard, allowing remote monitoring and control of these networks using different kinds of hardware and operating systems and avoiding the need to install specific applications, as it can be used through a common browser. All the information processing is done by the gateway developed in this work.


I. INTRODUCTION

Sensor networks brought significant improvements to building administration, or any other space they are built in. These improvements can be noticed in several areas, such as security, with motion sensors usually built in alarms, and gas, fire and flood detectors. Energy consumption can also be reduced with presence detectors managing lights, thermostats controlling heat and air conditioning systems, which also allow an increase in comfort enabling a remote administration of the environments where the sensors are placed in. Several types of sensors and actuators are illustrated in figure 1.

These devices have emerged based on different technologies. This diversity does not contemplate compatibility between each other, jeopardizing possible advances in a common centralized monitoring and control of these networks. The existing systems that allow some centralized management have low cost/benefit relationships and are difficult to use and to install. These factors caused a lower demand for these technologies than it would be expected considering their potential. Some approaches have been attempted that standardize the low-level communication of devices.

In order to create a system capable of monitoring and controlling a complete sensor network Prof. Renato Nunes developed the DomoBus system. This is a generic solution, open and independent of any technology that offers an infrastructure for communication that simplifies application
development. To that end it includes, among other things, a communication library – CommAPI – and a directory service – CommDir – that simplifies development of applications that communicate with each other, allowing mixed solutions involving multiple sensor technologies. This gives the possibility to offer more flexible and powerful solutions to adapt to the end user, where he has the opportunity to set them up and no longer need qualified technical support. The Domobus technology is based on a device’s type abstraction model that allows to control a sensor network and provides mechanisms flexible enough to enable an easy development of applications adaptable to the needs of each end-user. DomoBus offers also a communication infrastructure that allows an easy interaction between multiple applications and allows the access to different technologies through appropriate gateways. This system aims to support the development of high-level applications that provide the possibility to monitor and define the behavior of the system, interact with the user and enable remote access over the internet.

This paper presents an application that acts as a gateway between the DomoBus system and an Instant Messaging (IM) system, through the XMPP protocol. Over the years IM systems have increased their users and grown as a basic means of communication, through text messages exchange in real time. With this work, monitoring a sensor network can be done anywhere and with any device with internet access, using a browser. It will be no longer necessary to install specific applications to communicate with these systems and the compatibility problems with installing applications in different OS cease to exist. 

This paper is divided into four sections. Section two intends to frame the present study within developments made in this topic’s related areas. Once this framework is made up, in section three is given a description of the proposed solution focusing on the architecture and operation of the gateway developed. Finally, section five presents the conclusions, and also suggestions for possible future improvements of the proposed solution.

II. STATE OF THE ART

A. Sensor Networks

A sensor network consists of a wide number of sensor nodes that are placed on the physical space where the phenomenon is to be observed, or very near it. Some of the application areas of sensor networks are health, military, environment monitoring, housing, buildings, bridges, industrial plants. A sensor can be described, in general, as a device that converts a physical quantity in a digital value which is sent through messages. There is a wide range of sensor types, like motion, temperature, smoke, gas, water, pressure, humidity, vibration, magnetic field, various types of radiation, among others. Within the various types there are different technologies associated with sensors, such as infrared, microwave, photoelectric, ionization, photo-ionization, magnetic, electrical conductivity and ultrasound.

As it is referenced in [1], sensor nodes are usually scattered in a sensor field, figure 2. Each node disposed in the field has the capacity to collect and send data to the sink (it works as a container that collects data from all sensors). The sink can then communicate with the Task Manager Node, through a communication channel such as the Internet or satellite. The establishment of a network of sensors is influenced by several factors such as fault tolerance, scalability, production costs, operating environment, network topology of sensors, hardware limitations, means of transmission and power consumption. These factors are important because they serve as guidance for the construction of a protocol or algorithm for a network of sensors.

**Figure 2 – Sensor Nodes Disposed in a Sensor Field [1]**

Fault tolerance – Nodes’ failures should not cause an interruption in the overall operation of a sensor network. Fault tolerance is its capacity to sustain the operation of a sensor network without any interruption in the operation of it due to failure of some sensor nodes inserted in it.

Hardware Limitations - There are some requirements that may be somewhat limiting for sensor nodes. They must consume very little power, have a very low production cost, be dispensable and autonomous, operate without any type of scrutiny and be adaptable to the environment they are placed. Depending on the application's requirements some may be less relevant.

Sensor Network Topology – A wireless sensor network (WSN) can have different topologies. Some are represented in Figure 3, where the topologies include star, ring, bus, tree, and fully connected network. In a field of sensors there are among hundreds and thousands of nodes. They are placed several hundred meters apart from each other [4], and the density of nodes could reach 20 nodes/m$^3$ [6], which requires maintenance of the network topology.
with more than one service. It is possible to interact with the sensor network in different ways. For example the Services class allows to group device belonging to the lighting system or all devices that are in Zone 1.

In the DomoBus model each device is defined by a set of properties, each with a given value. With this model, the devices of a sensor network can be grouped into classes, allowing different ways to interact with the network. This enables to request a listing of, for example, all devices that belong to the lighting system or all devices that are in Zone 1. It is possible to interact with the sensor network in different ways. For example the Services class allows to group device types that share a functional relationship. In addition devices may posses more than one property and also be associated with more than one service.

The level of Monitoring and Control is mainly composed of control modules (CM) connected by a network, allowing them to interact and communicate with each other [12]. CM’s are boards with microprocessors that connect directly to switches, temperature sensors, infrared sensors and other input devices. These control electrical devices. Current CM’s are quite flexible, since they use micro controllers that include code, data memory and various peripherals for timing and communication purposes. Each CM has a transmitter (EIA-485) and interfaces for reading switches and other input devices, being able to run different applications and therefore perform different functions. Thus, a home automation solution through this system may become economically more advantageous, allowing a CM to control various devices, whereas in other existing home automation systems a module is typically connected to only one device. The Supervision Module (SM) belongs to the Management and Supervision level and is responsible for the administration and command of the global system. A SM receives information from the CMs and, in accordance with pre-established rules, process the information received and send the appropriate responses and commands to the CMs. A system can include several SM’s depending on the number of devices that comprise the network. A small network can contain only one SM, but in the case of a network of large scale, there may be several SM’s.

In a DomoBus network physical devices are addressed using 16-bit, where the 12 most significant bits identify the control application and the last 4 bits identify the device managed by this application. The identification of the control application can be interpreted as having a hierarchical structure in which the four most significant bits identify a network segment (allowing a maximum of 16 segments), the following 5 bits identify a node located in this segment (with a maximum of 32 nodes per segment) and the three least significant bits identify a task within a node (there can be up to 8 tasks). Each task controls up to 16 devices (identified by 4 bits).

The addresses at the Management and Supervision level uses 32 bits – the 16 most significant bits are used to identify applications for management, supervision and gateways, and the 16 least significant bits are used to address physical devices, as previously stated.

B. DomoBus

The DomoBus System was developed by Professor Renato Nunes in order to overcome difficulties in trying to use different products for testing purposes. DomoBus consists in a home automation approach that operates at two levels: 1) Management and Supervision, using a flexible approach that allows inter-operation between different technologies; 2) Monitoring and Control, with direct interface with the physical environment through suitable sensors and actuators.

DomoBus allows interaction with a sensor network in a common and flexible way, as it uses a generic model to represent any device. It is intended that this representation is as simple as possible, but enough to describe the core capabilities of a device and be independent of its technology. [9]. Although created initially with home automation systems in mind, it can be adapted to other sensor and actuator networks, as mentioned above.

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C. Instant Messaging

IM has emerged as a generic application being AOL the pioneer in the early 90s. In 1996 Buddy List, owned by AOL, and ICQ (I Seek You) made IM a phenomenon of popularity. Today it is used by millions of users and has a large number of protocols being the most popular and most used Microsoft Messenger, Yahoo Messenger, Google Talk, ICQ, Internet Relay Chat (IRC) and Skype. IM, as the name indicates, is an instant messenger service. This service allows two or more users to exchange messages in real time, between them, which was not possible with e-mail. The connection to these services can be peer-to-peer or through a server. The most common connection is through a server due to the fact that the connection through a server requires less computer knowledge, being a fairly simple process for the average computer user.

A client is an application used to make a connection to the desired protocol. Each application has its own protocols provided by the creators of that protocol. Some clients allow connections to different protocols, and some may allow connections to more than one account of the same protocol as to accounts of various protocols simultaneously.

There are several protocols implemented for the use of IM. For choosing the protocol to use in this work some features...
were considered, such as its complexity, being proprietary or public, as well as knowing if once implemented, it is simple to use and have an idea of the number of users, which may make the protocol a viable option or not. The protocols with larger number of users and which have received more attention were the Internet Relay Chat (IRC), OSCAR protocol, Yahoo Messenger (YMSG), Microsoft Notification Protocol (MSN), Skype Protocol and Extensible Messaging and Presence Protocol (XMPP). Since a major goal is that there may be communication with the sensor network from any computer connected to the internet without having to install any application, this is a possible exclusion factor. However, it is possible to connect to any of these protocols through a web browser so none were excluded for this reason.

All analyzed protocols can be used from any location, just needing an internet connection and a browser, no need to install any application or use a specific operating system for that purpose. However, only one of these protocols is open source, allowing anyone who wants to create an application and / or running an own server, if it is their wishes. The XMPP protocol provides all the features necessary for this work allowing future developments in monitoring and control of sensor networks. In the case of IM from Google, which uses XMPP, the protocol is used integrated with the e-mail allowing a different approach to the notification service as it is always active0. Given the characteristics shown, our choice went on using the XMPP protocol to develop the gateway.

III. DESCRIPTION OF THE SOLUTION

IM is a system that has had a huge growth in the last two decades both in terms of users and available applications and protocols. This system provides communication between users via text messaging, quite simple and in real time.

The DomoBus system provides a versatile, simple and powerful interaction with any sensor network, taking advantage of its abstraction model for devices. So far in order to monitor or act on a sensor network that uses the DomoBus system was necessary to install a specific application in the device the user was trying to access the network.

The aim of this work is to make use of these two technologies in order to allow any user to monitor and act on a DomoBus a network from any location through the XMPP protocol with no need to install any type of application. In addition the IM system also offers the advantage of being able to establish a connection from any operating system. The application was developed in C#.

A. Architecture

The gateway application connects to the IM system and to the DomoBus system using a directory service called CommDir. Once established the connections, the application starts listening to incoming messages from either system. The first incoming message from the IM system will generate an automatic response to indicate how to access the main menu with the available options. The user can then navigate the menus in order to reach the desired device and act on it. Once the desired action is chosen, the application will contact the DomoBus network to perform that action. Figure 4 is an outline of the presented solution.

![Figure 4 - Gateway between a Sensor Network and an IM system](image)

B. Basic Features

These are some of the basic features necessary for an interaction between a user and the DomoBus system. As already mentioned, the XMPP protocol is open source. A C# library was used available at the protocol’s official website. Some example applications were also available and were analysed to understand how the connection and basic features of the IM system work. The first feature to be implemented was the connection to the server. It was decided not to include the option to add or accept new users, as it is not an essential feature in implementing this solution, thus is necessary to make it directly in the server of the account used by the gateway. To establish a connection, the user must have a registered account in one of the IM services that use this protocol. This application has automatic server resolution. Once the connection is established a first check to the entire user's contact list is performed by filling up this list in the main window with an updated user status. The application then starts listening to new messages.

It is intended that this application performs the basic functions of an IM system for communication between users. The interaction with the system is made through written messages in real time. The system is prepared to receive messages from anyone who is in the contact list automatically replying with the corresponding menus. Some difficulties were found in implementing this automated reply. Initially, after a few exchanged messages between the application and the user, responses sent by the application returned an error message from the server. After running several tests it was found that the error was due to a server’s security measure that prevents large amounts of messages sent immediately after a received message. To avoid this, a function that waits a random amount
of time, of just a few seconds, was created to send replies to the user.

As mentioned earlier, the connection to the DomoBus system is done using a directory service named CommDir. At this time, and to simplify system tests, the gateway does not connect directly to a network of sensors but to a simulator that exchange messages according to the DomoBus logic. CommDir was created to allow greater versatility in communications between the DomoBus network and applications that make use of it. Every DomoBus application wishing to exchange information needs to register in this directory service. To register, the IP address and port of CommDir must be known. When connecting a DomoBus address is chosen to exchange information and is sent to all applications already registered. The messages exchanged subsequently don't pass through this service, thus it is used only for registration and to inform how to reach other applications in the system.

The communications infrastructure used corresponds to the latest update made to date, bringing more stability and reliability to the system. The connection to CommDir is via the User Datagram Protocol (UDP). To establish this connection an existing tool was integrated which allows the exchange of messages with the DomoBus network. This tool is permanently listening for incoming messages from the network, used by the notification system implemented in this solution.

Once established all the connections, the communication between the IM system and the network of sensors becomes possible. There are two ways to interact with a selected device – request the current status of a particular property or change its status. Depending on the desired action the corresponding function is invoked - GET to request the current status and SET to change its value - sending the request to the network and giving an answer to the user about the status of his request, again through the IM service.

To access the sensor network, a user must necessarily be in the contact list of the account that is connected in the gateway, representing the first security level of network access. There is a second security level that is represented as the access level for each user. In the XML file describing the sensor network, which represents all the devices that constitute it, there is a field in each device defined as the access level to the device, and for a user to access this device must have an access level equal or higher than the device’s. User access levels are stored in an XML file containing information about the gateway’s contacts list. By default the level is 0, reaching a maximum value of 10. Users’ access level must be changed at the gateway application.

To describe the sensor network, there are two XML files - House.xml and DomoticSystem.xml. One contains the characteristics of the network, such as existing device types, property types and value types associated with each property. The other describes the devices in the network as well as the different categories in which they are grouped, such as departments, divisions and floors. This way of describing the network makes this service quite versatile as the loading of these XML files is dynamic allowing the network’s configuration to easily fit the needs of any user. This description of the system is also, as the list of users, loaded into memory at the time of connection. The information in XML files allows an easy mapping between the DomoBus addresses of the devices and the names the user wants them to be shown with.

C. Favorites and Notifications

Two additional functions were implemented making the interaction with the network easier and more effective with the needs of each user. A user may choose to be notified whenever certain property of a given device changes according to the values of its choice. For example, a user can choose to be notified every time the temperature of a room goes under 20 °C or every time the main door of his factory is opened, not needing to constantly check the values of these devices’ properties. It is also possible for a user to have a favorites list of devices, allowing, if it is connected to a network that has a high number of sensors, to navigate in quickly between devices he interacts more often. This feature is presented to the user whenever a device is chosen.

D. Menu Structure

The aim of this work is not only making possible to interact with a network that uses the DomoBus system with no need to install any application fit for the purpose, but also making the interaction process as simple as possible. An intuitive navigation system based on menus was choosen, as described below. The menu structure was created on the assumption that a device can be accessed in several ways. One corresponds to a direct access to the device from a complete list of devices in the network. Alternatively, the devices can be grouped into categories, such as services, floors, rooms or areas. This process of accessing the network through menus, which is intended to be intuitive and flexible, is automatically generated reading the XML files that have all the information about the system. This means that the menus are generated dynamically and are adaptable to multiple networks with different amounts of devices, divisions, floors and services. When a user wants to interact with the network selects the gateway’s user from his contacts list and starts a conversation. When the gateway receives a message from user for the first time, creates a menu for this user maintaining the context of their interaction over time. To access the main menu the user only needs to send a text message with "h" or "H" getting as an answer the first menu. Menu options are presented on separate lines, preceded by a number that identifies them. To select the desired option the user needs to send a text message with the respective number, and the gateway will display the next menu. All menus follow this model. If a user wishes to return to the main menu, you can do so at any time by simply sending a text message with the "h" or "H". Given the simplicity of the menus and since there are few levels for a user to navigate through a full menu cycle, there is the possibility to return from one menu, if a user wants to return
more than once, he has to call the main menu. To implement this navigation logic an object "MenuPrincipal" was created and is invoked when whenever there is an incoming IM message to analyze its content. Initially waits for a message containing the request to access the main menu, otherwise returns a message with instructions on how to access it. For each menu that appears the function that makes the evaluation is invoked and if it is a valid menu option the next menu is printed. Otherwise prints again the same menu. In Figure 3.4 there is a flow chart showing the operation of menus.

![Figure 5 – Menu Structure](image)

### IV. Conclusions

As noted in the present work, sensor networks have emerged in order to enable remote monitoring and control of almost any kind of devices. However, due to differences in used technologies, the management of these networks has been developed specifically by their manufacturers, and the compatibility between one another was compromised. As a natural consequence, the development of generic applications capable of a common centralized management of sensor networks that contain devices of different technologies was prejudiced. The solution presented in this work creates an opportunity to interact with a sensor network at any location requiring only a device that can access the Internet and has a browser or an application to exchange instant messages using the XMPP protocol, thus avoiding the need to install specific software on the terminal to use. This is an application that makes use of the DomoBus system, which offers a generic model that allows to read and write values on the properties of the most diverse range of devices that are equipped with sensors and / or actuators whatever its specific features are, presenting as an extremely powerful and versatile model. It includes a directory service, called CommDir, which is a communication infrastructure that simplifies development of applications that interact between one another. The developed gateway application translates every message that is exchanged with the Domobus network into a logical and intuitive menu system.

The application was developed in C# which is based on object oriented programming. The use of this programming language was the first obstacle encountered in the development. It is a language with which I had never had contact with and a type of programming which also had no previous knowledge. However, by consulting some books and websites I acquired some concepts that enabled to conduct the development.

Besides the possibility of managing a sensor network without the need of installing an application itself, the aim was also to enable communication with the network in a simple and intuitive way. This was achieved by using a menu system in which, to navigate through it, the user only needs to send written instant messages with the corresponding number of the chosen option. Some difficulties were encountered in responding to the user’s requests. After some messages exchanged the server began to return an error message. After some tests we came to the conclusion that the error was due to server’s prevention from messages sent always with the same time interval from the incoming messages, as the processing of user requests is extremely fast, the answers were all sent almost immediately. To overcome this difficulty a function that puts the program on hold for a random time – always of a few seconds only - had to be created.

A logical division of the network was created in order to enable the gateway to represent devices in the physical space where they are positioned or by the services they belong to. This solution brings an innovation in the way we can interact with sensor networks, particularly with the ones using the DomoBus system. This work allowed a quick and easy way to do it, with the possibility of incorporating new features in it. It is already possible to establish audio and video communications in IM, yet still isn’t possible to establish such connections with multiple users and video sources. The development of such features could be used to monitor a sensor network through Video surveillance systems, which would be a breakthrough for these types of systems. The versatility on processing menus and messages sent by users can create many other features. With the advances on technology it is increasingly becoming more usual to have space for storing data on Internet servers and this could be used to accommodate statistics on the behavior of several sensors on the network and thus, users with adequate permissions can access such data and use the available information.

### REFERENCES


