Home Monitoring System (HomeSys) – Description of the problem domain

This project requires the development of a smart home system code-named HomeSys. The system consists of a smart home gateway that can communicate with plug and play sensors spread around the house, and a cloud system that synchronizes with the smart home gateway.

This document describes the project, the problem space and the additional constraints. Sections 1 and 2 provide some background about the domain of smart home systems and a description of how as we envision HomeSys. Section 3 lists the key stakeholders involved in the development of this system, and Section 4 describes a number of additional constraints the system should comply to. Finally, Section 5 elaborates on some more specific scenarios.

1 Context

Home automation

Home automation is the residential extension of building automation. It is automation of the home, housework or household activity to provide improved convenience, comfort, energy efficiency and security. Home automation may include centralized control of lighting, HVAC (heating, ventilation and air conditioning), appliances, locks of gates and doors and other systems. The popularity of home automation has been increasing greatly in recent years due to much higher affordability and simplicity through smartphone and tablet connectivity. The concept of the"Internet of Things" (IoT) has tied in closely with the popularization of home automation.

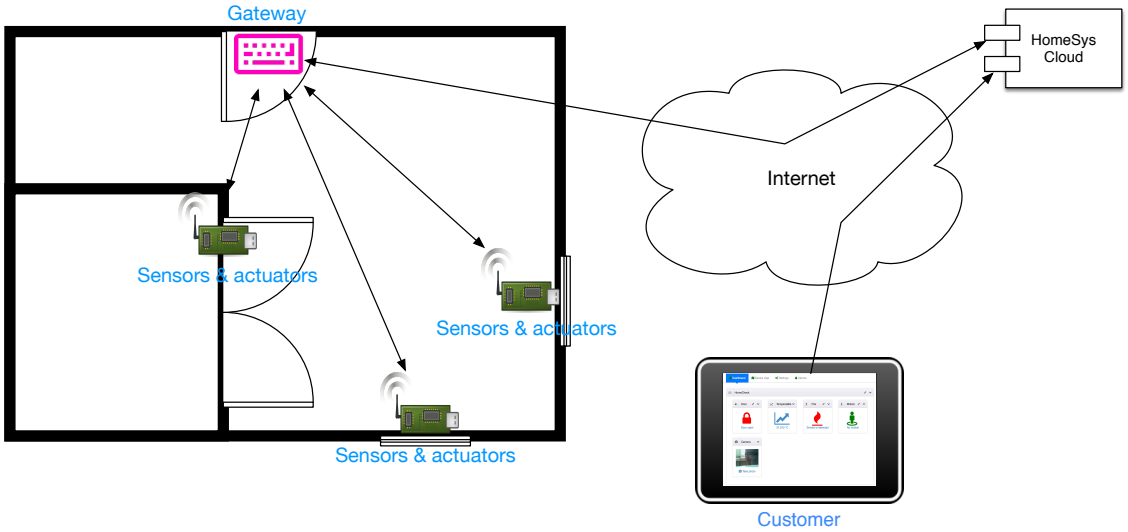

Figure 1: HomeSys overview

Figure 1 provides a schematic overview of a typical home automation system. **Sensors** and **actuators** are installed throughout the house and relay data to a cloud-based system via a **Gateway**. The cloud-based services are accessible to the customer via a tablet app or a browser and

provide the user with a management console as well as an information dashbord displaying the historical data produced by the sensors in the house. The customer can both monitor his house as well as control the actuators available (e.g., dim the lights, shut off the water supply). For certain alarming events (e.g., in case smoke is detected) the user can get immediate notifications.

Examples from the competitors

A number of commercial implementations for home automation systems are readily available on the market.

NEST

Perhaps the most widely known implementation of the home automation systems is NEST which has been acquired by Alphabet Inc. (the mother company of Google). NEST features a smart thermostat, a smoke/CO2 sensor and a camera. All NEST devices connect directly to the home WiFi router which serves as a gateway.

Philips Hue

Philips Hue is mainly focused on smart illumination. The sensors/actuators are in fact Philips lightbulbs with integrated actuators. The Philips Hue gateway is called a "bridge".

Belkin WeMo

Belkin WeMo mainly consists of lights and switches which are pluggable in various devices (e.g., the coffee maker). The Belkin gateway is in fact a wireless router Belkin produces.

Samsung Smart Things

Samsung Smart Things is probably the most extended implementation of home automation available today. The gateway here is referred to as the Smart Things Hub and it is interoperable with a large number of existing smart objects like light bulbs, cameras, speakers, locks, and thermostats.

Positioning

In this assignment, we assume the point-of-view of a software company that will develop a home automation gateway and its cloud-based services. The system is initially being built for the remote monitoring of residential apartments and houses. However, it would be beneficial if the same system could be easily extended for other purposes, e.g., monitoring of server centers, storage facilities, etc. Our target customers are people who would like to keep an eye on their apartment or house.

Our goal is to sell the HomeSys gateway as a hardware device enabling smart home automation. A basic cloud-based subscription will be offered with the device, free of charge. However, the basic subscription will only allow the customers to have data history (from sensors' data) up to 1 month and the gateway-cloud communication might be delayed (i.e., the sync will run every 15 minutes). We will also offer a premium plan (for a yearly fee) which will include data history up to 1 year and virtually a real-time communication between the gateway and the cloud services.

The main differentiation point with the existing technology providers will be twofold. First, the HomeSys gateway will feature a 3G communication module, hence the module will be 100% plug and play and it will not require any pre-existing infrastructure. Second, the gateway will be designed with explicit focus on incorporating new types of sensors and actuators, in order to be future-proof.

Technology stack

From a technical perspective, the HomeSys system leverages the following building blocks.

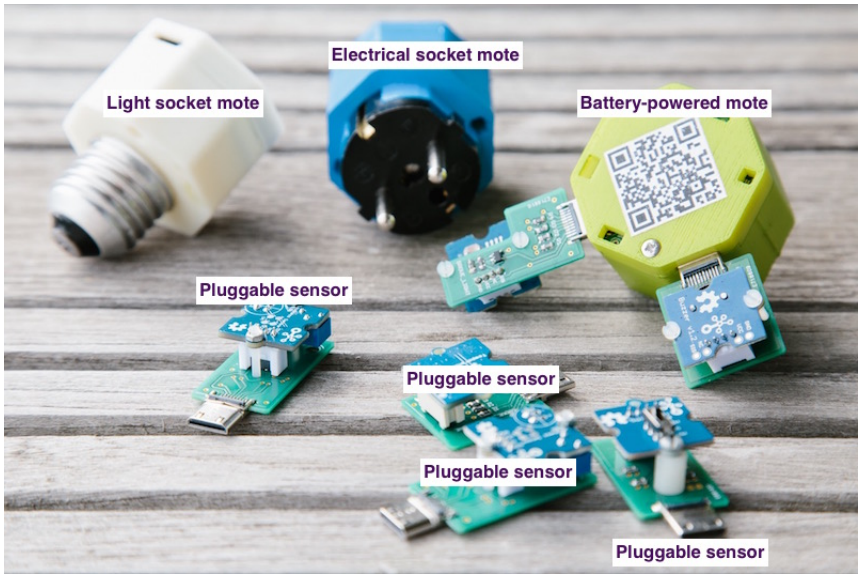

Figure 2: MicroPnP motes and sensors

MicroPnP mote (or just mote) is a hub where the sensors and actuators plugged onto and installed throughout the house. The MicroPnP technology is developed by iMinds-DistriNet (a research lab in Belgium)[1]. As presented in figure 2 motes are powered either by a battery or they can be plug into an electrical or light socket. Each MicroPnP mote has 4 USB-like ports where sensors and actuators can be plugged into. In figure 1 the sensors are represented as the green printed circuit boards (PCBs) with antennas.

Sensor is a hardware device that produces measurements and sends them to the gateway via a MicroPnP mote. The sensors are physically plugged into a mote (see figure 2).

Actuator is a hardware device that has one or more actions associated with it. For instance, a camera features "take picture" and "take video" actions, while a switch has a "turn on" and "turn off" actions. These actions are triggered by the gateway. The actuators are also plugged into the MicroPnP motes.

Figure 3: HomeSys gateway

HomeSys gateway is a pluggable black-box device that requires no technical knowledge for the installation. Figure 3 shows how the HomeSys gateway might look like. The gateway relays

[1]For more information on MicroPnP motes we refer to a very short video available on http://www.micropnp.com/ipso/index.html

the sensor data to the cloud and manages the actuators. The gateway is a Linux platform running software that our firm will develop. The gateway hardware is sufficiently powerful to run a high-level execution environment (e.g., to run Java/Python programs) and a modern database management server (e.g., MySQL). The gateway is typically installed at the front door of an apartment or a house (the pink icon on figure 1). It connects to the HomeSys cloud services via a 3G dongle (although connectivity via the home WiFi router is also feasible).

HomeSys cloud is a software system including a portal where the customers of our firm can log in and view the information about their houses.

Sensors installed on motes are also immediately available to the gateway, which can communicate with them using JSON messages. The MicroPnP supports four types of events.

1. **Heartbeat.** The motes send regular heartbeats to the gateway indicating that they are alive.
2. **Sensor plugged in.** Whenever a new sensor is inserted in the mote, a message is sent to notify the gateway that a new sensor was added.
3. **Data.** The motes send information from the sensors.
4. **Sensor removed.** Whenever a sensor is removed, the mote sends this information to the gateway.

Only the HomeSys Gateway and the HomeSys Cloud services need to be designed (as part of the assignment) as the remaining building blocks are provided by third parties.

2 Description of the problem domain

2.1 Overall system goals

The main goal of the system is to provide the customers with the necessary tools to monitor their home and to get prompt notifications upon critical events (e.g., smoke, low / high temperature, etc.). Initially our firm will work with a fixed set of sensors, i.e., temperature, humidity, smoke/gas, motion, open/closed doors and windows. However, in the future new types of sensors and actuators can be plugged in so that the customers can have much more thorough information about their home. For instance, water leak sensors, valves to turn on/off the water supply, actuators to turn on/off electrical devices, and so on.

In order to achieve the primary goals, HomeSys should realize (at least) the following objectives.

- **Home monitoring.** All sensor data should be synchronized (i.e. relayed) to the HomeSys Cloud where the customers can view all the information relevant to their home (possibly, in a summarized way).
- **Home management.** Customers should be able to manage their actuators as well as configure actuator actions depending on certain sensor value readings.
- **Usability and user friendliness.** HomeSys should be completely plug and play requiring no configuration[2].

The remainder of this section zooms in on these objectives.

[2]In case of the WiFi connectivity, the configuration to make the HomeSys gateway connect to the home WiFi network will be required though.

2.1.1 Home monitoring

The HomeSys gateway should store the sensor data internally and synchronize with the HomeSys Cloud system regularly. It is essential that the synchronization protocol works correctly in the presence of non-reliable communication network. The 3G network could switch to Edge and that would mean that the synchronization protocol could easily get timeouts or network errors. While basic sensor data (e.g., temperature, humidity readings) can be packaged in very small units of transfer, image data coming from the camera could be fairly large. Aside from simply syncing the sensor data, the HomeSys gateway should also monitor the health status of each sensor. Sensors could break or they could start sending faulty data. MicroPnP motes that are working on a battery could run out of battery and stop sending data. All this status information should be monitored by the HomeSys gateway and in case of problems the customer should get an alarm. For a more detailed description regarding alarms we refer to the next subsections. All the monitoring data will be available for the customers to consult at any time via the cloud-based services. For instance, the customer should be able to look at the last pictures taken by the cameras, or view the graph of the temperatures in the house rooms during the previous days (i.e., historical data).

2.1.2 Home management

We would like to allow the customers to easily create specific **events** of interest they would like to be notified about. These events are in fact based on specific sensor data values. Some examples of events are a temperature value that goes above 35 degrees, motion detected at night, an opened door, etc. So the customer should be able to receive **notifications** when these events are detected by the gateway and they should be able to define **rules** in the HomeSys cloud about how to handle the events (e.g., taking a picture when motion is detected).

Aside from simply defining events the customer should be able to indicate that some events are alarming (e.g., smoke sensor indicating smoke, very high or very low temperatures, very high or very low humidity values, etc.). **Alarms** should be handled faster than regular sensor data and notifications. Customers should be notified immediately upon alarms.

As mentioned, the MicroPnP motes also can have actuators (e.g., buzzer, camera, on/off switch). Each actuator type has a set of actions/states that it can take. These actions/states are pre-defined. For instance, a buzzer has “on” and “off” actions, a camera has a “take picture” action. Customers should have the possibility to define rules that link events to actuator actions/states. For instance the event “motion is detected” could be linked to the camera “take picture” action, or “door open” could be linked to a light switch “on” action.

All these rules are managed by the customer on the HomeSys cloud and synchronized to the gateway regularly.

All notifications are handled by the HomeSys cloud. This means that notifications and alarms are sent by the gateway to the cloud. The cloud then will notify the customer.

Actuators always have a certain lag before their state changes. While some actuators are pretty much instant (e.g., buzzer on / off), others may require some time before they complete the action (e.g., camera shutter speed). This means that an action will be acknowledged twice, i.e., once when received and once when successfully completed. The gateway will need to make sure that successive actions are queued and do not interfere with each other.

2.1.3 Usability and user friendliness

Existing systems similar to HomeSys require a relatively complex installation procedure. Something that most elderly people who are rich enough to have a second home are unwilling to accomplish. Thus the PnP goal has three dimensions:

- As soon as HomeSys gateway is plugged into the electrical socket it immediately connects to the Cloud and starts sending data.
- As soon as a new MicroPnP mote is powered up it is instantly recognized by the HomeSys.
- Sensors that are plugged in (or out) into the MicroPnP motes should also appear instantly within the HomeSys.

These goals are completely feasible from the technological point of view. For instance a 3G module allows HomeSys to require no configuration to get online. MicroPnP motes broadcast information as soon as they are powered. The broadcasted information contains both meta information regarding the sensors that are available, as well as sensor data. The only step the customer will have to do is a registration procedure on the HomeSys cloud and a linking of the gateway to the customer account.

For simplicity reasons we currently assume that each HomeSys gateway and its MicroPnP motes do not interfere with other HomeSys environments. This means that you don't have to worry about two neighbours each having a HomeSys gateway at home.

2.2 Sensors and Actuators

In this section, we briefly describe the sensors and actuators that we will use initially. Note that in general there are two types of sensors, i.e., analog and digital. The analog sensors require an explicit action from the MicroPnP mote (or the gateway) to get a value from the sensor. The digital sensors trigger an event whenever they sense a new value (or a state change). Such a triggered event is typically linked to what we refer to as callback. The callback is simply a low-level method that implements the business logic of processing that specific type of sensor data.

Temperature and humidity sensor. This is an analog combined sensor that samples the environment temperature and humidity. The temperature reading has a range from -30C to +85C. The humidity reading has a range from 0-100% relative humidity.

Smoke and CO2 sensor. This is a digital sensor that triggers an event in case of a smoke. Only when a smoke / CO2 is detected the sensor will spring alive. It will also report when the smoke/CO2 has stopped. It is possible to configure the sensitivity of this sensor. In the first version this is done using a hardware screw. However, in the future we expect to work with smoke sensors that will allow adjusting the sensitivity via the software (by sending actuator commands).

Motion sensor. This is a digital sensor that invokes a callback when motion is detected and when no motion has been detected after a motion. The motion detector operates on the Infrared frequency (so light is not strictly necessary to detect motion). It is possible to configure the sensitivity settings of the motion sensor.

Door/window sensor. This is a digital sensor that invokes a callback when the door/window opens or closes. The door/window sensor typically consists of 2 magnets and a wire running from one of the magnets all the way to the sensor plugged into the MicroPnP mote.

Camera actuator. This is a camera that can take pictures or video's on request. The request to take a picture, for instance, is not blocking. It means that the camera will callback when the picture or video is ready. The camera will give an error if two processes try to simultaneously take a picture or a video.

Buzzer actuator. This is an actuator that takes two commands, i.e., start and stop the buzzer.

Switch actuator. This is an actuator that can be hooked up to a variety of devices and turn them on and off using the appropriate commands.

2.3 Service Level Agreements

Our firm offers a Service Level Agreement (SLA) enclosed as a part of the provided support towards our customers. This agreement stipulates certain quality requirements (in terms of performance and availability). For example, there should be an upper limit in the time it takes for a notification to reach its recipient. Evidently the upper limit for alarm notifications should be much more strict than for normal notifications (e.g., 95% of alarm notifications should reach the recipient within 30 seconds, and 95% of event notifications should reach the recipient within 5 minutes).

Aside from the notification/alarm SLA, our firm will also provide different SLAs for customers. For instance, SLA level 1 will allow customers to access their data only for the past month. The

synchronization of data between the gateway and the cloud will take place every 15 minutes. SLA level 2 customers will be able to access the data for the past 6 months. The synchronization of data between the gateway and the cloud will take place every 5 minutes. SLA level 3 customers will be able to access their data for the past years. The synchronization of data between the gateway and the cloud will happen every minute. Customers can easily move from one SLA level to another. Hence, the SLA information should be synchronized to the gateway as well.

Also, our company has to negotiate a number of service level agreements with several third parties, like the telecom operators, to ensure the desired degree of remote monitoring module connectivity.

3 Main stakeholders

This section provides an overview of the main stakeholders in our system and their point of interest.

Customers. The customers' main stake in the system is that they would like to have a tool to monitor their home, define events of interest in a user-friendly fashion, get prompt notifications upon these events and link these events to specific actions. They would also like to add to plug new sensors/actuators to their HomeSys installation. Obviously, security and privacy related concerns are of the utmost importance to them.

MicroPnP mote manufacturer. The MicroPnP motes will be hubs for plugging multiple sensors and actuators. These motes will be linked to the HomeSys gateway via a mesh-up.

HomeSys call center. The HomeSys call center employs HomeSys operators that should follow up on various tasks. The operators take on every sort of question about the system from the customer's side and help them tackle any issues with the installation and configuration. The call center is a service offered by our company.

HomeSys system administrator. The HomeSys system administrator monitors the cloud system for its correct working. They are responsible for the scalability of the cloud system. They are notified in case of any alarming events.

Telecom operators. Telecom operators provide means for the gateways to communicate with the cloud and vice versa. A service level agreement between our company and the telecom operators determines the capabilities of these communication channels.

Cloud providers. The cloud providers provide virtual servers on the cloud that will be used to deploy the HomeSys cloud services. A service level agreement between our company and the cloud providers determines the server uptime constraints as well as the reaction time in case of problems.

Market researchers and statisticians. Given that the HomeSys produces a vast amount of data, this data could be used in various types of market research and the generation of certain statistics. For instance, it might be of interest to know the average temperature in houses around the year. This data will be sold by our firm in an anonimized format.

4 Additional constraints

4.1 Legal constraints

As the HomeSys gateway will feature a 3G connectivity it is essential to ensure all **regulations regarding the SIM card** that will be installed on the gateway. End customers will have to explicitly agree to terms and conditions regarding the use of the SIM card. This will make sure that the end users are liable for any misuse of the SIM cards. Our firm is also likely to consider

to use SIM cards from the cheapest mobile operators across EU (as the roaming costs are likely to be dropped after 2017). This might also have some legal implications regarding the end customer private information (such as, social security number and address).

Further, the **privacy** of the customer personal data as well as the sensor data need to be preserved in order to avoid leaks. This information needs to be transmitted confidentially, stored securely and preserved from unauthorized access. The customers also need to agree to the privacy policy of our firm.

4.2 MicroPnP constraints

The MicroPnP motes are constraint by the trade-off between latency, energy and bandwidth. Certain MicroPnP motes are battery operated which means that they sleep most of the time. The lower the latency of the motes, the higher the energy consumption. MicroPnP motes have a mesh network topology (i.e., data could be relayed through intermediary motes that are sometimes only used as intermediaries). This has an impact on the bandwidth that is currently limited to roughly 26 packets per second. The lower the latency of the motes the less the bandwidth.

5 Scenarios

In this section, we present a set of concrete scenarios concerning the typical installation and usage of the gateway and the cloud services. The presented scenarios involve a representative customer named John Appleseed who has a summer house in Marstrand, on the seaside of western Sweden.

5.1 HomeSys gateway installation

John buys in a store a HomeSys 3G gateway. John plugs the gateway into an electrical outlet somewhere in his house. Once the gateway is powered, it immediately connects to the cloud and sends information regarding its configuration. The cloud recognizes the HomeSys by its serial number and saves the connection timestamp and the initial configuration.

5.2 Customer profile creation

John goes to the HomeSys cloud and creates an account. The account creation requires John to enter the serial number of the HomeSys gateway. If the serial number is not found within the HomeSys cloud the account creation is disallowed. Otherwise John's account gets successfully created and from this moment on John can log in into his account.

5.3 MicroPnP mote installation

Together with the gateway John also buys a MicroPnP mote. He plugs the MicroPnP mote in his bedroom into the power socket. The mote immediately sends a broadcast notification which is received by the gateway. The gateway stores the information and upon the next next data transmission to the cloud includes the new mote information.

5.4 Sensor plugged in into MicroPnP mote

John buys temperature, humidity, smoke and motion sensors. He plugs them in one by one into the installed MicroPnP mote. The mote immediately recognizes the new hardware and sends this information to the gateway. The gateway stores the new sensor information and synchronizes this information to the cloud as well.

5.5 Actuator plugged in into MicroPnP mote

John buys a second MicroPnP mote which he installs above his house entrance door (see scenario 5.3). John buys a camera, a light switch and a buzzer. He plugs them in one by one into the newly installed MicroPnP mote. The mote immediately recognizes the new hardware and sends this

information to the gateway. The gateway stores the new actuator information and synchronizes this information to the cloud as well.

5.6 Sensor moved

John decides to move the smoke sensor from the bedroom to the entrance door mote. So he plugs the smoke sensor out of the MicroPnP mote in the bedroom. The mote immediately senses this and notifies the gateway. The gateway will store this information and notify the cloud that the smoke sensor is no longer used in the bedroom mote.
Then John plugs the smoke sensor in the mote above the entrance door (see scenario 5.4).

5.7 MicroPnP analog sensor data

Temperature and humidity sensors are analog sensors that periodically sample the environment for temperature and humidity values. MicroPnP periodically invokes the temperature / humidity sensors to sample the environment and sends this data to the gateway. The gateway stores this data.

5.8 MicroPnP digital sensor data

Smoke and motion sensors are digital which means that whenever the sensor value changes (e.g., from no smoke to smoke, or from no motion to motion detected) the sensor invokes a callback on the MicroPnP. The MicroPnP sends the new value to the gateway where this information is stored.

5.9 Normal sensor data transmission

At regular intervals the gateway (according to its configuration) sends data to the HomeSys cloud. By data we mean the following:

- information on which motes are installed,
- information about the sensors that are installed on each mote,
- information about the actuators that are installed on each mote,
- the sensor data,
- the actuator states.

Note that it is up to you to decide which data to send and how. For instance, you may send all this information on every transmission, or you could send only the new information. On every transmission the cloud can also send data back to the gateway (e.g., configuration data).

5.10 Data viewing

John logs in into his account on the HomeSys cloud and gets a dashboard with all his sensor data. For each sensor type he can request a more detailed view of the data.

5.11 Notification profile

John logs in into his account and configures an email address for all notifications and a mobile phone number for all alams (see scenario 5.12).

5.12 Event configuration

John logs into his account and creates three event configurations. The first event is a simple notification upon motion at night. The second event is a door opening that is then linked to the camera to take a picture. Finally, the third event is a smoke alarm that is linked to the buzzer on action. The last event is marked as an alarm event. This configuration data is sent to the HomeSys gateway, e.g., when the gateway connects to transmit sensor data (see scenario 5.9). The gateway receives this information and stores it.

5.13 Event notification transmission

A HomeSys gateway motion sensor records motion at 3AM and a notification is created and sent within a specific timeframe to the cloud. The cloud receives this notification and sends an email to the email address provided by John.

5.14 Alarm transmission

John's dad couldn't fall asleep and went for a smoke. Not knowing anything about the new gadget, he lighted up a cigarette before leaving the house, which triggered the smoke alarm. HomeSys gateway sends this info to the cloud. The cloud in turn saves this data and sends an SMS to John.

5.15 Actuator action

John has changed the configuration from the cloud so that his gateway will always take a picture when the door is opened. Upon such an event the gateway triggers the camera to take a picture. The camera picture is stored as sensor data and it is linked to the trigger event. When John checks his data on the cloud (see *Data viewing*) he can see the picture linked to the door opening.

5.16 Actuator malfunctioning

The gateway sends a new actuator action to one of the MicroPnP motes to switch off the light. The mote acknowledges that the command was correctly received, however after some time the mote still fails to report that the command was successfully executed. The gateway tries again, but after several failed attempts the actuator is flagged as malfunctioning and a new alarm is created and sent to John (via the cloud).