# KNX-Based Home Automation Systems for Android Mobile Devices

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***Abstract*—The adoption of smart environments is becoming more and more important in many applicative scenarios such as healthcare, asset management, environmental monitoring, and building automation. This last issue represents a very attractive use-case because of several scientific challenges that must be addressed in order to satisfy user requirements, which are mainly focused on the management of home's comfort parameters. The main goal of this work is to develop and validate an architecture, both hardware and software, able to monitor and manage a Konnex-based home automation system through an Android mobile device in an efficient and safe way. In this perspective, an Android application is realized based on a specific Java library, called Calimero, that provides several methods for interaction with the Konnex implant. Furthermore, a software system able to configure the Android application consistently with the home automation implant is designed and implemented. The proposed architecture was tested from both functional and performance point of view and the obtained results prove that it provides high performance in comparison with other solutions already affirmed on the market.**

***Keywords- KNX; Android; Smart Home; ETS; Test bed.***

## I. INTRODUCTION

The ability to sense environmental parameters is becoming more and more important in many applicative scenarios. This trend aims to spread smart environments able to capture, in a pervasive way, all useful information from the real world, contributing to assert the Internet of Things (IoT) concept. It refers to the extension of the Internet to the world of concrete objects and places, which can communicate data about themselves and access aggregated information from other objects or places. In this way, the Human-to-Machine (H2M) paradigm is increasingly moving toward the new Machine-to-Machine (M2M) paradigm, so leading to an improvement of several aspects in everyday life. In this context, cities management (Smart City), energy saving (Smart Energy), buildings and homes automation (Smart Building and Smart Home) are typical scenarios for the use of such technologies. Among these potential applications, home and building automation issues are particularly important, since they represent the link among the individual (city dweller, consumer) and abstraction layers allowing the adoption of the IoT paradigm.

Smart Home & Building applications are wide and varied since there are many fields where they can be applied. In addition to well-established solutions, there are various projects in experimental stage, which mainly concern the energy consumption and security management, implant maintenance, and environment management.

Another technological component, closely related to the automated home management, is represented by mobile devices. They are becoming more and more important in everyday life, since they are not only communication means, but also technological tools for controlling other devices. However, in the home automation field, the integration among the mobile world and home automation systems encounters several limits generally due to poorly user-friendly application, the inability to remotely control the home automation system, and the low security level in the data exchange between mobile device and home automation system.

Therefore, the aim of this work is to propose an automation system able to overcome these limits. The system allows the user to monitor and manage a home automation implant in a flexible, simple and safe way by providing a high level of abstraction of real devices. For this purpose, an architecture, able to combine the widespread Android Operating System (OS) and Konnex (KNX) standard [1], was designed and developed. The functional validation of the proposed architecture was carried out in collaboration with Gewiss S.p.A. company of Bergamo (Italy) [2], that is one of the most important vendors for building automation solutions. By exploiting this important industrial support, a real KNX system was configured in order to test the designed and implemented architecture. This functional validation showed that, through the proposed solution, it is possible to safely control each KNX device both locally and remotely and to monitor implant status anytime and anywhere thanks to the real-time feedbacks sent by the home automation system to Android device. The peculiar feature of the proposed application is that it can be downloaded from the Android market as "generic application", that means without any customization. Then, after the installation of the KNX implant, it can be consistently customized for the specific home automation system by using the output file provided by the Engineering Tool Software (ETS) [3].

Finally, a performance validation was carried out to demonstrate the effectiveness of the proposed architecture.

The paper is structured as follows. In Section II, the state of the art on KNX-based home automation systems and on techniques used for their management is summarized. In Section III, a technical overview of the main standards and software libraries used in this work is presented. In Section

IV, the proposed architecture is described and all its features are presented. The test environment used to validate the whole system is shown in Section V, whereas the functional and performance validation results are discussed in Section VI. Conclusions are drawn in Section VII.

## II. Related Work

In recent literature, the topic of smart environment is widely discussed, and particular attention is given to Home and Building Automation systems based on the KNX standard. This topic is addressed according to three main aspects: safety, congestion control, and energy saving in domestic implants. From the safety point of view, in [4], a technique to guarantee a secure data transmission for home and building automation networks is proposed and implemented in a KNX-based environment, which does not natively provide any security mechanism.

The congestion problem is addressed in [5] and [6]. In KNXnet/Internet Protocol (IP) systems this problem is due to the presence of a particular device, called KNXnet/IP router, that allows the integration of different KNX networks through an IP network. Since the bandwidth of a KNX network is limited, if the KNXnet/IP router receives more messages than it is able to send, it can represent a bottleneck in routing these messages to the KNX devices. For this reason, in [6], authors recommend the adoption of efficient forwarding rules in the implementation of KNXnet/IP routers.

The home energy consumption is a topic of interest for both researchers and consumers since it concerns the reduction of power consumption and the protection of the environment. In this context, in [7], a simulator of a household was developed and a strategy for the energy efficiency and user comfort based on neural networks was proposed and tested by using an experimental KNX-bus platform.

Beyond the aspects previously described, it is important to note that smart environments based on KNX standard are designed to improve the quality of people's lives by the creation of new systems able to control comfort parameters. To achieve this goal, the integration among wired and wireless networks is increasingly used. In [8], for example, the comfort into an office building is ensured by designing a KNX-based system joined with Wireless Sensor Network (WSN) [9][10] components able to monitor and control the lighting, heating and air ventilation. The use of a WSN provides the system with information about environment conditions allowing a better control of comfort parameters, with minimum energy consumption [11].

Another example of integration between a wireless technology and a KNX system is reported in [12], in which a ZigBee network, well suited to home automation, is integrated with the wired home automation system. A KNX/ZigBee gateway is proposed as an interface between KNX and ZigBee networks.

Finally, since the management of home automation systems is more and more entrusted to mobile devices, in [13], the design and implementation of an iPhone application that allows the integration of mobile devices in an existing KNX home automation system are presented. Similarly to this work, the Android market offers some applications, such as [14] and [15], which allow the management of a KNX-based implant through an Android device. However, such applications suffer some drawbacks particularly due to poor usability and a poor abstraction of real devices.

## III. Technical Overview

In this section, the main technologies used in the present work are briefly described.

### A. KNX

KNX is the worldwide standard for home and building control; it exploits a software tool, called ETS, for planning and designing implant of KNX-certified devices and for implementing interactions among these devices. Compared to conventional electrical installations, a smart control and automation system has clear benefits since all the different subsystems are integrated into the building, optimizing performance and energy efficiency by using the KNX bus.

The standard includes two different configuration modes for the home automation devices:

- System Mode (S-Mode) for well-trained KNX installers that want to realize sophisticated building control functions;
- Easy Mode (E-Mode), that provides limited functions compared to the S-Mode, and that it is intended for installers with basic KNX training.

The KNX standard allows each manufacturer to select the most ideal configuration mode and to choose the right combination for the target market segment and application.

### B. Android Operating System

Android is a mobile Operating System (OS) developed by Google. It is based on the open Linux kernel and it is open source, which means developers can modify and customize the OS for each phone. Therefore, different Android-based phones may have different Graphical User Interfaces (GUIs) even though they use the same OS. Android phones typically come with several built-in applications and also support third-party programs. Developers can create programs for Android (Apps) using the free Android Software Developer Kit (SDK). Android programs are written in Java and run through Google's "Davlik" virtual machine, which is optimized for mobile devices. Users can download Android applications from the online Android Market.

### C. Calimero

Calimero [16] is a Java library that enables the access to KNX systems. It consists of a collection of Java Application Programming Interfaces (APIs) fundamental for workstation-based KNX/European Installation Bus (EIB) applications. Still, these APIs can be used independently and their ease of use enables client applications to communicate with KNX devices hiding network protocol details. The development of Calimero evolves constantly and when new features have to be included, the developers try to add them maintaining both ease of use and a compact footprint. Therefore, a considerable reorganization effort was undertaken, leading to a redesign of the user API as well as internal architectural aspects. The new Calimero Next Generation (NG) API now supports additional connection protocols, management, property access, high-level convenience methods for common tasks, and more.

## IV. PROPOSED SYSTEM ARCHITECTURE

In Figure 1, the proposed system architecture is shown. The KNX system is equipped with a special device, called KNX/IP router, which links the KNX environment to the IP network in order to exchange KNX messages with remote devices. The KNX/IP router communicates through the KNXnet/IP protocol and includes, in addition to the tunneling function for the point-to-point connection, the line coupler function (i.e. routing), which allows the IP router to distribute and receive messages to other lines and areas. Since in the considered scenario there is only one home automation implant, the KNX/IP router is used in tunneling mode in order to exchange messages with Android smartphone across the IP network.

As mentioned in the previous section, the communication between the Android application and the KNX system is enabled by the Calimero library, whereas the local Wi-Fi router features guarantee an adequate security level for the home automation system management. In fact, in addition to the local access guaranteed by the Wi-Fi access point, the end-user can remotely control the home automation system through the smartphone by using a Virtual Private Network (VPN) tunnel between mobile device and local router. Once this access occurred, whether local or remote, the end user can act on her/his home automation system devices (e.g., switch, dimmer, heating, air conditioning) and monitor the environment status at any time. Also a manual change on the home automation system is shown on the smartphone display in real-time.

It is important to note that the application downloaded from the Android Market is a generic application: once downloaded and started, the application asks the user for a configuration file; this file is produced by a Java application, called “App Configurator”, used by the technician in order to configure the App in accordance with user requirements. Relevant information for this configuration can be automatically extracted from the output file exported by ETS or they can be manually entered. These interactions are summarized in Figure 2. The App Configurator helps the technician to set up the access parameters, build the screens, and place the control/monitoring components.

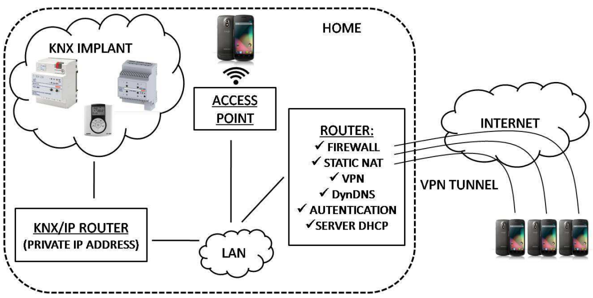


Figure 1. Proposed system architecture.

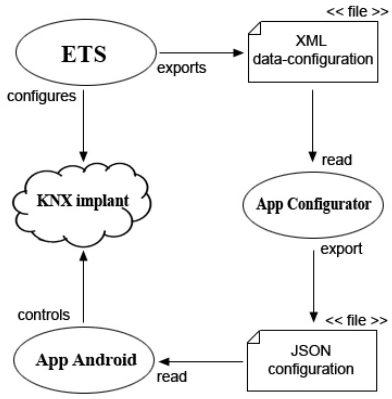


Figure 2. Android App configuration.

## V. TEST ENVIRONMENT

The test environment used in the validation phase reflects a simple scenario of a two-floor home (Figure 3). The ground floor consists of a single room containing a light. The first floor consist of three rooms: a living room containing two lights and a thermostat; a bathroom containing a light (managed through a dimmer) and a rolling shutter; and a hall in which there are two controls that trigger two different home scenarios. In particular, these scenarios are: morning scenario (all lights are off and the rolling shutter is pulled up) and night scenario (all lights are on and the rolling shutter is lowered).

In order to reproduce the described environment, a system consisting of the following KNX devices was realized: actuators and push button panels for lighting, a dimmer, a power supply and a KNX/IP router. In particular, all electric devices used in the test are compliant with KNX standard and made by Gewiss.

Two different types of user access were emulated: a local Wi-Fi access, inside the home, and a 3G access for remote control. In particular, if the access to the KNX network is local, the wireless access point connected to the home router assigns a private address to the Android device by using its Dynamic Host Configuration Protocol (DHCP) server, so that the mobile device can communicate with the KNX/IP

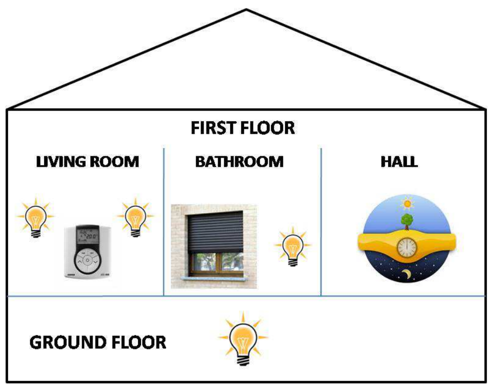


Figure 3. Test environment.

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router. Instead, if the access is remote, a VPN tunnel is established between the smartphone and the home router. In this way, the smartphone becomes a local network device and it can communicate with the KNX/IP router as in the previous case.

## VI. Functional Validation and System Performance

In the functional validation phase, the application was tested to demonstrate the effectiveness of the proposed architecture. In particular, each KNX device was successfully managed by using the Android application running on the smartphone. Furthermore, any status change manually carried out on the home automation system was displayed in the end-user interface.

In parallel to this test, another type of validation was performed. Its purpose was to demonstrate the efficiency of the proposed solution from the point of view of smartphone resources usage. In particular, the application was deployed on two different types of smartphone (i.e., Samsung Galaxy SIII and Samsung Galaxy Nexus) and it was compared with the two other applications already mentioned in Section II. The comparison results, reported in Table I, demonstrate that the proposed Android App is not only perfectly comparable to the other two applications for both the memory usage and CPU peak load, but it also shows to have higher performance. In fact, during this performance validation, the competitor applications were tested by managing only one or two devices, whereas the devices managed by the proposed application were eight. Similar results were obtained with both smartphone models.

## VII. Conclusion and Future Works

In this work, the problem of the interaction between a KNX-based home automation system and an Android mobile device is afforded. More specifically, a complete hardware and software architecture has been designed, implemented and tested. The validation phase was carried out in laboratory by reproducing a real KNX home automation system. The proposed solution is able to guarantee an end-user secure access to monitor and manage the home automation system, both locally and remotely. The results obtained in both functional and performance validations are substantial. In fact, the proposed solution presents higher performance compared to other consolidated solutions.

Ongoing and future works aim to extend the application to the use of iOS mobile devices and to carry out a performance validation by comparing an increasing number of heterogeneous mobile devices. Finally, a more stressful validation of the proposed solution in wider scenarios (e.g. building automation) will be carried out, in order to further appreciate its flexibility and scalability.

TABLE I. Performance Validation Results

| | ayControl | KNXController | Proposed solution |
|---|---|---|---|
| **Nr. devices** | 2 | 1 | 8 |
| **Memory usage** | 49 MB | 41 MB | 31 MB |
| **CPU peak load** | ~ 30mW | ~ 30mW | ~ 30mW |


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