TAMPERE UNIVERSITY OF TECHNOLOGY

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Social Devices Client for Arduino

Master of Science Thesis

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Viime vuosikymmeninä älylaitteiden kehitys on edennyt suurin harppauksin. Samalla Internetin mahdollistamat sosiaaliset palvelut, kuten Facebook tai Twitter, ovat tulleet osaksi arkipäiväistä elämäämme. Tämän diplomityön kirjallisuuskatsauksessa on esitelty Social Devices -konsepti, joka vie sosiaalisten palvelujen ideaa vielä pidemmälle: konsepti ehdottaa uutta lähestysmistapaa, jossa älylaitteet ja ihmiset keskenään muodostavat uudenlaisen sosiodigitaalisen järjestelmän. Tässä järjestelmässä laitteiden on tarkoitus osallistua ennakoivasti sosiaalisiin tilanteisiin rikastuttamalla niitä jollakin tavalla. Konseptin mukaan laitteet pystyisivät esimerkiksi osallistumaan keskusteluun tai tuottamaan sellaisia palveluita, jotka rohkaisevat sosiaaliseen kanssakäymiseen.

Tämän diplomityön tarkoituksena on tutkia onko resurssivajavaisen sulautetun järjestelmän, kuten Arduinon, mahdollista toimia osana Social Devices -järjestelmää. Jotta laite voi toimia osana Social Devices -konseptia, sen äytyy omata asiakasohjelma, jollainen tässä työssä on yritetty myös toteuttaa. Tämän lisäksi kirjallisuuskatsauksessa on tarkoitus tutustua Social Devices -käsitteeseen tarkemmin.

Kirjallisuuskatsauksessa läpikävimme Social Devices -konseptin vaatimuksia sekä ominaisuuksia. Lisäksi esittelimme konseptille kaksi eri toteutusta, Social Devices Platformin sekä OrchestratorJS:n. Tutustuimme myös näiden arkkitehtuureihin ja komponentteihin. Ohessa esittelimme myös aihetta sivuavia kommunikaatioprotokollia sekä alustan, jolle toteutettu asiakasohjelma on tehty.

Toteutusosuudessa toteutimme asiakasohjelman Arduinolle sekä käsittelimme asiakasohjelman suunnitteluun liittyviä asioita sekä niihin vaikuttaneita haasteita. Lisäksi esittelimme ohjelman muodostaneet komponentit ja lopuksi kokeilimme asiakasohjelman toimivuutta Sovial Devices -rajapintaohjelmalla.

Totesimme, että toteutettu asiakasohjelma kykenee toimimaan osana Social Devices -järjestelmää. Se täyttää sille asetetut vaatimukset, kuten itsensä rekisteröinnin pal-

velimelle sekä kommunikoinnin palvelimen kanssa. Lisäksi se osaa päivittää tilansa ja lähettää RSSI-arvoja lähellä olevista laitteista palvelimelle. Tunnustimme myös, että on tilanteita, jolloin laite ei kykene vastaamaan palvelinkutsuihin luotettavasti. Suorituskyvyltään asiakasohjelma täyttää tiettyjen ohjelmien vaatimukset, mutta tiukkoihin reaaliaikavaatimuksiin se ei pysty vastaamaan.

ABSTRACT

TAMPERE UNIVERSITY OF TECHNOLOGY
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In the last few decades we have been witnessing great technology advancements regarding smart devices. At the same time we have accepted few social web services, such as Facebook or Twitter, to become a part of our everyday lives. Social Devices takes a step further regarding social services and proposes a new approach where people and devices would form together a new socio-digital system. In this system devices could participate proactively in social situations by enriching them somehow. According to the concept, the devices could, for instance, participate in a conversation or enable certain services that would encourage socialising.

This thesis' research question is to find out if a modest embedded system, such as Arduino, is capable of functioning as a Social Device. For a device to function as a part Social Devices, it needs to have a client software that is tried to be implemented in this thesis. In addition, the Social Devices concept is introduced in the literature review part.

In the literature review part we discussed about requirements and characteristics of Social Devices. Additionally, we presented two implementations, the Social Devices Platform and OrchestratorJS, and introduced their architecture and components. Furthermore, relating communication protocols and the target platform were presented.

In the implementation part, we designed a client software that is compatible with the two implementations of the Social Devices. Additionally, general design paradigms and matters that influenced the design were introduced. Furthermore, the architecture and the components that the client consists of were presented as well. Finally, an example of Social Devices application that demonstrates the client was shown.

We concluded that the implemented client functions as a proof of concept for Social Devices. The client fulfils the requirements as it is capable of registering itself to the server and communicating with it. In addition, the client is able to update its

state values and informing RSSI values of nearby devices to the server. However, we acknowledged that there are specific circumstances where the client can not respond reliably. Performance-wise we stated that the client is fast enough for certain applications but can not meet the requirements of an application that needs real-time responsiveness.

PREFACE

This thesis has been made possible by the Tampere University of Technology and its department of Pervasive Computing. The thesis was funded by Tekes as a part of Cloud program.

I would like to express my gratitude towards my supervisor, Prof. Tommi Mikkonen and M.Sc. Niko Mäkitalo who have guided me through the writing process and given me excellent advice.

Most of all, I would also like to thank my girlfriend Niina, mother Anne and father Arto for their continuous and endless support throughout the years.

Tampere, December 3, 2014.

SISÄLTÖ

LIST OF ABBREVIATIONS

AcOP	Action-oriented Programming Model
API	Application Programming Interface
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol
JSON	JavaScript Object Notation
OS	Operating System
OSI	Open Systems Interconnection
REST	Representational State Transfer
RSS	Really Simple Syndication
RSSI	Received Signal Strength Indicator
SD	Social Devices
SDP	Social Devices Platform
SOA	Service-Oriented Architecture
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
URI	Uniform Resource Identifier
RAM	Random Access Memory
SRAM	Static Random Access Memory
WLAN	Wireless Local Area Network

1. INTRODUCTION

In the last few decades we have been witnessing great technology advancements regarding smart devices. Nowadays, mobile phones or tablets are more powerful than 1990s supercomputers [1]. The trend of making devices smart does not just involve mobile phones but other everyday devices as well: televisions, car computers or even watches are equipped with capable hardware and networking capabilities for example.

At the same time when devices have gotten smarter, we have accepted web services to become a part of our everyday lives: e.g. Facebook, Twitter and Instagram have hundreds of millions monthly active users. The aforementioned services have something in common: they thrive from humans' need to socialize. In one way or another, these web services offer a way to share experiences and feelings and means to stay in touch.

Social Devices try to combine these powerful smart devices and the social aspect of services like Facebook. Social Devices proposes a new approach where people and devices would form together a new system, where devices participate proactively in social situations by enriching them somehow [2]. Devices could, for example, take part in conversations or provide applications that encourage socialising. Figure 1.1 shows such an application: in this scenario a group of people have joined together. The system recognizes this and proposes users to take part in an application that is made possible by the devices.

This thesis' first purpose is to implement a Social Devices Platform client for Arduino devices. The client is based on the requirements set for an SDP client. The client is supposed to act autonomously and asynchronously accepting requests from the server side. The client also gathers proximity information about devices nearby.

The thesis' second purpose is to implement the client in a way that a developer can easily add in his own code modules that would include the implementations of functionality that can be used for applications in the system.

The Third intention for this thesis is to present the Social Devices concept and the two implementations that exist for the concept. Additionally, some of the relating concepts are introduced in the literature review.

In addition to the topics above, as the fourth purpose of this thesis is to learn developing software for an embedded system as well. This is important as developing

Kuva 1.1: Social Devices use case [2].

software for embedded systems usually involves specific problems that usually are not typical when it comes to regular desktop softwares.

Chapter 2 introduces the Social Devices (SD) concept that is the base idea for the implementations, the Social Devices Platform (SDP) and OrchestratorJS. The chapter also elaborates the implementations' architecture and explains the functions of related components.

In Chapter 3, the communication protocol between the client and the server is explained more thoroughly. In addition to the actual protocol used in SDP, the sections in the chapter clarify few underlying protocols as well.

Chapter 4 presents the Arduino platform. First the discussion about why Arduino platform was chosen is rationalized and the latter sections introduce all the subcomponents needed for the device to function as an SDP client.

The actual implementation is shown in Chapter 5. The chapter consists of sections where general designs paradigms are presented and sections to introduce the components that the client consists of. In the latter sections, examples of using the client and performance evaluation are shown as well.

Chapter 6 presents overall evaluation of the client. In addition, the client is evaluated performance-wise. For instance, response times and discussion how they might influence the user-experience is presented.

Finally, Chapter 7 sums up the thesis by discussing about conclusions.

2. SOCIAL DEVICES

In this chapter *Social Devices* concept is introduced along with two prototype implementations called *Social Devices Platform* and *Orchestrator.js*. Section 2.1 includes general overview and needs of Social Devices. Section 2.2 elaborates implementations' underlying programming model and Section 2.3 discusses the needs and characteristics for the implementations. Implementation and architecture of Social Devices Platform are explained in Section 2.4 and Section 2.5 for Orchestrator.js respectively. Related work is presented in Section 2.6. This chapter is based on the reference [2] unless stated otherwise.

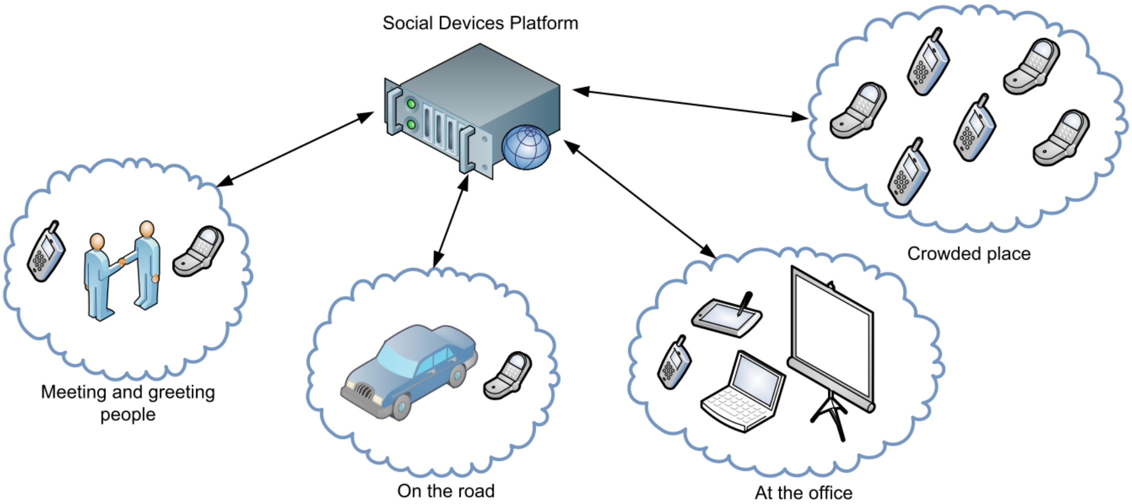
2.1 Social Devices concept overview

Mäkitalo et al. introduce the concept Social Devices in [2]. Social Devices aim at enriching the interaction between devices or between the user and device by means of technology. According to the concept, context aware and proactive devices form together with users a new kind of a socio-digital system. In this system it is possible for each participant, including devices, start an interaction with devices or people.

In situations where people meet face to face, Social Devices can enrich the interaction and at the same time enrich the interaction between devices. It is possible, e.g., make the device-to-device interaction explicit to the users.

The term *action* can be used for any interaction that is caused by Social Devices (in Section 2.2 action is explained more thoroughly). The actions can differ greatly from one another but they share the same purpose: they typically provide some explicit information to human users. Figure 2.1 demonstrates a variety of actions. For example, in a situation where people meet, their devices can participate as well by greeting each other aloud or they can just change business cards silently in the background. It is also possible to make the communication process between mobile phone and laptop more explicit to the user if the devices speak of progress out loud. An example use of Social Devices can also be guiding or informative by nature: an elevator can instruct a visitor to find what he is looking for based on the calendar entries the visitor has on his mobile phone.

Since nowadays most people own a mobile phone and usually carry it everywhere, mobile phones are very ideal social devices. Besides mobile phones, many other devices can be considered as social devices as well, and the only preconditions for



Kuva 2.1: Example uses of Social Devices Platform [2].

Social Devices are computational capability and ability to be aware of and interact with surrounding devices. This means Social Devices can be very heterogeneous and include, for example, devices which are highly personal like mobile phones. However, devices can be impersonal and stationary and possibly located in public places like an elevator or a screen in a meeting room. Furthermore, heterogeneity is also visible in devices' different resources, such as speakers, microphones or screens.

Regarding Social Devices, the environment in which actions are executed can be very dynamic as people do their daily tasks. Sporadic nature of social situations might lead into a situation where devices, like mobile phones, move in and out of range of each other so the devices that are able to take part in an action, change constantly. Considering the devices' state, such as battery level or other modes, are also notable factor for making the environment more dynamic.

2.2 Action-Oriented Programming

Aaltonen et. al. introduce a paradigm *action-oriented programming model* (AcOP) in [3]. The paradigm suggests a new model for programs that involve multiple devices that function in a cooperative way. The Socials Device Platform and OrchestratorJS implementations are based on Action-Oriented programming (AcOP) model that this section discusses in more depth. This section references to [3].

Typically traditional programming languages do not support multi-device programs by nature. For instance, they do not have the primitives to support synchronized and coordinated activities between multiple devices. Next, the key concepts that AcOP consists of are introduced.

Devices and Capabilities. In this context multi-device programs consist of actions as their basic building blocks. Actions, in turn, rely on devices and *capabilities* that the devices offer. A capability refers to an operation related to a capability that device is able to perform. It is also expected that the device provides means to use its capabilities. Additionally, capabilities function as indicators for an ability to participate in an action: if user has installed a capability on his device, the device is able to join in an action that utilizes the capability in question.

At the implementation level capabilities are manifested as *interfaces.* that consist of operations. In other words, interface is a contract of operations that are related to a specific device and its capability. For instance, later presented (Section 5.3) TalkingDevice capability's interface contains operation *say()*. Listing 2.1 shows an example how interface can be used.

AcOP model does not define which programming language interfaces should be implemented in. For example, the client presented in this document and its interfaces are implemented as C++ classes. In practice, communication protocol between the server and a client abstracts differences in programming languages.

Device capabilities or the number of interfaces are not defined by the programming model. Since a device can only be invoked through its interfaces, a device with no capability cannot participate in an action. Furthermore, capabilities are reusable across different actions and therefore a developer can write new actions without having to implement device-specific programming code.

Actions. An action is the basic unit of modularity, encapsulating the joint behaviour of several devices, and defining roles, parameters, preconditions, and a body. *Roles* are used to determine what roles the participating devices will be a part of. For instance, in an imaginary action *PhotoSharing* users can share photos between each other and roles can be used to define which device shares photos and which devices can only view the photos.

Parameters include action-specific information. In the case of PhotoSharing, parameter can contain, e.g., file path or URI to a website where photos are stored. In TalkingDevice example (Listing 2.1), strings are passed as parameters.

Precondition is a part of an action as well. Precondition defines what is expected from devices that are participating in an action and it must evaluate as boolean value true. Again when considering PhotoSharing as an action, system could check if participating devices' owners are Facebook friends for example. TalkingDevice example on the other hand expects that the devices are near of each other and their users are friends.

In the *body* part of an action is defined what devices will do during an action and in which order. Listing 2.1 shows an example of an action body: as a result of execution of the body two devices will talk to each other.

Triggers and Scheduling. *Triggers* are AcOP model's manner to initiate actions proactively. An action execution will be tried to get started when a trigger is received. Triggers can be sent by dedicated service or by the devices themselves. Triggers are not necessarily needed in AcOP but the use of triggers reduces constant evaluation of preconditions and therefore results in the system being less resource-intensive.

Listing 2.1: An example of Action definition.

```
class GreetEachOther(Action)
  @actionprecondition
  def precondition(self, d1, d2):
    return proximity([d1, d2], 2.0) and
           d1.hasInterface(TalkingDevice) and
           d2.hasInterface(TalkingDevice) and
           d1.isFriend(d2)

    @classmethod
    def getTriggers(cls):
      return ['GetCloseTrigger']

    @actionbody
    def body(self, d1, d2):
      s1, s2 = smallTalkServer.getSentenceAndReply(d1, d2)
      d1.talkingDevice.say("Hello, " +
                           d2.getOwnerName() + "!")
      d1.talkingDevice.say(s1)
      d2.talkingDevice.say("Oh, hello " +
                            d1.getOwnerName() + "!")
      d2.talkingDevice.say(s2)
```

2.3 Requirements and Characteristics

Requirements and characteristics are essential since the requirements for implementation of Social Devices are derived from these. The prototypes for the Social Devices Platform and OrchestratorJS are described later.

In order to keep track of devices, a registry is needed. The devices are associated with *identities* since users usually have preferences regarding their devices and therefore an identity can tell what the device is allowed to do. Identities can furthermore be used for indicating users' proximity e.g., the more personal the device is, the better approximation of user's proximity is possible to calculate. Registry can in addition hold information on users' personality that can for example be used for suggesting actions in different contexts.

As precondition for Social Devices suggests, proximity of users and their devices is needed for social interaction. Proximity is calculated, by each device, with respect to each device that is supposed to participate in an action. The devices report the proximity information to the centralized server, which maintains proximity information of each device. From the information, the SDP forms a mathematical graph, where nodes denote devices and edges denote the mutual distance of the devices. The advantage of such a procedure is that this reduces the required computing on the devices.

In addition to registering and reporting proximity of other devices, devices have to inform the server necessary information for *action precondition*. Action precondition defines what is expected from the participants for the action. Action precondition is a part of *action description* along with *action body*, which defines what participant devices should do during an action. In action preconditions the term *interface* is used to characterize the precondition, for example, a device with interface *TalkingDevice* has the ability to talk. The owner of a social device can enable and install multiple interfaces, capabilities, to his liking and by modifying interfaces, user can choose which privileges SDP can have access to. In case of interface *CalendarDevice*, user can give SDP rights to use work calendar in actions with colleagues.

Furthermore, the system needs a mean to determine which devices can and are willing to participate in an action. This is solved by including information on devices' logical expression in the precondition part of the action description. Interface itself can function as a logical expression: an action involving a dialog may require capability to talk; thus participant devices have to implement *TalkingDevice* interface. Since the environment is usually fairly dynamic, more information is needed from the devices. For example, a device might be able to talk but in case it is located in a silent environment it may not be willing to talk. This is handled by monitoring devices' *states*. States can vary from boolean-value to any more abstract value which can indicate, for instance, specific state as if device is turned to silent mode or not.

Operations regarding when and if actions are to be executed are decided automatically at runtime. Requests for initiating an action are handled with *triggers*. Using of triggers prevents perpetual searching of devices which can be computationally hard. When certain trigger is received, corresponding action is attempted to be scheduled. Triggers can also hold update to a state value of a device, an external event, or change in the proximity group. The decision which action and whether the action is launched is up to the centralized server that also receives the triggers. This type of procedure further reduces the computing load of the devices and enables concentrating functionality to one location.

In addition to scheduling an action, a decision must be made concerning which concrete devices are to participate in the action. For example, it may be the case that after a trigger, there may be several potential actions and several devices that possibly meet the action preconditions. This leads to a configuration problem: decide the action corresponding the trigger, find a set of devices and device roles that fulfil the action preconditions. In practice, problem gets simplified when it is required that the device, which raised the trigger, fills a certain role in the action and other participating devices are in its proximity.

Finally, executing the action requires additional coordination and orchestration for the devices since they have been designed to run their own software regardless of other devices. This is solved by using a coordination approach by defining a platform into which coordination is built in. Platform will take care of the control flow for the independently operating devices.

The goal of the design approach is to rely on concentrating functionality on the server side rather than on device autonomy and intelligence. This shows in proximity management and decision making about actions and device configurations that are not handled by the devices themselves. Hence, rather modest devices can act as social devices which this thesis arguments about as well.

2.4 Social Devices Platform

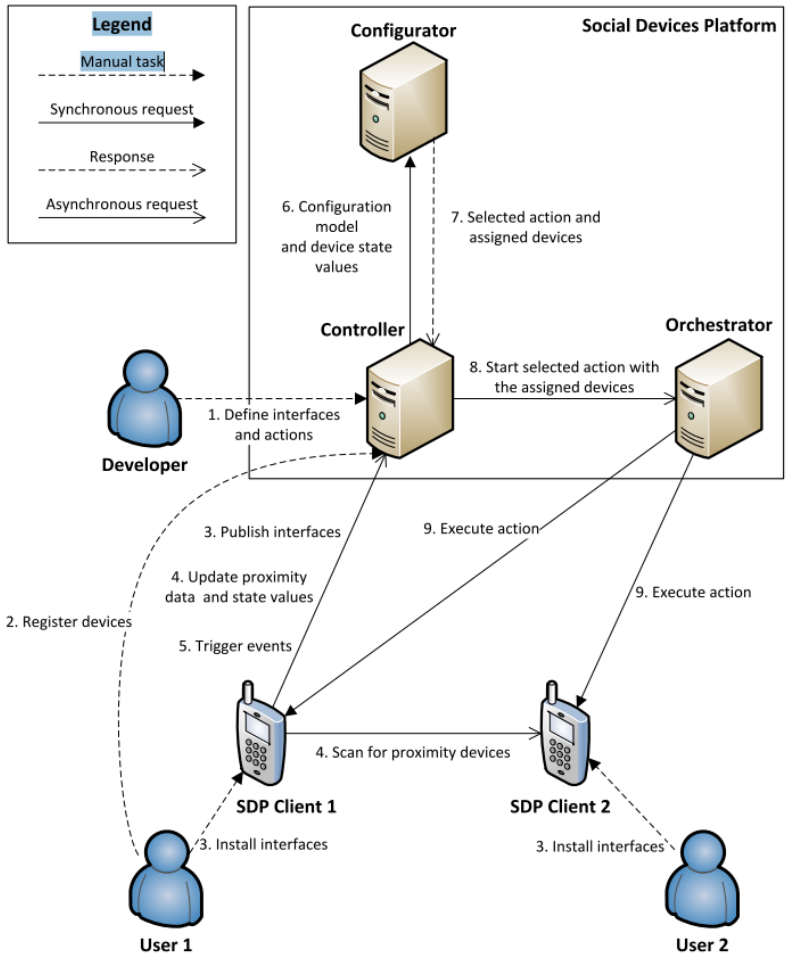
Above we introduced the concept of Social Devices and described the characteristics and requirements of Social Devices. This section suggests an answer to these requirements by showing the architecture and implementation philosophies of Social Devices Platform. This section is based on the reference [2] unless stated otherwise.

The following subsections first introduce the architecture roughly and in the following subsections the necessary components for SDP are presented. The components can be categorized as server side components and client component also known as SDP Client. Server side components include Controller, Orchestrator and Configurator components.

2.4.1 Architecture

Figure 2.2 illustrates the SDP architecture. Architecture is divided into device side and server side, which consists of *Controller* with *Proximity* subcomponent, as well as the *Configurator* and the *Orchestrator*. *Client* component is a software that is installed on devices.

Figure 2.2 introduces typical steps required running an action successfully among devices. Step 1 involves pre-preparations: possible interfaces and actions have to be defined first for the Controller and this is done by a developer. Next, users register their devices and install new capabilities by installing interface implementations



Kuva 2.2: An overview of the SDP architecture [2].

(Steps 2 and 3). Furthermore, in order to maintain proximity graph and information about devices' states, devices report their proximities to other devices and state values (Step 4). Step 5 presents a situation, where a device recognizes a potential need for an action and raises a trigger. System responds to the trigger by finding corresponding action and suitable set of devices for action's preconditions (Steps 6, 7). Finally, if preconditions are met, the execution of the action is started and the execution is orchestrated among devices (Steps 8 and 9).

2.4.2 Social Devices Platform Client

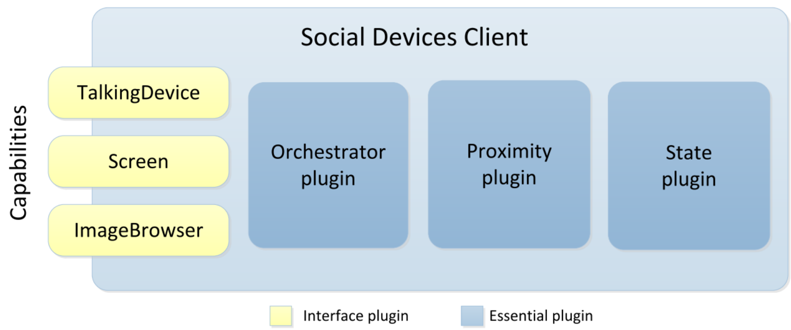
The SDP Client's main task is to handle device's communication between Controller and Orchestrator. As Figure 2.2 suggested, firstly client handles the registration to the Controller and publishes the installed interfaces. By publishing interfaces the device indicates that it implements operations regarding the interface. To ensure that privacy concerns are handled properly, the user can at this point define what operations are allowed and which preferences are used. After publishing an interface, the device can participate in action that requires the respective interface.

The ongoing task of SDP Client is to keep its device's state values up to date and informing the Controller about the changes. This is important as state values are part of action precondition that defines, for example, which devices can participate in an action.

The number of interfaces is not necessarily fixed since the SDP Client allows users to install and enable new interfaces on a device. Information about the new interfaces is sent to Controller after installing and enabling an interface.

SDP Client takes care of collecting proximity info. The Current implementation approximates closeness of devices by the Bluetooth received signal strength indicator (RSSI) value. Therefore the SDP Client devices keep their Bluetooth turned on and they periodically search for other devices. Information of found devices and the respective signal strengths are sent to the server, where the proximity graph is formed. Since the proximity is calculated as symmetric relations, it is not requisite that every device collects the proximity information.

The heterogeneity of the devices results in having specific client software for each device type. Additionally, some devices can be relatively passive, for example a speaker or a screen, therefore every device is not required to send proximity information or trigger events. At simplest, the client needs only to implement software that communicates with the Controller and the Orchestrator and interface plugins that the device is offering.



Kuva 2.3: The Social Devices Client plugin architecture [3].

Figure 2.3 illustrates a possible architecture of an SDP Client. Architecture is modular and divided into plug-ins that manage the subtasks introduced before: *Orchestrator plug-in* maintains the connection to the server and, for example, registers the device to the server. *Proximity plug-in* manages proximity info by measuring Bluetooth RSSIs and storing nearby devices' MAC-addresses and reporting them to the server. *State plug-in* is used for reporting all the contextual data and state values such as battery level or silent mode. Additionally, capabilities are implemented as plug-ins. For example, *TalkingDevice* plug-in would implement TalkingDevice interface. The implementation of the SDP Client for an embedded system that is introduced in this paper somewhat follows the architecture seen in Figure 2.3.

2.4.3 Controller Component

The Controller acts as a front-end for the SDP meaning it provides all the necessary interfaces for accessing and modifying data on the server side. For example, it provides a REST (Representational state transfer) API but a web user interface as well. Furthermore, the Controller manages data such as actions, interfaces, triggers, devices and user model, within the server side. Managing proximity information is decentralized for the Proximity subcomponent.

As seen in Figure 2.2, the developer defines new interfaces and actions. This is done in Python, and new code can be uploaded either using a REST API or a web user interface. The Controller parses the interfaces and action descriptions and stores them in a database. Furthermore, user can download the SDP client from the Controller and register their devices to the Controller. The state values, which indicated device's role in an action, are also stored in the Controller.

The Proximity subcomponent maintains the proximity information of the devices registered to the SDP. Information is stored as mathematical graph $V = (N,E)$, where N is a set of nodes and E is a set of edges. Graph gets updated when devices send their RSSI values and by using these signal strengths the Proximity component calculates new distances that are attached to the edges between the nodes. To know how old the proximity information is, distance is tagged with a timestamp, which indicates when node was created or refreshed.

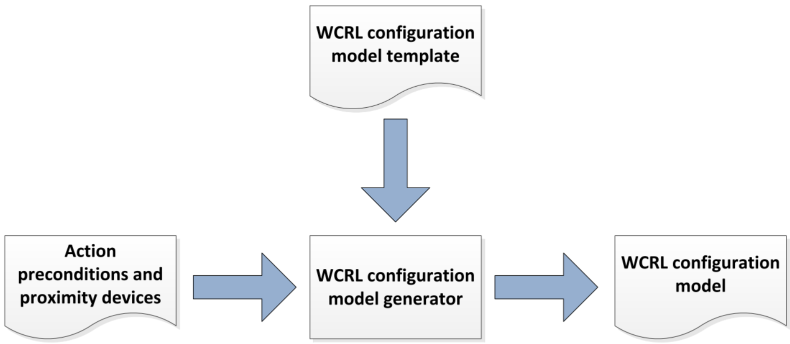
Utilizing REST, the Proximity subcomponent offers interface for querying proximities with respect to a specific device. For example, it is possible to search devices around a device within a given radius. In practice, such subgraph is only an approximation: all the nodes are not always connected and devices might be closer than subgraph indicates.

Additionally, the Controller provides a REST API for the SDP Client to update its device's proximity data and state values. Correspondingly a similar REST API is used for triggers as well. When the Controller receives a trigger, it processes it and forms a request that is sent to the Configurator. The request holds information on configuration model and state values of all the devices including the ones within the proximity of the device that sent the trigger. The Configurator processes the request and chooses an action and assigns action-specific roles to each participating device. The Configurator component and its tasks are explained more thoroughly in the following subsection.

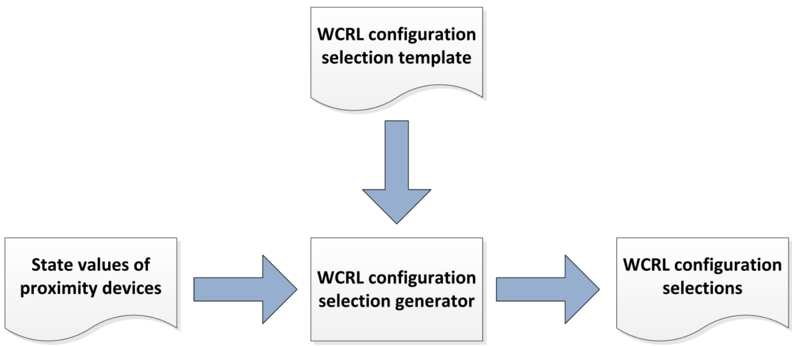
2.4.4 Configurator Component

The decision whether an action can be executed for a set of devices is up to the Configurator Component. The Configurator Component needs to consider several issues when making the decision: Devices need to implement certain interfaces for a specific role and state value conditions must be met as well. In addition, the Configurator Component must assign roles in an action for each device. This set of decisions can be formulated as a configuration problem where certain action and configuration model, the task is to find a valid configuration of devices and their assignments to the action roles. The configuration model includes, for example, action preconditions and interface definitions.

The group of devices that are close to each other is dynamic since devices may be constantly moving. Therefore the configuration model needs to be generated at runtime based on the information of the triggered actions and participating devices. In addition to the configuration model, the final configuration depends on the configuration selections as well. The configuration selections consist of devices' state values. The Configurator acts as a service that finds a valid configuration based on the configuration model and selections and returns the configuration to the Controller.



Kuva 2.4: An illustration of the configuration model generation process [2].



Kuva 2.5: An illustration of the configuration selection generation process [2].

To produce a valid configuration, the Configurator utilizes the *smodels* inference engine. *Smodels* is a general-purpose inference tool based on stable model semantics of logic programs [4]. As Figure 2.4 illustrates, the tool takes action preconditions and proximity devices as input and generates Weight Constraint Rule Language (WCRL, a general-purpose knowledge presentation language) configuration model using WCRL configuration model template. WCRL configuration selections are produced similarly using state values of proximity devices as input and utilizing WCRL configuration selection template as seen in Figure 2.5. The Configurator uses both, WRCL configuration model and selections, to form a valid configuration that results in assigning specific devices for specific roles of the action.

2.4.5 Orchestrator Component

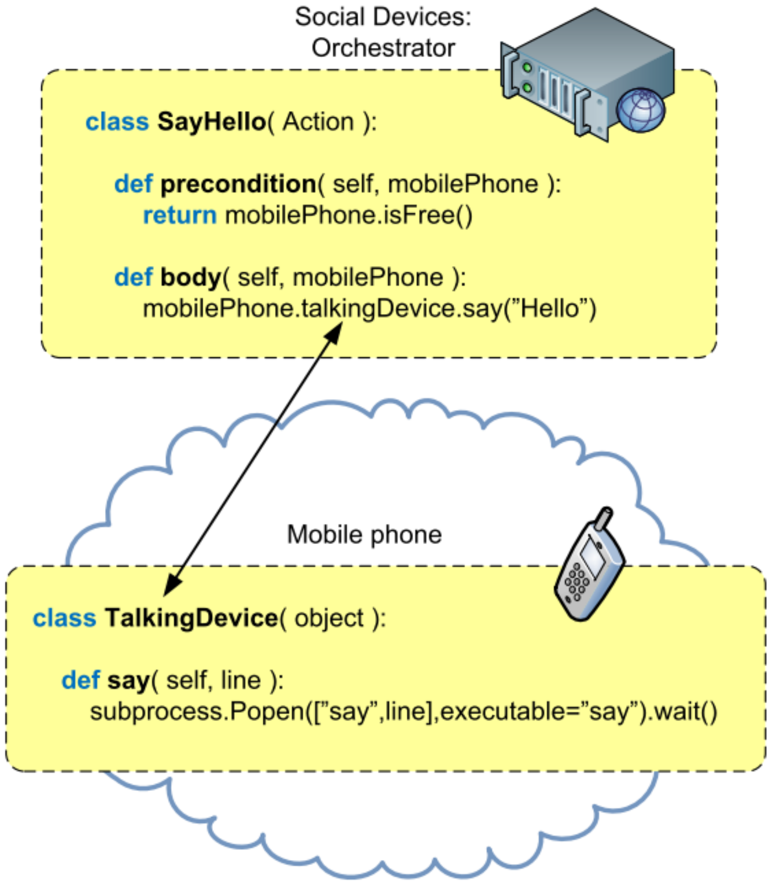
Devices in the same proximity set can be considered as actors in an action. Actors are responsible for their own local operations regarding an action but coordination between actors is up to the server side, the Orchestrator Component to be exact.

The Orchestrator acts as centralized server that handles executing the actions. The actual code to be executed is described in the *action body* part of the *action description*. Executing actions utilizes services of the devices that the Controller has selected. Services have interfaces for operations that define what the device is capable to do when an operation is invoked.

As seen in Figure 2.6, on the server side services are implemented in Python but used programming language on the client side depends on the platform. Figure 2.6 also shows the relation in programming code between the server and the client side: in this case the action body utilizes the interface by calling function *say()*.

Using a REST API, the Orchestrator offers a way to initiate action executions. Specific parameters are given to the API and they are used to initialize the action and the actor devices. During the initialization process it is checked that the devices and their services are still available and after successful initialization action execution can start.

The operation calls (e.g. *mobilePhone.talkingDevice.say("Hello")* in Figure 2.6) somewhat correspond to regular method calls: the calling is synchronized and possible return values are relayed to the action execution that is being processed at the server side. This design approach enables also relaying the values to every other actor in an action. Furthermore, the design allows relaying exceptions and in case of a failed operation, actors are notified and possibly released from an action. Similarly devices can cancel an action if they need to. However, if an error occurs at the server side, actors can be notified with using the same functionality.



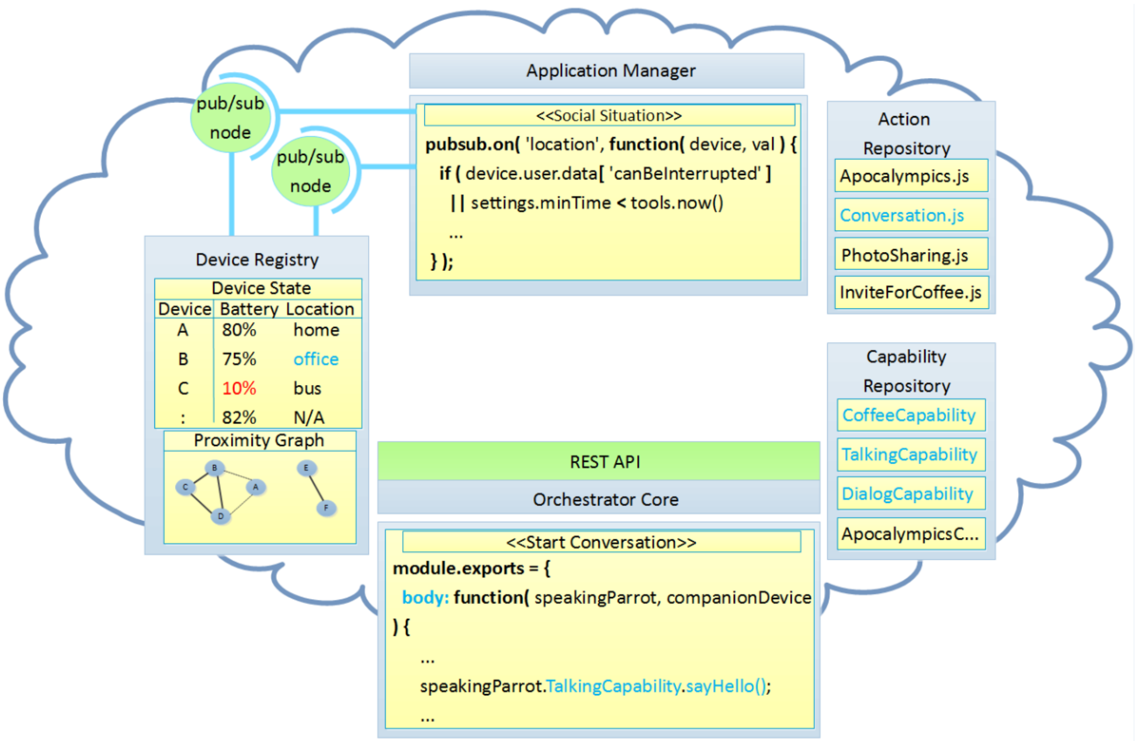
Kuva 2.6: Execution of service operations. [2].

2.5 Orchestrator.js

This section presents an alternative implementation for the SDP that supports Social Devices. *Orchestrator.js* is the next iteration of the SDP that, for example, is implemented in a cloud service unlike the SDP [5]. Additionally, Orchestrator.js middleware is designed to reduce the complexity of the architecture to improve compatibility with embedded devices and to improve prototyping abilities [5]. Next, the architecture of Orchestrator.js is presented.

Figure 2.7 presents the most relevant components related to the architecture of the Orchestrajor.js middleware: it consists of *Orchestrator Core*, *Application Manager*, *Device Registry*, *Action Repository* and *Capability Repository*.

Orchestrator Core handles the creation of actions and ensures that actions work correctly. In addition, it coordinates the executions of actions between devices. When compared to the SDP, Orchestrator Core combines some of functionality of the Controller and the Orchestrator components into single unit.



Kuva 2.7: Orchestrator.js middleware.

The Application Manager stores and executes applications and provides user interface for starting and stopping applications. The application utilizes the help of observers that monitor changes in various sources. These sources can be, for example, websites or RSS feeds.

The Device Registry functions similarly as the Controller component in the SDP: it preserves contextual information about devices and keeps proximity graph up to date. In addition, it provides suitable API that offers notifications about devices' context data.

The Action Repository is reserved for storing the action definitions. In this implementation definitions are written in JavaScript holding preconditions and error handling. Additionally program code includes description how the devices function together. In contrast to the SDP, the Orchestrator component was used to contain action definitions.

The Capability Repository includes descriptions for each capability. In practice, descriptions only define what methods (and parameters) need to be implemented. The actual implementation depends on the device and the language used and it is up to the developer how the implementation is done. This kind of approach can simplify designing new applications when there's explicit agreement which methods certain capability requires, which was not the case in the SDP.

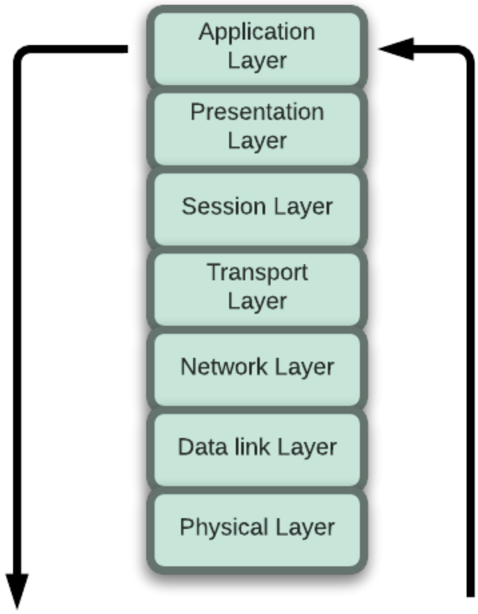
2.6 Related Work

Various other research fields are somewhat related to Social Devices. For example, *smart spaces* resembles Social Devices as they both make use of the proximity of devices when providing services. Especially social devices, which are stationary, function as smart spaces like elevator or meeting room screen. What distinguishes these two, is that Social Devices are not tied to a specific location nor specific devices. The philosophy behind the actions is also rather different: Social Devices tend to provide more user-visible behaviour instead of just background services. This is also in contrary to pervasive computing and Internet of Things which intend to minimize user distraction [6]. For example, Social Devices precisely might interrupt social interactions and therefore is in contrast to pervasive computing that has the vision of indistinguishable form or minimal user distraction [6].

In comparison to Web Services or Service-Oriented Architectures (SOAs) [7], Social Devices utilizes resources and capabilities of various physically co-located devices and the proximity of the devices in a user observable manner rather relying services that are produced on the server side.

3. COMMUNICATION PROTOCOLS IN THE SOCIAL DEVICES PLATFORM

This chapter aims at clarifying the communication between the client and the server. The sections introduce few key concepts and explain their reliance to the software.



Kuva 3.1: OSI model.

The concepts of this chapter are mainly related to the *Open Systems Interconnection* (OSI) *model*. OSI model (Figure 3.1) is a conceptual model that divides internal functions of a communication system into abstraction layers [8]. Abstraction layers are grouped into seven logical layers that provide services for the layer above it and it uses services provided by the layer under. The following sections introduce protocols that belong to *transport, session* and *application* layers of the OSI model. Sections 3.1, 3.2,3.3 and 3.4 discuss Transmission Control Protocol, Hypertext Transfer Protocol, Websocket and Socket.IO protocol, respectively. Section 3.5 is reserved for presenting the protocol that is used in OrchestratorJS.

3.1 Transmission Control Protocol

Transmission Control Protocol, commonly known as TCP, belongs to the core protocols of the Internet protocol suite (IP). TCP is a part of transport layer and it provides reliable, ordered and error-checked transferring of *packets* between programs that run on different computers and that are connected through a network. Packets consists of data and of *header* that describes packet's source, destination and control information. [9]

TCP acts between IP and application layer. It accepts any data sent from an application. TCP takes care of sending data by breaking it into appropriate pieces suitable for IP. When receiving data, TCP makes sure, for example, that the data is in right order and the passes the data for the right target application.

3.2 Hypertext Transfer Protocol

The Hypertext Transfer Protocol (HTTP) is an application-level protocol for distributed, collaborative, hypermedia information systems that is layered on top of TCP [10]. It is widely used protocol for data communication for the World Wide Web (WWW). HTTP is the actual protocol for exchanging or transferring hypertext that usually carries information of websites in the form of HTML-files. In this context, hypertext includes information about SDP-specific communication protocol.

Hypertext and its contents differ from the normal use but HTTP still functions in traditional way as a *request-response* protocol. Request-response is a basic method used for computers to communicate with each other, which works as follows: a computer shows interested in some data by sending a request and a target computer simply responds to the request. In the case of HTTP, normally a computer sends a request for a server for an HTML-file and if the request is successful, the server responses by sending the requested HTML-file. Similarly in the SDP if, for example, device wants to register itself to the server, it sends a request holding information about the device and the server responds to the request.

Comet is an application model that allows a web server to push data to a client without the browser explicitly requesting it [11]. This can done by *AJAX Long-Polling* that functions as follows. A client requests normally but the response is put on hold until there is new information available. The server responds when there is new information available and the client immediately responds starting a new cycle. The approach described is used in the Social Devices Platform.

3.3 Websocket

Websocket is rather new protocol that provides, unlike HTTP, full-duplex (simultaneous communication in both directions) communication over a single TCP connection [12]. Websocket was developed mainly to answer real-time requirements of various applications. The client and the server are able to send messages at any time and they must handle message receiving asynchronously.

The advantage of Websocket connection over HTTP connection is that after initial *handshake*, which is done over HTTP, Websocket has lower overhead per message. Additionally, the transmission of packets is faster as one data frame can be sent as soon as one frame is filled and there's no need to know the complete length of data beforehand.

3.4 Socket.IO protocol

Socket IO adds another abstraction layer on top of Websocket and HTTP. Socket IO functions nearly similarly to Websocket but adds some additional features: It offers disconnection detection through heartbeats and enables optional acknowledgements. Socket IO also has reconnection support with buffering. [13]

As Socket IO protocol works typically on top of Websocket, connection is started with handshake, which is done over HTTP. After the handshake, a client receives a session id that will be used for opening connections. Client also receives information about how often heartbeats are sent and when socket is considered disconnected after transport connection has closed.

After the initial handshake, the actual payload consists of *messages* that implement the protocol in question. The messages can be seen in Table 3.1.

The protocol requires that the messages are sent in specific encoding, that has the following format:

```
[message type]':'[messageid ('+')]':'[message endpoint](':'[data]),
```

where in addition to self-explanatory message type, format includes messageid that is used for optional ACKs and message endpoint that indicates the socket used if multiple channels of communication is in use.

3.5 Implementation of the SDP Communication Protocol

This section describes how the communication between a client and the server is initialized and used in practice. The SDP supports communication protocol over HTTP or Websocket (and SocketIO), but the latter one is presented next.

Before the device can be used in the system, it needs to be registered to system and this is done by sending a message to the server holding *client identity*. An example message using format required for SocketIO is given as follows:

```
5:1::{"name":"login", "args":["username@devicename"]}
```

Attribute consists of key *name* and value that indicate which kind of message is in question. Currently client identity consists of username and devicename.

Taulukko 3.1: The messages in Socket.IO protocol [13].

Type	**Explanation**
(0) Disconnect	Signals disconnection. If no endpoint is specified, disconnects the entire socket.
(1) Connect	Only used for multiple sockets. Signals a connection to the endpoint. Once the server receives it, it is echoed back to the client.
(2) Heartbeat	Sends a heartbeat. Heartbeats must be sent within the interval negotiated with the server. It is up to the client to decide the padding (for example, if the heartbeat timeout negotiated with the server is 20s, the client might want to send a heartbeat every 15s).
(3) Message	Regular message.
(4) JSON Message	A JSON encoded message.
(5) Event	An event is like a json message, but has mandatory name and args fields. name is a string and args an array.
(6) ACK	An acknowledgment contains the message id as the message data. If a + sign follows the message id, it is treated as an event message packet.
(7) Error	Error message.
(8) Noop	No operation. Used for example to close a poll after the polling duration times out.

After initializations are done, a device starts to listen if there has an action started. A method invocation by server has the following format:

```
5:1::{"name":"methodcall", "args": [
     action_id, methodcallId, capabilityName, methodcallName,
     [arguments]]}
```

Before the device can join in an action, it is checked that the device meets capability requirements (capabilityName) and if it does, the device changes its *method call id* to match the current method call id received in the message. Method call id is used to keep track of the execution status of an action. In other words, it keeps all of the participating devices synchronized regarding an action. When the action execution continues, the device updates its method call id accordingly. *MethodcallName* is rather self-explanatory, *arguments* on the other hand includes method-specific parameters.

Responsing to a method call has same attributes as the request but also includes return value:

```
5:1::{"name":"methodcallresponse", "args": [
     action_id, methodcallId, returnvalue, returnvaluetype,
     [arguments]]}
```

Return value can be of any type but the type must be informed in the corresponding parameter. If action execution fails or the client wants to raise an exception for another reason, it is done with following message:

```
5:1::{"name":"exception", "args": [
      action_id, methodcallId, clientidentity, reason]}
```

When the device changes its state, the information is sent to the server with context message:

```
5:1::{"name":"context_data", "args": [
      action_id, clientidentity, [medata]]}
```

Metadata includes necessary state changes.

For instance, when running an example that involves a device registering itself, the server invoking a method and the device responding to the request, messages are as following:

1. 5:1::{"name":"login", "args":["akseli@arduino"]}
2. 5:2::{"name":"methodcall","args":[78,47,"TalkingCapability","say",["Hi"]]}
3. 5:3::{"name":"methodcallresponse","args":[121,47,"TRUE","BOOLEAN"]}

In step 1, the device gets registered with specific identity. The device's capability's method *say()* is invoked with a string parameter in step 2. In the response message, the device has updated its action id and method id to match the invocation (step 3). Additionally, the response has a return value, simply a boolean value in this case.

4. ARDUINO PLATFORM

In this chapter the Arduino platform is introduced and some argumentation is shown. Additionally, the platform and all the related components are introduced. Furthermore, some key concepts regarding designing software for an embedded systems are presented as well.

Section 4.1 discusses about why Arduino platform was chosen over other options and which components developing toolchain consists of. In Section 4.2, the target device for the client software is presented. The components WiFi Shield and Bluetooth module are introduced in Sections 4.3 and 4.4, respectively.

4.1 Motivation

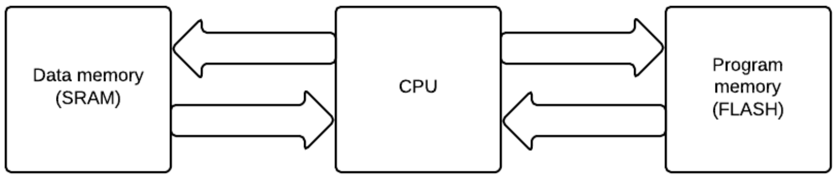
Arduino platform is intended to make the development of interactive objects or environments more accessible [14]. The hardware consists of components that are open source, meaning their circuit diagrams or drivers for example, are freely available.

Arduino has its own programming language (based on *Wiring*) that simplifies many functions like input or output operations in a user friendly way without configuring microcontroller's registries for instance. As a toolchain, Arduino uses *GNU* and *AVR Libc* to compile programs. *Avrdude* is an utility for uploading the actual programming code into the program memory. [14]

Arduino was chosen as a target embedded system mainly due to easy prototyping and open source nature of the platform. The availability of the accessories such as WiFi-shield was also a key factor. Another embedded system would have been, for example, very popular *Raspberry Pi*: the device is capable of running a Linux, has networking capabilities and enough amount of general IO-ports. Development of the client would have been also as straightforward as developing for any desktop computer. Still Raspberry Pi was left out, since developing a software for Raspberry Pi would have been "too straightforward"and would not have served one of the purposes this thesis has learning developing a software for an embedded system. Raspberry Pi offers much more powerful hardware and it has, for instance, roughly 50 times faster processor and 50 000 times more RAM than average Arduino board. As developing software for an embedded system usually involves challenges regarding performance and memory consumption, Raspberry Pi would easily handle this sort of software.

Arduino offers several prototyping boards that differ in various ways. For instance, microprocessor, amount of analog and digital ports and amount of SRAM or Flash memories each depend on the Arduino board. Almost every Arduino is suitable to run the Social Devices client, but currently the amount of RAM is the deciding factor.

Usually embedded systems like an Arduino board and its microprocessor are designed with *Harvard architecture*. As Figure 4.1 illustrates, in Harvard architecture instructions and data are stored in different physical memories. For example, the microprocessor ATmega1280, used in the Arduino Mega, utilizes Harvard architecture and uses different memory technologies for data and program memory. Atmega 1280 stores the actual executable code in the program memory, which in this case is implemented with Flash technology. Correspondingly, SRAM (*Static Random Access Memory*) is used for data memory. Data memory consists mainly of data that is manipulated during run-time.



Kuva 4.1: Harvard architecture.

4.2 Arduino Mega

This section introduces the Arduino Mega that was chosen as the prototype board mainly due to having the largest RAM amount in the Arduino family. Like most of the Arduino boards, Mega is also equipped with Atmel's 8-bit microprosessor. Table 4.1 lists few features of Arduino Mega.

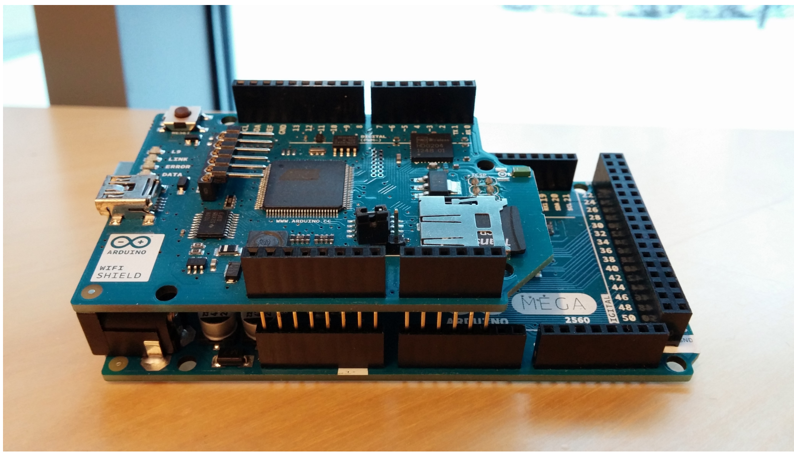
To highlight some of these, the size of SRAM is rather high since typically Arduino boards have an average of 1 KB SRAM and therefore our program is easily fit into the SRAM [14]. Operating voltage is ideal considering that it can be powered by a regular battery and no external power source is necessarily needed. For prototyping purposes the amount of analog or digital input pins suits rather well. Considering that by attaching, for instance, a simple LCD panel can take up to 10 pins so more modest Arduinos will have issues with the lack of pins. Processor's clock speed of 16 MHz turned out to be more than enough as our program does not include any intensive processing.

Taulukko 4.1: Arduino Mega specifications.

Microcontroller	ATmega1280
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Digital I/O Pins	54 (of which 15 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	128 KB of which 4 KB used by bootloader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz

4.3 WiFi Shield

PCB boards that can be placed on top of the Arduino board (or another *shield*) are called *shields*. Shields are plugged into the Arduino board's pin-headers and using long wire-wrap headers that extend through the shield leaves the board's original pin layout intact. However, Arduino board communicates with the attached shield using SPI (*Serial Peripheral Interface*) bus and therefore it uses certain pins for *SCLK*, *MOSI*, *MISO* and *SS* signals. Therefore additional peripherals need to have the slave select signal on a separate pin. Arduino Mega with the WiFi Shield attached can be seen in Figure 4.2. [14]



Kuva 4.2: Arduino Mega with the WiFi Shield attached.

WiFi Shield enables networking capabilities on an Arduino board and can connect to wireless networks using 802.11b and 802.11g wireless specifications. The WiFi Shield has Atmel's ATMega 32UC3 microcontroller, which supports TCP and UDP connection and additionally, provides secure connection using WEP or WPA2. [14]

Arduino provides a library that has all the necessary classes to scan available networks, connecting to a network and to establish a connection to a server and exchange data with it. Using of WiFi Shield is rather straightforward:

- *scanNetworks()* looks for networks around and returns their SSIDs,
- *begin(ssid, pass)* is used for connecting to certain network,
- *disconnect()* disconnects from the current network,
- *connect(URL, port* makes TCP connection to an URL or IP,
- *connected()* used to check if the client is connected,
- *available()* turns boolean-value indicating if there is data available to read,
- *write(data)* writes data to the server the client is connected to.

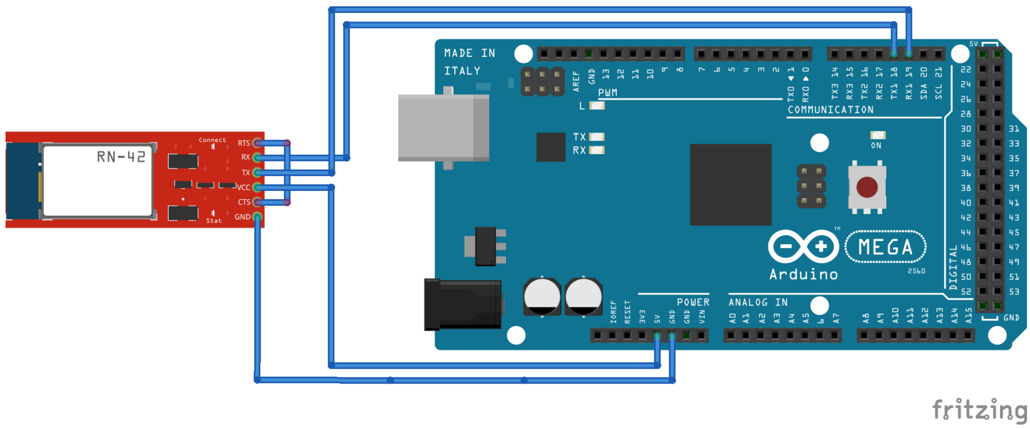
Besides WiFi Shield, Arduino can be connected to the Internet using Ethernet Shield.

4.4 Bluetooth Module

The SDP concept presumes that devices are locally aware of each other. At the current moment Bluetooth technology is used for sensing other, nearby devices.

The Bluetooth module used in the project was RN-42 manufactured by Roving Networks. The module is compatible with Bluetooth standards 2.1, 2.0, 1.2 and 1.1, therefore it was qualified enough for the purpose as the module is discoverable and is capable of scanning other devices [15]. The module is rather energy efficient as it consumes only 26 μA while idling (still staying discoverable) and 30 mA while transmitting data. Low power consumption can be very important issue since embedded systems used for the SDP are not necessarily stationed and therefore they are usually powered by a battery [15].

The actual Bluetooth module is soldered onto a PCB board that offers voltage regulators and connectors for example. The schema can be seen in Figure 4.3. The module communicates through serial connection and therefore it needs its transmit and receive pins attached to the other device's corresponding pins. In this case Arduino Mega offers hardware serial port on pins 0-1, 14-15, 16-17 and 18-19. Typically for Arduino boards, the amount of hardware serial ports is very limited and it might be the case that hardware serial is not available. To avoid this problem, it is possible to communicate with the module through software serial, which means that hardware connection is being emulated by software. This was also tested but resulted in having more unstable and slower connection.



Kuva 4.3: Schema of Bluetooth module and Arduino Mega hooked up.

In the schema (Figure 4.3), the Bluetooth module is powered through Arduino but to reduce the load on the board, external power source could be useful. CTS (*Clear To Send*) and RTS (*Request To Send*) pins are normally used for hardware flow control but they were not needed so they were short circuited to avoid any noise that could be interpret as a signal.

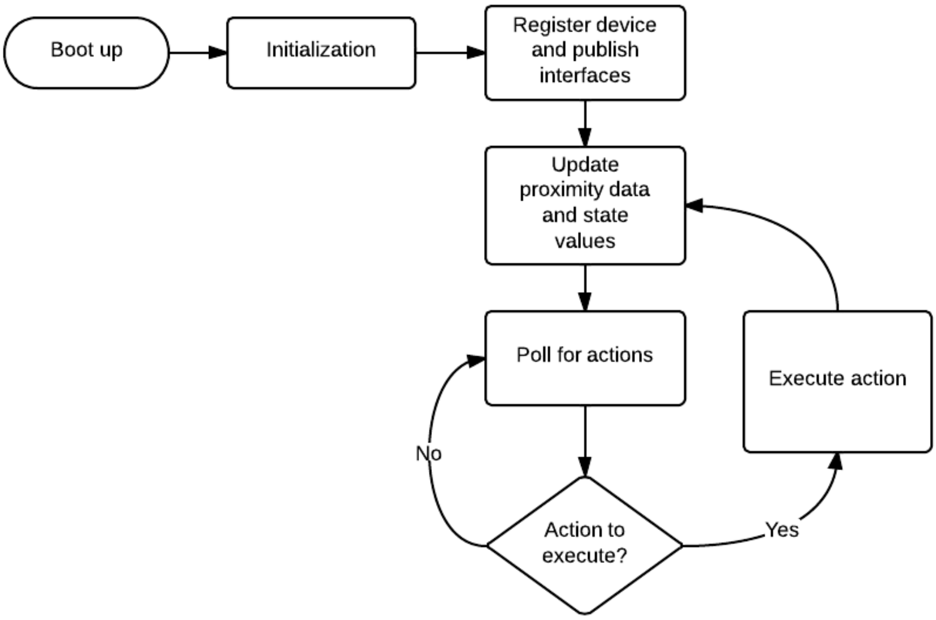
5. SOCIAL DEVICES CLIENT FOR ARDUINO

In this chapter an implementation of the Social Devices Platform -client for the Arduino platform is introduced. The chapter is divided followingly: Section 5.1 discusses about general design methods and how the client is implemented to be as easy as possible to use in developer's point of view. The actual implementation is shown in Section 5.2. In the later part of the chapter an implementation of *TalkingDevice* interface and how the client can be utilized in practice are shown in Section 5.3. Future work is presented in Section 5.4 and the chapter is summarized in Section 5.5.

5.1 General design paradigms

One of the first design decisions was considering whether to use an operating system or not. An operating system would have allowed, for example, using of *tasks* that would suit well with the Social Devices architecture: typical scenario would include, for instance, an Orchestrator, a Proximity and State modules that have their own specific task and they run parallel. Additionally, if the device is involved in an action, the execution of the code related to the implementation of an interface would have to be handled as well. Executing parallel code led to a problem: will the performance be enough? For example, in the case of capability *TalkingDevice* (see Section 5.3), users expect nearly instant response and slow execution hinders the user experience. Keeping mind that the coordination of the devices is cloud-based that adds latency in itself, therefore the execution of the device needed to be as fast as possible. This resulted in making the execution sequential rather than parallel, so the need of an operating system became obsolete. Additionally, RAM is a valuable resource in an embedded system and considering an operating system always utilizes some of the RAM, it was deciced to implement the system without an operating system.

In contrast to an ideal solution where updating proximity info, connection to the server and possible execution of an action happen parallel, the current implementation behaves as follows (Figure 5.1). After booting, the device is initialized and it connects to a network and possibly initializes any attached peripherals. Initialization is followed by registering the device to the server side and at the same time the device publishes its interfaces. At this point proximity data is gathered via the Proximity plug-in and state values are updated by the State plug-in. Next, the client starts to listen to the Orchestrator and keeps listening until it receives a request to start executing an action. After the execution, the cycle starts over by updating proximity and state values to the server. Noteworthy is that the Bluetooth module autonomously runs parallel during the cycle and broadcasts its identifier so the device stays discoverable continually.



Kuva 5.1: Flow of execution.

One of the purposes of this thesis was to provide an easy-to-use client from a developer's point of view. Ideally this means that a developer would import the Social Device client and just include a module of a capability he or she has developed and start using the client with the new interface installed without any additional configuring. As there is no abstraction level to hide the hardware specifics, it makes that in reality configuring is more complicated than that: the core functionality of the client is platform independent (atleast for Arduino) but, for example, every different Bluetooth module used for querying nearby devices and transmitting your own MAC-address requires specific, hardware dependent code. Same goes for networking: connecting to a network and keeping the connection to the server depends on the hardware used. Additionally, it gets more complicated when adding new capabilities: capabilities usually utilize some of the general IO-ports and keeping track of the used ports gets harder the more peripherals are attached. Usable IO-ports also vary between Arduino boards so same configuration might not work for each board.

To simplify the configuring process, additional *Configurations.h* header file was used. An example of such header file is shown in Listing 5.1. For example, developer instantly sees what ports are already used and can check if the selected ports meet the board requirements. Additionally, a developer can disable or enable an interface easily: in the example config header, commenting out the line *#define TALKING-DEVICE* would leave out the implementation from the build in case it is not needed.

Listing 5.1: Configurations.h

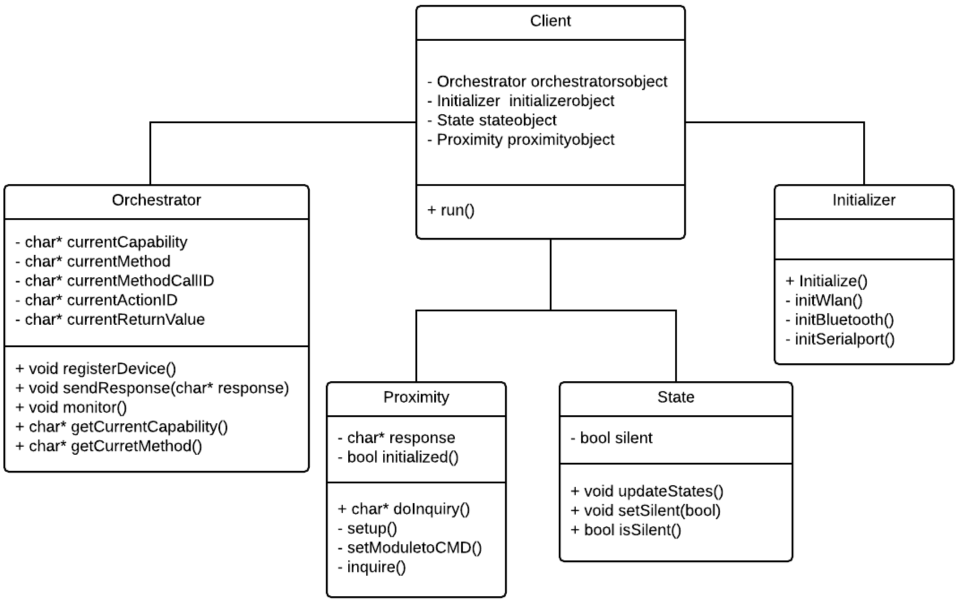
```
#ifndef CONFIGS_h
#define CONFIGS_h
#define BLUETOOTHMODULE
#ifdef BLUETOOTHMODULE
  #define PORTRX 8
  #define PORTTX 9
#endif
#define WIFISHIELD
//#define ETHERNETSHIELD
#define TALKINGDEVICE
#ifdef TALKINGDEVICE
  #define BEAKPORT 2
  #define LEFTWINGPORT 3
  #define RIGHTWINGPORT 4
#define DEVICENAME "akseli@arduino"
#define ORCHESTRATORADDRESS "social.cs.tut.fi:8000"
#endif
#endif
```

Additionally developer can modify this file if, e.g., the address of the server changes or developer wants to change other attributes. This approach simplifies the work needed by the developer as there is no need to edit the actual programming code files.

5.2 Client architecture and implementation

The client architecture loosely follows the architecture seen in Figure 2.3. In contrast to the plug-in architecture, the separate modules can not be considered as plug-ins as they are tightly coupled with each other and can not be removed from the build.

Arduino platform provides the necessary tools to implement the program either in C or in C++. The most intuitive approach was to implement the needed modules as classes and therefore the program is written in C++. Figure 5.2 includes the class diagram. The client architecture is divided into five classes: *Client, Initializer, Orchestrator, Proximity* and *State*.



Kuva 5.2: The client architecture.

The following subsections introduce the classes and describe how they meet the general requirements set to SDP Clients. Additionally, discuss about challenges and problems is presented as well.

5.2.1 Client class

The Client class basically works as component that offers an entry point for the whole Social Devices client. It also makes sure that the execution flow follows the design and, for instance, the Client class verifies that all the initializations are done before making the connection to the server.

This class also offers an opportunity for a developer to put his or her own capabilities in use. The function *MethodCallReceived(eventargs e)* receives information about the methods to be executed. The parameter holds knowledge about method's name and which capability is in question. A developer can add functionality by just adding an *if*-block to match his own capability. The code that implements a capability can be included in the *if*-block or developer could instantiate an object for example. A developer needs make sure his code can recover from an error by itself as there is no operating system and threads or other mechanisms to monitor if the developer's application crashes for example. An example how to add an interface is shown in Section 5.3.

The program uses several constant string values like device name or HTTP body and normally such values are stored in the RAM. However, in order to save RAM, every constant string value is forced to load into the program memory instead of the data memory. This is done in the Client class by using various keywords that are defined in a special library:

```
prog_uchar variableName[] PROGMEM = {"Example string."},
```

where *prog_uchar* indicates that the variable's (variableName, in this case) datatype is an unsigned char. The keyword *PROGMEM* can only be used with certain datatypes and its sole purpose is to tell the compiler to put the variable into program memory instead of data memory. The logic behind all this is to save data memory as Arduino boards have typically more (atleast 16 times) program memory space. In the example variable, transferring the variable into program memory would save 15+1 bytes, which does not sound much but is almost one percent of Arduino Uno's RAM for example. Considering that this program has dozens of similar constant strings, this sort of approach was very effective way to save data memory.

5.2.2 Initializer class

Embedded systems usually involve many peripherals and it is hardly ever a case where processor acts alone. Like in this project, there are many devices attached that each one has its unique way of configuring and initialising. This class' main purpose was to offer a single place where the devices get initialised and configured.

First of all, sometimes it matters when and in what order the devices get initialised and by putting them in the same place reduces possible misbehaviours. Secondly, gathering all the initialisations to the same place in the code helps the developer to add new devices as it is rather explicit where he or she has to modify the code to get the device working.

The class interface can be seen in the Figure 5.2 that shows the class diagram. To keep it as simple as possible for the class' user, using the class is very straightforward:

```
Initializer.Initialize()
```

does all the necessary initialisations. The implementation part takes care of all the above mentioned requirements so users do not have to worry about anything. The actual initializations are done in the private functions of the class, which are then called in the function *Initialize()* in the right order.

Device-specific initializers depend heavily on used ports for example. In the current implementation, constants, like port numbers, are not relayed as function parameters but they can be found from *Configs.h*-header file that was introduced before.

5.2.3 Orchestrator class

This section introduces the implementation of the Orchestrator class. The implementation aims at fulfilling all the requirements set for an SDP Client, that can be reviewed in Subection 2.4.2.

As Orchestrator class' main task was to communicate with the server, it was intuitive to derive the class from the class that implemented the communication protocol. In this project, the underlying communication protocols were HTTP and SocketIO and therefore two implementations exist.

The version that was built on HTTP used a library by Adrian McEwen that implemented the protocol in question [16]. SocketIO version was based on Bill Roy's library of SocketIO protocol [17]. In both cases, Orchestrator class offers the same interface to work with but the underlying components are different.

Before making a connection to the Orchestrator, the Orchestrator class assumes that the Arduino is already configured properly. After registering the device, Orchestrator keeps monitoring the connection and if it receives information e.g. about methods, that information is passed to the Client class where it can be handled. Additionally, Orchestrator offers interfaces to pass information, return values or exceptions from the current actions to the server side. Orchestrator also makes sure that the connection does not die while there is not any communication for a while by sending *heartbeats*.

According to the Socket.IO protocol, the messages between client and the server consist of JSON messages. Normally handling JSON messages is rather stress free but when it comes to embedded systems, used libraries need a little more attention. Due to *fragmentation* (discussed more deeply in the Section 5.5), at one point dynamic memory allocations needed to be removed and therefore traditional JSON libraries could not be used. In the final version, Benoit Blanchon's JSON parser [19] for Arduino that did not rely on *malloc()*, was used.

5.2.4 Proximity class

As stated before, Proximity class keeps track of surrounding devices by using Bluetooth. When a device is in *discoverable mode* it transmits the following information:

- Device name.
- Device class.
- List of services.
- Technical information (e.g. MAC-address).

We are interested in devices' names and Bluetooth MAC-address that are used for identifying users and their devices respectively in an action for instance.

To keep it as simple as possible, Proximity class offers only one method to use. *Inquiry()* executes an inquiry to scan around devices and passes the information including the devices' MAC-addresses and their names to the server. Worth mentioning is that the method call is *synchronous* meaning that the execution continues after the method has finished its own execution. In practice this can lead to problems as scanning the devices is relatively slow operation (2-10 seconds) and during this the system does not respond to action triggers for example. The SDP does not necessarily require continuous scanning of the devices so in the current implementation scanning is done only once after the boot up.

Each Bluetooth module needs to handled differently so the current version of Proximity class supports only Roving Network's RN-42 -Bluetooth module. The following pseudocode is used in the implementation:

1. **Set up communication**. This step is required for the communication between the module and Arduino. In order for serial communication to work, both devices need to be configured properly. Configuring involves setting baud rates to match and informing both devices that parity bit is not used.

2. **Put the module in command mode**. During this step, specific strings are sent that will put the module in a mode where it accepts commands

3. **Execute scan**. The Bluetooth module starts scanning nearby devices.

4. **Read and parse the scan results**. If the scanning is successful, the module responds with a result and the result is parsed in step 4.

5. **Send results to server**. Finally, the values including devices' MAC-addresses and names are passed to the function that sends the information to the server.

Noteworthy is that the communication needed special attention: first the serial communication was done programmatically but it had poor results as communication was slow and some times data got corrupted. Even though hardware serial was used, data corruption still happened randomly for unknown reason. This was handled by sending commands until the command was processed successfully. Another issue was related to timings since the module could handle only one command at a time so consecutive commands needed to be delayed by certain duration.

5.2.5 State class

State class' purpose is to keep states up to date. Additionally, it provides interfaces to check what states the device currently has and offers methods to change them. An example interface to handle device's state concerning silent mode is the following:

- *bool isSilent()*
- *void setSilent(bool)*
- *void updateStates()*

The method *isSilent()* is used to check if the device is set to silent mode or not, *setSilent(bool)* sets the device into a desired mode and *updateStates()* updates all of the states to the server side. One option would have been updating state changes to the server side every time device changes its state but it was considered better way to update all of the states at once at certain point of the execution flow. The argument for this is that it is better to include as much information as possible into a single data transmission to improve the responsiveness of the device.

5.3 TalkingDevice interface

This section introduces an implementation of TalkingDevice interface. This section also aims to clarify how the client is utilized in practice.

In Figure 5.3 is shown the set-up that was used for demonstrating a device with TalkingDevice-capabilities. Set-up consists of Arduino board, parrot and loudspeaker system. Parrot consists of six servomotors that are used for controlling its beak, wings, torso and head. Loudspeakers are used for producing speech.

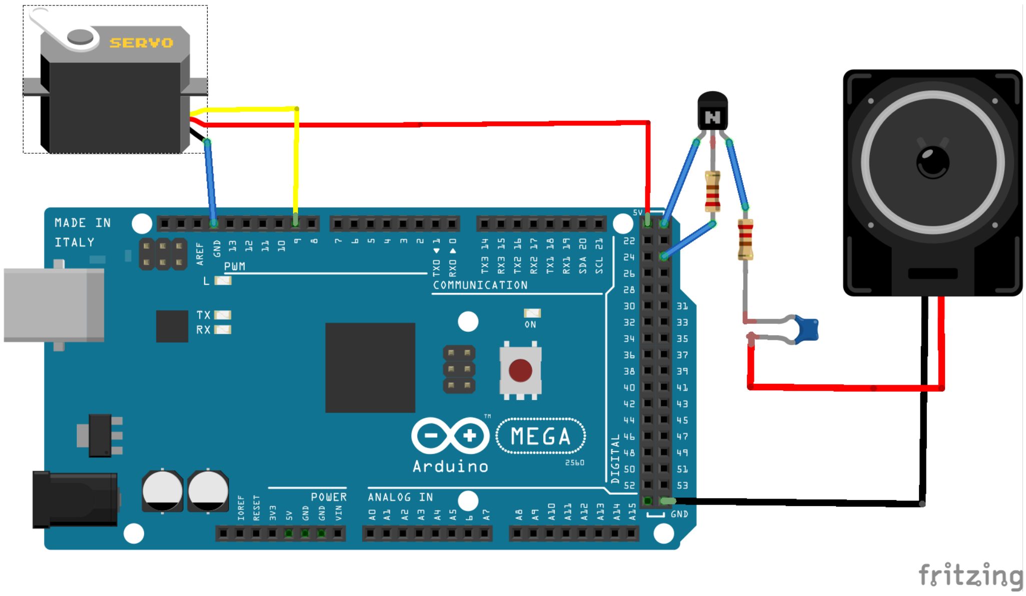
Above described system can be used, for instance, in an action that requires TalkingDevice-capabilities. The parrot can speak and while speaking, it moves its beak, wings, torso and head.

Kuva 5.3: Final set-up.

Figure 5.4 presents the schema of the device that was used. For the sake of simplicity, only one of the six servomotors is drawn on the schema. Servomotors are actuators that allow controlling angular position, velocity and acceleration of a shaft by pulse width modulation [20]. Arduino provides a library to work with servos and therefore pulse width modulation did not need to be implemented. The usage of the library was quite straightforward:

- *Servo.attach(pin)* is used for defining certain pin to be used with servomotor.
- *Servo.write(angle)* writes value to the servo that then changes its shaft's angle accordingly.
- *Servo.detach(pin)* detaches the Servo variable from its pin.

Figure 5.4 also shows the circuit of a loudspeaker and its amplifier along with low-pass filter. The transistor works as an amplifier to make the volume levels a bit higher. Capacitor is hooked up with a resistor to make a low-pass filter in order to improve speech quality by cutting unnecessary high frequencies.



Kuva 5.4: Parrot sketch.

At program code level the implementation for the parrot was done as a class. Class provides an interface including one method to use. The method *void Parrot.say(char* string)* accepts char pointer to a string as a parameter and the execution is done synchronously. Listing 5.2 shows an example how the TalkingDevice-interface is used.

Listing 5.2: Client usage.

```
void onmethod(OrchestratorClient client, char *data) {
    if (client.getCurrentCapability() == "TalkingDevice") {
        // Check what method is in question and
       //  check if the device is set to silent mode.
        if(client.getCurrentMethod() == "say" &&
            !client.getState().isSilent()) {
            parrot.say(client.getCurrentArguments());
                client.sendResponse("true");
       }

    }
    // Other if-blocks for different capabilities
}
```

One of the problems we faced was related to the power consumption of the servomotors. A servo draws relatively great amount of power so in practice, only one servomotor could be used at a time if powered by an Arduino. To avoid clunky behaviour in a movement that included several servomotors, servos were driven one at a time but only for a very small time period. The best way to deal with such problem could have been using an external power source for the servomotors.

Producing speech was also problematic: even though active speakers were used, the sound volume of speech was quite low. When the system was tested with simple tones with only few frequencies, the volume was just fine. Problem with speech was probably due to the fact that the energy to produce sound disperses into multiple frequencies resulting in low volume. This could be fixed with dedicated text-to-speech synthesizer for instance.

5.4 Future work

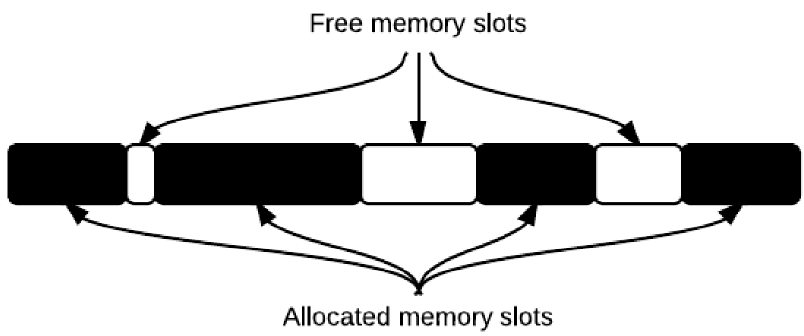
To make the client more compatible with other Arduino boards basically means that memory consumption should be lowered. At the moment, the client uses various libraries for, e.g., SocketIO-protocol and JSON parser that consume reasonable amount of RAM. Investigating these libraries and optimizing their code might be useful.

Without the existence of true parallel execution, it might be the case that the client does not respond to server's queries sometimes. For example, when an execution of an application is ongoing, the client is not able to respond. Queries can always be resent but this adds unnecessary load for the server side. In practice this is solved by using an operating system that supports parallel execution and is compatible with Arduino.

WiFi Shield was pointed out to be hindering the client's response times. Trying different network enabling shields could perhaps perform better. Another option could be optimizing the WiFi Shield's drivers as they are open source.

5.5 Summary

One of the worst problems during development was *fragmentation* related to dynamic memory allocation. Fragmentation means that after memory has been allocated and freed dynamically multiple times, the memory is filled with different sizes of free or allocated memory slots [18]. Figure 5.5 gives an example of fragmentation: system has unallocated space available but it is distributed into three smaller chunks. This can lead into a situation where free slots can not satisfy the application's demands anymore. Typically the problem is related to memory allocation routines and there is not much developer can do to avoid it [18].



Kuva 5.5: Memory fragmentation due to dynamic memory allocation.

Problems occurred when client had run successfully for a 5 to 10 minutes: first the debug messages into terminal got corrupted and then the whole program crashed which resulted in Arduino booting itself. Fragmentation was detected after outputting free memory into terminal after certain time intervals. The amount of free memory decreased in every cycle even though reserved memory slots were freed after they were used. This was clear indication of memory fragmentation. To solve this, every dynamic memory allocation was removed from the program code.

Networking, the lag issue aside, worked mostly flawlessly: the client stayed connected for long time periods. Sometimes transmitting data was troublesome as WiFi Shield stopped responding. This was resolved by delaying data and splitting it into smaller pieces before sending it to the Wifi Shield.

During the development, the backend implementation was changed as the next iteration (OrchestratorJS) of the SDP was published. The development started using the SDP but was changed to OrchestratorJS at one point. The main reason for this was the protocol change from HTTP to Websocket (and Socket.IO): this reduced the response times greatly due to Websocket's technology. Secondly, along with HTTP came relatively huge overhead since each message between the client and the server needed to be included in the HTTP request. This meant that with each message, the mandatory headers need to be sent as well, which could take up to 500 KB. For embedded systems this may lead to problems as memory is valuable resource like in this case. Each HTTP request from WiFi Shield had to be read as small chunks and sometimes this lead to weird behaviour of the system. This was probably caused by WiFi Shield's buffer overflow since Arduino handled reading the messages too slow.

6. EVALUATION

This chapter's purpose is to evaluate the client. First, Section 6.1 evaluates the client's performance. Second, the client is evaluated from overall perspective: discussion about how the client meets the set requirements is presented in Section 6.2.

6.1 Performance

Evaluating performance is important as in typical user scenarios in the SD the user experience is vastly affected by, e.g., lag. The section presents results of latency tests using different connections and discuss about how latency affects user experience and what are the causes for the lag is presented as well. The following tests were done using OrchestratorJS as the implementation of Social Devices.

Listing 6.1: Action body of lag test.

```
class LagTestCapability {
  public:
    LagTestCapability();
    // For initializing variables
    void initMeasurement(); // definition omitted
    void dummyMethod(int round) {
    // millis() returns the number of milliseconds since the
    // Arduino board began running
    if (lastEndTime_ != NULL) {
      timedeltas_[i] = lastEndTime_ - millis();
    }
    lastEndTime_ = millis();
        };
    void printResults(); // definition omitted
  private:
    unsigned int timedeltas_[15];
    unsigned int lastEndTime_;
}
```

The testing was done somewhat similarly than in [21]. In order to measure lag, a test interface that calculates time difference between two method invocations was used. In practice, time difference between method invocations is heavily influenced by the time of execution of methods and therefore methods used are as simple as possible.

Test interface used for lag test is presented in Listing 6.1 as a C++ class. Test interface consists of method *initMeasurement()* which initializes the needed variables and *dummyMethod(int round)* which calculates time deltas between invocations and stores them in a table. The method *dummyMethod(int round)* was invoked 16 times in a row resulting in 15 time delta values. The method *printResults()* was used to print all the values at once through serial port.

Taulukko 6.1: Communication latency between the client and the server using different connections. In the case of 3G and 4G, the test results include the latency to the router.

Δt_i	WLAN (ms)	4G (+ WLAN) (ms)	3G (+ WLAN) (ms)
1	2028	2059	2310
2	2031	2055	2285
3	2036	2060	2292
4	2026	2061	2341
5	2034	2056	2311
6	2039	2058	2309
7	2032	2060	2315
8	2029	2058	2286
9	2031	2057	2290
10	2037	2059	2303
11	2027	2062	2295
12	2029	2054	2290
13	2030	2053	2302
14	2031	2058	2289
15	2033	2055	2337
$\overline{\Delta t}$	2032	2058	2304
σ	3.7	2.6	17.4

Results are presented in Table 6.1. In addition to time deltas, average and mean values are calculated as well. WLAN measurements were done using high quality Internet connection provided by Finnish University and Research Network (Funet). In measurements for 3G and 4G, connections were provided by Finnish network provider Saunalahti. During testing server side components were located in Ireland on Amazon servers meaning "base latency"was around 70-80 milliseconds.

Latency is roughly around two seconds for each connection type. Latency mainly consists of time that it takes the Arduino to handle the method invoking and sending the response. Noteworthy is that the standard deviation of the latencies using WLAN and 4G is quite low. Latency with 3G on the other hand, is much more unsteady due to its technology. In comparison to [21] where similar latency test was made, a modern mobile phone performed roughly 20 times faster. Interesting observation was that the standard deviations were clearly higher in [21] than values seen in this test. One of the reasons might be related to the mobile phone used in [21]: mobile phone uses OS that supports parallel execution using threads which can result in nondeterministic behaviour. Arduino in turn, offers more deterministic processing.

Miller [22] has categorized system's responsing times followingly from user experience perspective:

1. 0.1 seconds is about the time limit for having the user feel that the system is reacting instantaneously.
2. 1.0 second is about the time limit for the user's flow of thought to stay uninterrupted.
3. 10 seconds is about the time limit for keeping the user's attention focused on the dialogue. For longer delays, users will want to perform other tasks while waiting on the computer to finish.

When compared to Miller's guideline, our system does not respond fast enough to make end-users feel like the system responds instantaneously. When coordination is done over cloud service, like in this case, it will be impossible to make the system react in 0.1 second due to base latency. 1.0 second mark on the other hand, might be reachable if certain optimizations were done. Last stage, 10 seconds, is fulfilled rather easily: even if methods used are more complexed and computing intensive, they will most likely be handled under 10 seconds. Miller does not discuss about how stable responsive time reflects to user experience but as we have seen, response times are rather stable which makes the behaviour more predictable resulting perhaps in better user experience.

Sources for the latency were investigated as well. It turned out that only minor part (~150ms) of the latency was caused by the execution of the programming code itself. It makes sense as the programming code does not include any intensive calculating and the amount of slow memory operations (RAM) is relatively low. The only major component for the lag seemed to be related to the WiFi Shield. The execution of the program code part where the client asks (method *WiFi.available()*, see Section 4.3) the WiFi Shield if the server has responded or not, was clearly the most time consuming. Typically waiting time was around 1.5 seconds, although this time period includes base latency and the time that it takes the server to handle the client's response and send a new invocation.

6.2 Overall evaluation

The SD client is required to communicate with the server. In practice this means that the client needs to register itself and be able to respond to requests from the server. As we have seen, our client fulfils these requirements mostly: the client is able to register itself and responds to the requests. However, we might face a situation where the client is processing previous request and can not respond. Additionally, while scanning nearby devices the client can not respond either but this can be easily solved as continuous scanning is not necessarily needed.

One of the necessities for a SD client was updating state values to the server as well. Currently the client is capable of updating and posting its state values. In reality, the client implementation has a component to update state values to the server and a developer needs to add his own functionality to add desired states and keep them updated (internally).

As said, the client is expected to send RSSI values to the server to keep the proximity graph up to date. In our client implementation we added a functionality that serves this purpose. However, without proper hardware abstraction layer the implementation is only compatible with specific Bluetooth module.

Finally, we are safe to say that the client can act as Social Devices client or atleast is a proof of concept.

7. CONCLUSION

As a part of this Master's Thesis a Social Devices client was developed for Arduino platform. The client fulfils the necessary requirements to act as Social Devices client. The client also functions as a proof of concept for Social Devices. A modest device, such as Arduino, is capable of functioning as a part of Social Devices and provides an ideal platform for developers to design certain applications for Social Devices that are not possible with more traditional devices like mobile phones for example. In addition, our client was an example how diverse the devices in Social Devices can be: Social Devices' implementations function as an abstraction layer for all different devices. As a future work we discussed about improving the performance: we might face situations where the client can not respond to requests from the server and this may lead to problems. This could be solved with a thread-supporting OS. Additionally, performance-wise we concluded that the performance of the client satisfies the needs of most applications. However, in applications that require real-time responsiveness, our client does not function fast enough and this might result in hindered user-experience, for instance.

The secondary purpose was to implement the client a way that a developer can easily attach his own program code modules that would include the implementations of functionality that can be used for application in the system. To serve this purpose, a hardware abstraction layer was implemented. In practice, a developer can edit a configuration file that holds information which interface implementations the build will include. In addition, the configuration file also helps setting up an embedded system since it is easier to see which resources are currently in use. Finally, adding own programming code is rather simple as you need include your own *if*-block in a certain source file.

In the literature review part Social Devices concept was introduced. Social Devices presents a new kind of sociodigital system where humans and devices both participate in. We also presented two implementations for Social Devices and became familiar with their architecture and components. Both implementations, the Social Devices Platform and OrchestratorJS, try to fill the requirements for Social Devices in practice. For instance, the implementations take care of keeping track of the closeness of the devices and find a suitable configuration for devices that are near of each other. Additionally, the implementations orchestrate operation execution between the devices.

During the development of the client we faced many typical challenges regarding developing software for an embedded system. Rather modest resources, such as RAM memory, lead to a different set of problems: issues like fragmentation and the lack of memory had to be taken into account when designing the software. Matters like these were good examples of challenges that are related to developing software for embedded systems. Therefore, we can agree that implementing the client provided valuable insight, which was also one of the thesis' purposes.

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