ROBOTS IN ASSISTED
LIVING ENVIRONMENTS

UNOBTRUSIVE, EFFICIENT, RELIABLE AND MODULAR SOLUTIONS FOR INDEPENDENT AGEING

Research Innovation Action

Project Number: 643892 Start Date of Project: 01/04/2015 Duration: 36 months

DELIVERABLE 3.2

Conceptual architecture for sensing methods and sensor data sharing II

Dissemination Level	**Public**
Due Date of Deliverable	Project Month 18, September 2016
Actual Submission Date	11 October 2016
Work Package	WP3, *Modular conceptual home architecture design and ICT method development for efficient, robust and flexible elder monitoring and caring*
Task	T3.1, *Conceptual architecture for sensing methods and sensor data sharing*
Lead Beneficiary	S&C
Contributing beneficiaries	NCSR-D, TWG, RUB, AVN
Type	Report
Status	Submitted
Version	Final

Project funded by the European Union's Horizon 2020 Research and Innovation Actions

Abstract

Architecture document, pertaining to the information dependencies and interoperability between RADIO components for satisfying the medical information requirements set in WP2. This document guides the development of recognition methods in Task 3.2.

History and Contributors

Ver	Date	Description	Contributors
01	1 Jun 2016	First draft, adapting document structure from D3.1. Removed the state of the art analysis from Sections 2 and 3, which is now the subject of other deliverables (D3.4, D5.4) produced after D3.1 was deliverabled.	S&C, NCSR-D
02	17 Jun 2016	List of components and versions of the system deployed at FSL trials (Sect. 2.2).	NCSR-D
03	26 Sep 2016	Updated Section 4.2 “Wireless Communication” and Section 4.3 “Robot Platform”	TWG, RUB
04	29 Sep 2016	Revisited list of user requirements and relevant technologies (Sect. 2.1) taking into account development up to now and outcomes of WP2.	NCSR-D
05	30 Sep 2016	Re-worked Section 4.3 “Robot Platform” to a higher level of abstraction	RUB
06	5 Oct 2016	Re-worked the component interconnections (Sect. 5)	NCSR-D, TWG, AVN
07	10 Oct 2016	Internal review comments and corrections	RUB
Fin	11 Oct 2016	Final document preparation and submission	NCSR-D, S&C

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1 INTRODUCTION

1.1 Purpose and Scope

This deliverable is the second version of the *conceptual architecture* that specifies the information dependencies and interoperability between RADIO components for satisfying the medical information requirements set in WP2.

Within the scope of this document is:

- To identify the recognition methods that will be extended and adapted in the context of Task 3.2 in order to extract the interRAI assessment items that are required by WP2.
- By studying the information dependencies between these components, to specify the conceptual architecture of the RADIO Home system that integrates the processing elements executing the recognition components above with the sensing elements (including smart home and robot-mounted sensors).

Outside the scope of this document is:

- To specify the physical architecture, such as whether components will execute on FPGA boards or general-purpose computers. This is dealt with in Task 4.1.
- To specify the architecture (either conceptual or physical) of the communication between the RADIO Home and other nodes of the RADIO ecosystem, such as cloud storage components and components meant to be used by hospital personnel or informal care-givers. This is dealt with in Task 5.1.

1.2 Approach

This deliverable documents work in Task 3.1, which analyses the user requirements collected by work in WP2 in order to develop the system architecture. The work plan in this task includes:

- Identifying recognition methods that can cover requirements on collecting information.
- Studying the data interdependencies between the different recognition methods in order to specify what intermediate results can be shared. This leads to providing technical requirements regarding data processing and data transfer.
- The analysis above can also identify alternatives (data and processing) for extracting the same information item. This can be used to balance between robustness and ethical requirements. For example, suppose bathroom ADLs can be recognized using only acoustic data or (more robustly) using a combination of acoustic and visual data. This deliverable will describe the alternatives in order to provide input to the relevant ethical discussion in WP2.

S&C leads this task and provides knowledge and experience with current smart home systems to match requirements from WP2, and the information exchange between the smart home system and the robot. **NCSR-D**, **TWG**, and **AVN** carry out the analysis that identifies appropriate recognition methods for the interRAI assessment items. **TWG** and **RUB** explore different approaches focusing on WSN and short range wireless communication technologies that can be exploited in RADIO.

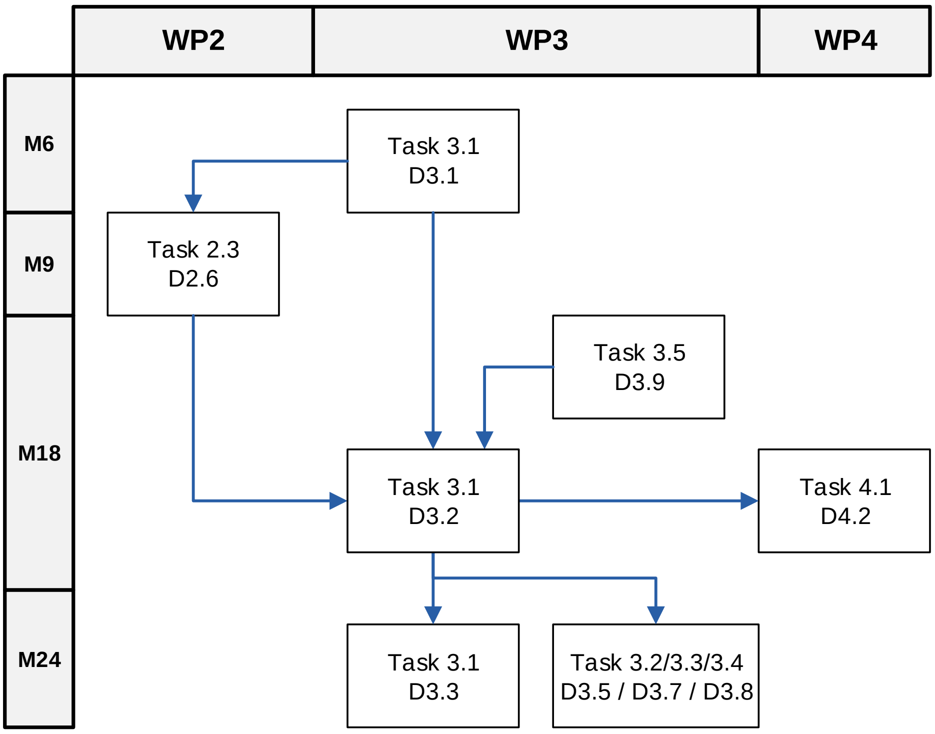

Figure 1: Relation to other Work Packages and Deliverables

1.3 Relation to Other Work Packages and Deliverables

This document is part of a cluster of closely related deliverables. The initial conceptual architecture (D3.1) planned development work (carried out in Task 3.2) until M18, including a first overview of the state of the art upon which RADIO development was based. In this version, all methodological information has been moved to D3.4 *ADL and mood recognition methods* and this document only retains the architectural design and component interconnections needed to satisfy the user requirements (WP2) and the findings of D3.6 *Network robustness and efficiency methods*.

In this manner, work around ADL and Mood recognition is organized as follows:

- D3.2 *Conceptual architecture II* (R): design and interconnections of components
- D3.4 *ADL and mood recognition methods I* (R): methods developed in order to implement the components specified in D3.2
- D3.9 *Integrated data analysis system I* (DEM): prototypes of the methods from D3.4

From M19 until M24 the architecture is maintained as a *living document* updated to record adjustments necessitated as development in WP3 progresses. The final version (D3.3, M24) documents the architecture and interfacing of the final data analysis (D3.5, D3.8) and networking (D3.7) methods as prototyped in D3.10.

The first version of the architecture (D3.1) was used in WP2 to drive the discussion on balancing between clinical requirements, obtrusiveness, and technical feasibility. The outcome of this discussion (D2.6 *Guidelines for balancing between medical requirements and obtrusiveness*) is used by this second architecture document to focus technical effort on those recognition items that will have the most impact.

Finally, this deliverable is used by Task 4.1 in order to prepare the second version of the physical architecture, D4.2 *Architecture for extending smart homes with robotic platforms*.

2 Determining interRAI items Through sensor data

This chapter specifies the sensor data analysis technologies that will be developed in T3.2 and T3.4.

2.1 Recognition of interRAI Items

We assume as a starting point the interRAI assessment items that have been marked as relevant to RADIO in D2.2. Specifically, we assume the items marked as "Observation" in D2.2, since these are assessed by observing the user. Other interRAI items are assessed by interviewing the user or by accessing the medical record, and are outside the scope of work in WP3.

For each of the observation items, we provide an initial estimation of (a) the kind of data and processing over this data that can be used to assess the item; and (b) the maturity of the technologies involved in this processing.

These estimations are collected in Tables 1, 2 and 3 following the way interRAI organizes assessment items in ADL items, cognitive and mood items, and health conditions and continence items. For each item, we note the data modalities (visual, audio, 3D/range) that can be used for its recognition, the analysis technology that will be applied to this data, and the level of maturity of these technologies. The technologies are discussed in more detail in Section 2.2 below, but, in brief, they revolve around:

- Pattern recognition over visual (including 3D vision), range, and acoustic sensor data.
- Extracting mood and other behaviour features from speech content.
- It is also foreseen that mood will be extracted from textual content and on-line social networking interactions. This is not treated in this version of the architecture, but will be included in the next version (D3.2), as it also depends on specifications work to be carried out in WP5.

An estimation of the level of maturity of the specific technologies is given in the *Status* column of Tables 1, 2 and 3 as follows:

1. It is unclear how this recognition can be achieved, and novel algorithmic design is needed. Although some initial experiments might be carried out, usable and robust outcomes are beyond the scope of the RADIO project.
2. There is a clear path to achieving this by adapting existing algorithms and methods. The compilation of annotated test data and extensive experimentation will be needed, but usable and robust outcomes are expected for most of these items by project's end.
3. The methods for achieving the recognition of these items are already developed. Minor testing and tuning is needed. Usable and robust outcomes for all of these items will be integrated in the RADIO prototype.
4. X marks items that have been excluded as a result of the obtrusiveness discussion in WP2.

Table 1: ADL-related data extraction methods

Assessment Item	Name	Technology	Status	Comments
ADL Self Performance	Bathing, personal hygiene	Audio-visual event recognition	X	(Almost) raw visual content is required (qualitative information) - inference of occurrence of events is not satisfactory (see Section 4.2, D2.6).
	Dressing upper body; dressing lower body	Clothes recognition	X	(Almost) raw visual content is required (qualitative information) - inference of occurrence of events is not satisfactory (see Section 4.2, D2.6).
	Walking, locomotion	Human pattern recognition (HPR) in range data and face identification	2	Assuming the scene is not crowded, face identification is used to identify user and HPR to characterize walking patterns.
	Toilet transfer	Visual event recognition Simple proximity sensor	X	(Almost) raw visual content is required (qualitative information) - inference of occurrence of events is not satisfactory (see Section 4.2, D2.6).
	Toilet use	Audio event recognition	3	Event log only, without qualitative information
	Bed mobility	Visual event recognition	2/3	This has already been tested during the Intermediate phase pilot studies. Further testing and tuning is needed
	Eating	Visual event recognition	X	(Almost) raw visual content is required (qualitative information) - inference of occurrence of events is not satisfactory (see Section 4.2, D2.6).
Locomotion and Walking	Timed 4-meter walk; distance walked	Human pattern recognition (HPR) in range data and face identification	2/3	This has already been tested during the Intermediate phase pilot studies. Further testing and tuning is needed
	Distance wheeled self	*N/A, as ability to walk is required (cf. inclusion criteria, Sect 2, D2.2)*		
Activity Level	Total hours of exercise or physical activity in last 3 days	Visual	2	Assuming it is not necessary to classify to different exercise activity types. Further clarifications are needed here for the nature of the information required.
	Number of days went out of the house in last 3 days	Visual	2	Detecting exit and entrance. Simple post processing can separate substantial exits from going just out of the door and back again. Further clarifications are needed here for the nature of the information required.

Table continues from previous page.

Assessment Item	Name	Technology	Status	Comments
Activity Preferences and Involvement	Cards, games, or puzzles; crafts or arts; reading, writing, or crossword puzzles	Audio-visual event recognition	1	**Aggregate** of event occurrence is OK.
	Computer activity	Audio-visual event recognition	1	**Aggregate** of event occurrence is OK.
	Conversing or talking on the phone	Audio-visual event recognition	3	**Aggregate** of event occurrence is OK.
	Dancing	Audio-visual event recognition	2	**Aggregate** of event occurrence is OK..
	Exercise or sports	Audio-visual event recognition	2	**Aggregate** of event occurrence is OK.
	Gardening or plants	*N/A, RADIO operates indoors*		
	Helping others	Audio-visual event recognition	1	**Aggregate** of event occurrence is OK.
	Music or singing	Audio-visual event recognition	3	**Aggregate** of event occurrence is OK.
	Pets	*N/A, presence of pets is not considered in the RADIO experiment environment*		
	Spiritual or religious activities	Visual event recognition, automatic speech recognition	1	**Aggregate** of event occurrence is OK.
	Trips/shopping	*N/A, RADIO operates indoors*		
	Walking or wheeling outdoors	*N/A, RADIO operates indoors*		
	Watching TV or listening to radio	Audio-visual event recognition	3	Detecting if TV or radio is on, detecting if end-user is actually watching TV. Further clarifications are needed here for the nature of the information required.
	Discussing and reminiscing about life	Automatic speech recognition	1	Further clarifications are needed here for the nature of the information required.
Time Asleep During Day	Time Asleep During Day	Audio-visual event recognition	X	(Almost) raw visual content is required (qualitative information) - inference of occurrence of events is not satisfactory (see Section 4.2, D2.6).

Table 2: Cognitive and Mood Items data extraction methods

Assessment Item	Name	Technology	Status	Comments
Cognitive skills for daily decision making				Need more details: this item is high-level and needs more detailed description
Memory/ recall ability	Procedural memory Situational memory			Too general. Will be re-assessed in D3.2.
Periodic Disordered Thinking Or Awareness	Episodes of disorganized speech	Audio	1	Annotated recordings are needed.
Acute Change in Mental Status from Person's Usual Functioning				Too general. Need more details
Indicators of possible depressed anxious or sad mood	Made negative statements	Audio (Speech)	2	Detailed examples of speech
	Persistent anger with self or others	Audio	2	Audio recordings and annotation of affect status are needed.
	Expressions, including non-verbal, of what appear to be unrealistic fears	Audio-visual event recognition	1	Examples AND training data (annotated samples)
	Repetitive health complaints; repetitive anxious complaints and (non-health related) concerns	Automatic speech recognition	2	Detailed examples and characteristic keywords are needed.
	Sad, pained, or worried facial expressions	Facial expression analysis	1	Annotated samples. It is extremely difficult to get reliable estimations, unless calibration on each individual person can be applied.
	Crying, tearfulness	Audio event recognition	2	Annotated samples are needed.
	Recurrent statements that something terrible is about to happen	Automatic speech recognition	2	Detailed examples and characteristic keywords are needed.
	Withdrawal from activities of interest; Reduced social interactions		–	Too general. Will be re-assessed in D3.2.
	Expressions, including non-verbal, of a lack of pleasure in life	Automatic speech recognition	2	Detailed examples and characteristic keywords are needed. Non-verbal expressions cannot be reliably recognized (level: 1)

Behaviour Symptoms	Wandering	Visual	2	Need annotated samples and advanced post-processing to fuse with other detected events
	Verbal abuse	Automatic speech recognition	2	Characteristic keywords are needed.
	Physical abuse	Audio-visual event recognition	1	**Aggregate** of event occurrence is OK.
	Socially inappropriate or disruptive behaviour	Automatic speech recognition	2	Detailed examples and characteristic keywords are needed.
	Inappropriate public sexual behaviour or public disrobing; Resists care	Audio-visual event recognition	1	**Aggregate** of event occurrence is OK.

Table 3: Health Conditions and Continence items data extraction methods

Assessment Item	Name	Technology	Status	Comments
Falls	Falls	Visual event recognition	2	-
Health Condition Frequency	Difficult or unable to move self to standing position unassisted; to turn self around and face the opposite direction when standing	Visual event recognition	1	Annotated samples. One foreseen difficulty is to understand when there is a will to stand-up. Could count e.g. when is standing up but cannot know how many times tried and failed.
	Dizziness			It is unclear how this can be observed.
	Unsteady gait	Visual	2	Annotated recordings are needed.
	Difficulty clearing airway secretion; Constipation; Diarrhoea	Audio event recognition	1	Annotated audio recordings are needed.
	Vomiting	Audio-visual event recognition	1	Annotated recordings are needed.
	Difficulty falling asleep or staying asleep; waking up too early; restlessness; non-restful sleep; Too much sleep	Audio-visual event recognition	2	Visual sensor in bedroom
	Aspiration, coughing while eating	Audio event recognition	2	Depends on ability to recognize eating ADL (cf. above)
Dyspnea	Dyspnea	Audio and Visual for activities	2	Need annotated samples & examples
Fatigue	Fatigue		1	Unclear how this can be observed.
Pain symptoms	Frequency with which person complains or shows evidence of pain (including grimacing, teeth clenching, moaning, withdrawal when touched, or other nonverbal signs suggesting pain)	Audio-visual event recognition	1	Annotated recordings are needed.
	Consistency of pain	Audio-visual event recognition	1	Annotated recordings are needed.
Continence	Bladder continence			Will be revisited in D3.2

Table 4: Health Conditions and Continence items data extraction methods

Assessment Item	Name	Technology	Status	Comments
ADL SELF-PERFORMANCE AND CAPACITY	Meal preparation—How meals are prepared (e.g., planning meals, assembling ingredients, cooking, setting out food and utensils)	Visual event recognition	1	Annotated recordings are needed.
	Ordinary housework—How ordinary work around the house is performed (e.g., doing dishes, dusting, making bed, tidying up, laundry)	Audio visual event recognition	1	Annotated recordings are needed.
	Managing finances—How bills are paid, checkbook is balanced, household expenses are budgeted, credit card account is monitored		1	
	Managing medications—How medications are managed (e.g., remembering to take medicines, opening bottles, taking correct drug dosages, giving injections, applying ointments)	Visual event recognition	1	A first method of pill intake has already been tested during the Intermediate phase pilot studies. Further testing and tuning is needed
	Phone use—How telephone calls are made or received (with assistive devices such as large numbers on telephone, amplification as needed)			This needs further clarification on the quality of data needed.
	Stairs—How full flight of stairs is managed (12–14 stairs)	Visual /depth pattern recognition	1	Annotated recordings are needed.
	Shopping—How shopping is performed for food and household items (e.g., selecting items, paying money	*N/A, RADIO operates indoors*		
	Transportation—How travels by public transportation (navigating system, paying fare) or driving self (including getting out of house, into and out of vehicles)			

2.2 List of Components

Table 5 below gives the current list of ADL recognition components for the RADIO robot, navigation and other robot components besides those directly used for ADL recognition, the components of the Main Controller that are relevant to ADL recognition, logging, and reporting, and the off-line tools used for the development of the recognition components.

The versions given on the table reflect the prototype that was deployed at FSL premises to conduct the intermediate trials.[1]

Table 5: ADL recognition and other auxiliary components

ADL recognition robot components			
Camera and depth sensor	Bed transfer and pill intake recognition and measurements	v1.1	https://github.com/RADIO-PROJECT-EU/motion_analysis
	Logger for bed transfer and pill intake	v1.0	https://github.com/RADIO-PROJECT-EU/motion_analysis_wrapper
	Chair transfer recognition and measurements	v1.1	https://github.com/RADIO-PROJECT-EU/ros_visual
	Logger of chair transfer events	v1.0	https://github.com/RADIO-PROJECT-EU/ros_visual_wrapper
	User identification and tracking	*N/A*	https://github.com/RADIO-PROJECT-EU/clothes_detection
	FPGA implementation	*N/A*	https://github.com/RADIO-PROJECT-EU/HW_components_for_ADL
Range Finder	Tracks walking human and measures walking speed	v1.2	https://github.com/RADIO-PROJECT-EU/HumanPatternRecognition
	Logger of walking speed measurements	v1.0	https://github.com/RADIO-PROJECT-EU/hpr_wrapper
Microphone	Audio analysis	*N/A*	https://github.com/RADIO-PROJECT-EU/AUROS
Navigation and other auxiliary robot components			
Navigation		v1.0	https://github.com/RADIO-PROJECT-EU/turtlebot_apps
Robot description		v1.0	https://github.com/RADIO-PROJECT-EU/turtlebot
Initialization scripts for motor and sensing hardware		v1.0	https://github.com/RADIO-PROJECT-EU/turtlebot_radio_bringup
Node orchestration platform		v1.0	https://github.com/RADIO-PROJECT-EU/radio_node_manager

[1] Cf. D6.6 *Controlled Pilot Trials Report*

Navigation and other auxiliary robot components (continued)		
Utilities	v1.0	https://github.com/RADIO-PROJECT-EU/kobuki
Definition of general purpose messages	v1.0	https://github.com/RADIO-PROJECT-EU/robotnik_msgs
Drivers for Kobuki motor and built-in speaker	v1.0	https://github.com/RADIO-PROJECT-EU/kobuki_core
Main Controller components		
Central action planner for integrated RADIO Home	v1.0	https://github.com/RADIO-PROJECT-EU/radio_actions_manager
Gateway between ROS and Radio user GUI	v1.0	https://github.com/RADIO-PROJECT-EU/rostful
The frond end for the Radio user GUI Web app (mobile device side)	v1.1	https://github.com/RADIO-PROJECT-EU/radioUserGUI
The back end for the Radio user GUI Web app (main controller side)	v1.0	https://github.com/RADIO-PROJECT-EU/radioWebApp
Gateway between ZWave sensors and ROS components	*N/A*	https://github.com/RADIO-PROJECT-EU/motion_detection_sensor_py
Emergency stop Android application	v1.0	https://github.com/RADIO-PROJECT-EU/radio_stop_button_android
Offline R&D Tools		
RoboMAE multimodal sensor data visualization and annotation tool	v2.0	https://github.com/RADIO-PROJECT-EU/RoboMAE
Gazebo models for the RADIO Robot	2.2.2-radio	https://github.com/RADIO-PROJECT-EU/turtlebot_simulator
Logger and visualizer for bed transfer and pill intake events	v1.0	https://github.com/RADIO-PROJECT-EU/motion_analysis_consumer
Navigation testing tool	v1.0	https://github.com/RADIO-PROJECT-EU/turtlebot_checkpoints

3 SMART HOME ARCHITECTURE

3.1 Introduction

The smart home architecture in RADIO has several requirements that need to be fulfilled. The product that RADIO will employ for creating the smart home solution is called *enControl*™. *enControl*™ provides an initial solution for home automation, and will be enhanced and upgraded complementing other technologies and developments within RADIO that will form the final RADIO solution.

enControl™ is a white label B2B product by Sensing & Control Systems providing a smart home solution.

At a glance, *enControl*™ has four main functions:

1) Comfort
2) Security
3) Energy Management
4) Automation

Users of *enControl*™ are able to monitor and control remotely their homes & business using smartphones or any device running Web browsers, like tablets or PCs.

enControl™ can be divided into three main components, (i) home devices, (ii) IoT Platform and (iii) graphical user interfaces (as shown in Figure 2).

At home level, *enControl*™ is composed by (i) end devices (sensors and actuators) and (ii) home controller (Gateway). The gateway supports communication using different protocols, but mostly uses ZWAVE radio technology for the communication of off-the-shelf end devices and home controller.

There are more than 300+ companies providing ZWAVE with more than 1300 products[2] which enables *enControl*™ to deliver the four main functionalities highlighted above. The following list[3] extends the four main functionalities from the point of view of the information triggered by the end devices:

1) Comfort
    a. Climate monitoring
    b. Climate control
    c. Temperature, Humidity, CO_2 (etc…) levels
2) Security
    a. Detection of door/window opening
    b. Detection of movement
    c. Detection of Smoke
    d. Detection of CO
    e. Detection of water basement
3) Energy Management
    a. Energy consumption
    b. Energy control (switch on/off electricity, water, gas, etc…)
4) Automation
    a. Switch on/off appliances
    b. Switch on/off lights
    c. Open/Close doors, curtains, shutters

[2] According to http://z-wavealliance.org

[3] The list does not pretend to cover all possibilities, the Reader should understand that the smart home solution can integrate any ZWAVE standard product, thus enabling the functionality delivered by a particular product. For a full list of products, please visit ZWAVE alliance web page.

By exploiting or aggregating smart home information per se, and/or with other RADIO components information, insights on the activity being generated by sensors can provide means of inferring the end-users' activity. The combination of the smart home with other RADIO components provides an assisted living environment that does not rely on any intrusive devices, such as wearables attached to the end-user.

The home controller is a product from Sensing & Control, and complements the smart home functions delivered by the IoT platform.

The IoT platform contains the core of the smart home solution. It provides an open REST API enabling the home controllers to exchange information bi-directionally, based on synchronous or asynchronous actions triggered by IoT or end users through *enControl*™ interfaces.

The IoT platform serves as well as main repository of information, keeps historical information about end devices data (information and status) as well as basic actions triggered by different actors, so users of the smart home solution know in real time who-when-what of actions monitored (for instance "the TV set has been switched on by Maria on 11 July 2015, 20:30 CET").

The open REST API is used by user interfaces through web clients and smartphone apps in order to present to end users the information being acquired from home end devices, and the action than can be triggered to them, so it encapsulates the offered smart home functions.

It is important to notice that *enControl*™ clients (smart phone apps and Web interfaces, 3rd party services, etc.) require internet connection to interact with the smart home through the API. It should be noted that experience with deployment of the solution is that this introduces no perceptible delay in executing actions by ZWAVE devices.

The main home controller target is to timely exchange information between devices and the IoT Platform (and thus with end users), and information being generated by the home controller itself. However, it additionally provides three important functions:

1) Management of ZWAVE network and devices
2) Basic pre-processing capabilities (mainly energy calculations)
3) Local information repository in order to deal with temporal internet cut offs (so historical information is kept to be sent when internet connectivity is resumed).

The current smart home solution provides an intuitive and user-friendly interface, which is similar for tablets and PCs (web interface) and smart phones.

3.2 Home Automation Conceptual Architecture

Figure 2 represents *enControl's™* service architecture. Following up on the high level details about overall service provided above, this section focuses on those aspects of *enControl™* that facilitate the integration of the current *enControl™* version into the RADIO's AAL solution.

The IoT platform is able to connect, transport, process, analyse and manage data from the sensors to the real world to high-level applications and vice versa. It is able to operate in a booth wireless/wired network environments and supports different communication protocols. As a function summary:

- **Collect data**

  Collect data refers to the ability to retrieve and store information for further exploitation about all the parameters that are relevant to the system: messages, device status, commands, errors, exceptions.

- **Analyse data**

  The IoT Platform has processes in charge of analysing data and taking decisions based on the quality/importance/integrity of this data.

- **Data Aggregation/Data Fusion**

  Data aggregation refers to the ability to concatenate info from devices, for example when there is a mix of information between data from mash-up sensors.

  Data fusion, is the process of integration of multiple data and knowledge representing the same real-world object into a consistent, accurate, and useful representation.

- **Translate data**

  This feature is related to the ability to transform raw data in bytes from the devices to high-level information.

- **System monitor**

  The IoT Platform is able to monitor the communication between devices and high level apps; and the overall status of the platform and device network. For instance, it is used to monitor key performance indicators like the number of messages sent per minute, number of exceptions/errors, number of devices connected to the platform, etc.

- **Transfer**

  The platform provides mechanisms to publish subscribe information to the queues exposed by the SDK.

- **Audit information**

  In order to enable traceability of the functionality of all sub-systems, active logging is implemented within the software components. Log files are stored and made available for analysis.

- **Secure components and communications**

  Communication between components and devices are secured.

The current solution of *enControl™* provides means of interaction with home devices by accessing dedicated functions of the open API of the IoT platform. This implies that other ICT solutions (either at home like other RADIO components or remotely) willing to interact with *enControl™* must have internet connection.

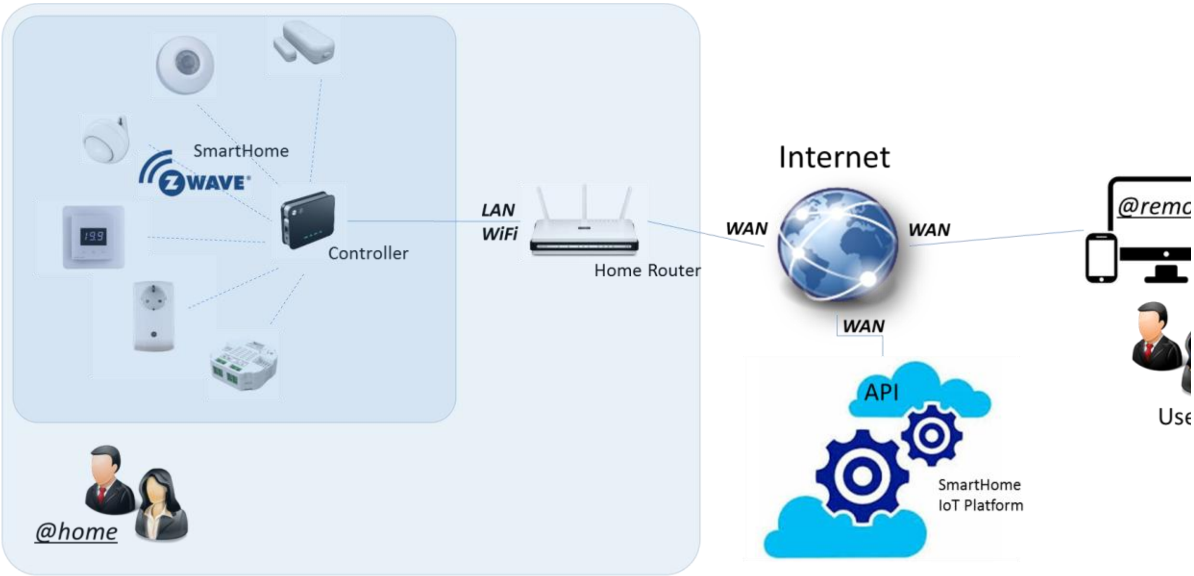

Figure 2: enControl™ *Service Architecture*

The API is divided into following main groups:

1) Authorisation and Authentication
    a. Functions used to grant access to different IoT resources and API functions
2) Devices
    a. Functions related to push and retrieve device status and data (including historical data)
3) Users
    a. Functions related to the management of users
4) Installations
    a. Functions related to the management of smart home installations
5) Monitor
    a. Functions related to the status monitoring of the IoT

On the other hand, the smart home controller has computational resources as well as physical interfaces that can be used to connect third-party transceivers so to enable connectivity via WiFi or Bluetooth for example. The controller is a compendium of Java programs, from the Hardware Abstraction Layer (HAL), devoted to ZWAVE communication, and other available HW transceivers, to the smart home application (controller part) running on top of a Linux-enabled controller. For RADIO, *enControl*™ controller will be delivered running on Raspberry Pi.

Any additional code targeted to run on the home controller should only minimally affect the running main functions. Otherwise the responsiveness of the controller in front of potential user actions may be compromised leading to poor performance, which in turn may trigger potential rejection of the overall solution.

Table 6 summarizes the functionality from the smart home to be exploited by the overall RADIO solution (locally at home), and at which level this can be achieved and the expected effort (using a three level scale when not already available)

3.3 Smart Home contribution to recognition of interRAI items

Section 2 provides a summary of InterRAI assessment items for different ADL items, cognitive and mood, conditions and continence items, which have been listed in D2.2. Section 2 provides a wide vision on different technologies (deployable at home) capable to provide means of assessment of the InterRAI items, in combinations with health records and interviews.

This section provides a link between the different capabilities of the smart home (based on sensors data and current functionalities) that can be used to complement the methods described in Section 2.2.

The Smart Home solution continuously collects and stores data and status of different sensors and actions requested to actuators. The type of data collected directly depends on the off-the-shelf devices available on the market and deployed at home.

Table 7 provides an overview of the potential of smart home sensor data to complement the sensors and methods presented in Section 2.2. Further exploration will be done together in coordination with WP2 and other tasks in WP3 to take full profit of smart home service on this goal.

Table 6: Local Smart Home API functions vs. development effort

Smart Home API Function	Impact on ICT resource		
	IoT	Gateway	Other
Real Time Data/Status (smart home devices)	Available	Med	-
Real Time Actuation (smart home Devices)	Available	Med	-
Access Historical data (generated by smart home devices, data aggregation/fusion)	Available		High (1)
Configuration (smart home devices)	Available	Med	-
Scheduler	Available	High (2)	-

(1) Data base and associated services are needed, including high capacity hard drive to keep historical data
(2) Including scheduler engine running at GW level

Table 7: Smart Home data for ADL computation

Assessment Item	Name	Smart home Contribution	Sensor Data / comments
ADL Self Performance	Bathing, personal hygiene	Yes	Presence and water consumption.
	Dressing upper body; dressing lower body	No	
	Walking, locomotion	Yes	Presence.
	Toilet transfer	Yes	Presence and water consumption.
	Toilet use	Yes	Presence and water consumption
	Bed mobility	No	
	Eating	No	
Assessment Item	**Name**	**Smart home Contribution**	**Sensor Data / comments**

Locomotion and Walking	Distance walked	Yes	Presence
Activity Level	Total hours of exercise or physical activity in last 3 days	Yes	Presence, mobility at home. Where has been and when
	Number of days went out of the house in last 3 days	Yes	Presence detection, arm/disarm
Activity Preferences and Involvement	Cards, games, or puzzles; crafts or arts; reading, writing, or crossword puzzles	no	
	Computer activity	yes	Smart plug, energy consumption
	Conversing or talking on the phone	no	
	Dancing	no	
	Exercise or sports	no	
	Gardening or plants	yes	Presence detection
	Helping others	no	
	Music or singing	no	
	Pets	*N/A, presence of pets is not considered in the RADIO experiment environment*	
	Spiritual or religious activities	no	
	Trips/shopping	*N/A, RADIO operates indoors*	
	Walking or wheeling outdoors	*N/A, RADIO operates indoors*	
	Watching TV or listening to radio	yes	Smart plug, energy consumption
	Discussing and reminiscing about life	no	
Time Asleep During Day	Time Asleep During Day	no	

4 WSN AND COMMUNICATION ARCHITECTURE

In this chapter, the wireless sensor network of RADIO is explained. This includes the technical requirements for the integration of the robot platform and the sensors it mounts with the RADIO Home automation devices and their communication gateway. The particular point of interest is that besides the sensors that are mounted on the robot platform's on-board computer, the platform also foresees Bluetooth sensors that directly interact with the BLE network in the Radio Home.

4.1 Technical Requirements on Wireless Communication

In this section we identify and analyse the main requirements based on which adequate wireless communication technologies will be adopted, configured or even extended so as to meet the objectives of the RADIO project. Respective requirements stem both from the user requirements as they are defined in WP2 as well as the purely technical demands of a state of the art wireless sensor network. It is noted that in this version we mainly focus on the main requirements axes pertinent to the first phase RADIO system prototype and that the architecture will be extended and adapted.

4.1.1 Low Power Operation

The ability of a wireless communication to promote power consumption minimization comprises a characteristic of paramount importance. Meeting such objective is a multifaceted task involving many critical aspects of a wireless communication platform concerning both hardware and software aspects. Starting with a physical medium, the respective technology must support low power transmission, receive, idle, and sleep operation modes (e.g., typically transmission power in nowadays WSN technologies do not surpass 0dBm but can go as low as -30dBm). Additionally, other relative mechanisms such as modulation schemes, frequency bands, frequency channels etc. must also be selected taking into consideration power conservation.

With respect to the typical WSN software stack as depicted in Figure 3, moving up the network stack the MAC layer is also of critical importance as far as power consumption is concerned. In this context efficient, flexible and adaptive scheduling allows the network device to remain in sleep state (i.e. support of very low duty cycle) is without a doubt a cornerstone in nowadays dominant communication technologies striving towards power conservation. Of course such an objective entails highly efficient mechanisms so as to avoid robustness degradation. Additionally, optimized control operations/communication come into play also representing a substantial part of the MAC overall duties. Adequate routing support (when/if needed) can also pose important challenges with respect to power consumption, thus dominant communication technologies promote specific routing approaches further enhancing their power conservation capabilities.

Although respective standards do not indicate specific restrictions, another aspect pertaining to the system-wide low-power capabilities is related to processing units supporting any specific technology. On one hand specific architectural characteristics such as bus width, cache support, pipeline utilization, hardware accelerators support, multi-core support etc. drastically affect the trade-off between processing speed and power consumption. On the other hand, the adequate support of low power operation modes is very important in the context of the specific requirements definitions. When it comes to WSN networks and cyber-physical systems, all key companies (e.g. TI, ARM) offer solutions focusing on this aspect such as the well know TI MSP430 or/and the ARM Cortex M family (with Cortex M0 being the most power conservative representative).

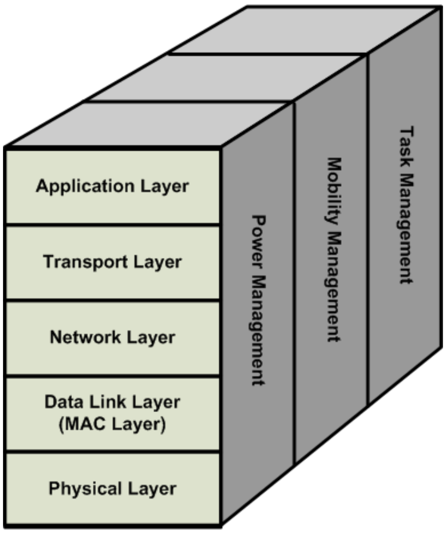

Figure 3: Wireless Sensor Network Software Stack

4.1.2 Easy and Rapid Connection Support

Typically, all connections between two specific nodes are characterized as either *connection-based* or *connectionless*, with each approach offering specific advantages and disadvantages. Connectionless communication is less complex since it needs no extra mechanisms to setup/maintain/end a specific connection which also means the whole protocol is much lighter. It also claims to pose less delay by comparison to the delay a connection-based communication adds to either form a connection, or re-establish a connection. Finally, such a connectionless communication makes multi-hop and mesh networks much easier to form. Connection-less communication is typically found in IEEE 802.15.4 networks.

However, connectionless communication offers no inherent support towards robust data transfer, load balancing, QoS and in general traffic control. It is noted that such requirements are increasingly required in nowadays and future WSNs since the applications increase in complexity, criticality and communication demands. In connection based communication, the two communication nodes usually assume a specific role (e.g. master/slave) and agree on the characteristics of the communication, so as a scheduler can anticipate traffic workload and QoS demands so as to prepare an efficient packet transmission schedule. Typical communication technology traditionally following this approach is the Bluetooth technology.

Finally, it is noted that since both approaches offer important advantages in nowadays WSN application dominant communication technologies, more and more offer functionalities enabling both communication approaches. Such capabilities are expected to offer increased flexibility and must also be taken into consideration.

4.1.3 Data Throughput Capabilities

Without a doubt a data volume per specific time period a communication can handle comprises a critical metric in all network types. However, in WSN typical application scenario and specifically in RADIO the respective requirements are anticipated to be low or moderate (e.g. in the order of a few tens kbps) so as to be easily accommodated by existing solutions. Specifically, the modality that will comprise the most demanding case will be low/medium quality audio which effectively will be an important guideline as to the technology and additional mechanisms that may be needed (e.g. telephony speech audio source produces 8bit samples with a frequency of 8kHz yielding a traffic of 64kbps which can be considered the upper limit of what might be required).

Of course an unpredictable factor is the concurrent traffic flows and how they are accommodated, especially the burst traffic that is typical of realistic WSN scenarios. Such scenarios will also introduce respective requirements as far as data handling is concerned.

Furthermore, throughput capabilities relate to the mechanisms a wireless technology employs to assure robust communication. By this requirement we refer to the mechanisms each communication employs so as to, on one hand, avoid packet collisions and on the other hand, accurately and rapidly identify a packet collision and recover from it. Such mechanisms include efficient clear channel assessment mechanisms, CTS/RST control packet exchange, CRC (Cyclic Redundancy Check) and support for acknowledgment mechanisms.

4.1.4 Delay - Jitter requirements

Analogous to the throughput capabilities, mean delay and respective requirements are anticipated to be relative relaxed, although this expectation remains to be confirmed by testing on use cases and scenarios specific to RADIO. Once again audio will most probably comprise the most important challenge and particularly with respect to the delay jitter that the network will exhibit. Delay jitter can prove to be important either to the understanding of a particular audio modality as well as to the processing algorithm of that audio modality by the respective algorithms demanding the packet sequence to have a specific inter-arrival delay (e.g. to accurate reproduce the actual audio).

4.1.5 Quality of Service Support

As the WSN technologies are utilized in an increasing range of applications scenarios and as the users' tend to pose increasing demands upon respective deployments, the needs for advanced quality of service capabilities is drastically increasing and is expected to do so in the future. By quality of service we refer to the differentiation among data traffic flows with respect to various (as well as dynamically changing) parameters as well as differentiation among users. With respect to such differentiation a communication technology is able to apply appropriate methodologies so as to meet the different requirements posed by each category in each particular time (to the degree that is possible). Also it is valuable to allow the developer to apply custom algorithms so as to apply specific policies. In the MAC layer, such capabilities are typically dependent upon the access scheme utilized, typically CSMA, TDMA or a combination of these two.

Carrier Sense Multiple Access (CSMA) is the most common distributed access approach where each node operates independently from each other trying to access the wireless communication medium. Being very simple to implement and not requiring any coordination was quite prominent in earlier WSN deployments were no QoS was required or/and the traffic demands were very low. However, as demands increase CSMA reveals some significant disadvantages since it is very difficult to apply algorithms to meet strict QoS demands. Furthermore, in high traffic scenarios packet loss increases exponentially leading the network congestion and even effectively communication collapse. Different versions of CSMA based approaches are quite popular among the IEEE 802.15.4 based platforms. By contrast, *Time Division Multiple Access (TDMA)* assumes a commonly known schedule which clearly defines which communication node can transmit in each particular time slot and, in general, assigns a specific role in each particular time slot of a more extended time period usually referred to as frame. As it is easily understood through such a framework, an algorithm can allocate each traffic flow appropriately so as to meeting each particular requirement and minimize the possibility of collision. Also through such mechanisms, maximum power conservation can be achieved since a node is aware of when for how long it needs to be awake. However, WSN being a typical network facing both low and possible burst traffic periods a prominent approach is to combine the two extreme approaches so as to exploit the benefits of both. Bluetooth is such an example segmenting the time in large frames and time slots when specific needs are to be met, but allowing during specific time period to all interested nodes to compete for access to the medium using CSMA approach.

4.1.6 Open Source Approach Support

As RADIO is primarily a research project, the open source approach is highly appreciated in all aspects of it. Particularly with respect to the WSN communication technology, offering accessible standards, well-defined APIs and even access to the internal functionality of respective communication protocols and mechanisms also comprise a valuable requirement. Without a doubt the degree by which aforementioned features are offered by a specific communication technology can greatly influence the configurability and extensibility of the respective solution offered in the context of RADIO. Also availability of adequate development environments play an important role, since they can help reduce the time required from the thinking a solution to actually developing it and testing in the actual environment drastically.

4.1.7 Network topology flexibility

Unpredictable, rapid and dynamic topology changes are an inherent characteristic of WSN networks. Even more, support of such conditions is an important advantage of such technologies over other typical network types. Therefore, it is a critical requirement for a respective communication technology to support or/and give the tools to develop algorithms to support such cases. On the one hand, unpredictable topology changes lead to increased/decreased of network congestion in particular areas of the network and in general changes in the communication conditions that the technology must take into consideration and adjust adequately. On the other hand, unpredictable topology supports cases were a node can't communicate directly with the intended receiver and thus intermediate nodes act as relays to forwarding data packets towards the final receiver. The communications technology must facilitate that specific nodes (or all nodes) of the network can assume the role of a relay. Furthermore, the communications technology must allow for dynamically changing multi-hop data routes. This includes providing the route discovery, maintenance, and deletion functionalities of routing protocols. It is noted that in realistic WSN networks such as RADIO, a tree based data flow topology will be required so that when/if a node(s) cannot reach directly the gateway they may have the opportunity to convey respective data over multihop data paths.

4.1.8 Well accepted by Industry and Academia

Aiming towards a platform of an extended and evolving life cycle it is beneficial to rely on communication technologies that have a significant footprint in both industry and academia. Having a substantial impact and acceptance in industry through respective commercial solutions or/and being integrated as 3rd party solutions in commercial products indicates a viable and practical solution as well as adequate support can be anticipated. Also being adopted by key players comprises a critical advantages concerning longevity, extensibility as well as expandability (in different application domains, modality support etc.) of the respective communication technology. On the other hand receiving high interest from academic research groups is also important in the context of the RADIO as a research project since it indicates an open approach allowing researchers/designers/developers to further experiment and extent respective solution to meet specific research objectives. This leads to the formation of an extended research community which resembles a significant plus when specialized research is needed.

4.1.9 Security Support

Although left for last, security support comprises one of the most important and critical features of nowadays and future communication technologies in WSNs. This is due to the fact that WSNs' utilization is expanding to highly critical application domains such as healthcare and wellbeing of users which directly relates to safekeeping of highly private personal data as well as the adequate management and distribution of them. The RADIO project platform lays in this context since private data or/and events may be acquired, stored, wireless transmitted and processed.

Security support comprises by three services: data privacy, authentication and authorization. The first one relates to the assurance that data can be "understood" (i.e. by useful information) only by nodes that have the right to do so, while for the rest of the nodes effectively are useless bytes. This service typically relies on the capabilities of WSN nodes to execute sophisticated encryption algorithms offering high security level. Consequently, inherent support of such cipher algorithms by the used communication technology is a significant added value. The second service allows nodes to prove they are who they claim to be which effectively allows accountability and is a prerequisite for the third service which effectively determines what level of access can a specific user have to certain data or/and functionalities. It is easily understood that in scenarios of RADIO which accesses personal data, habits, activates, whereabouts and environmental conditions such features can be of critical importance.

4.2 Wireless Communication Architecture

The operating environments targeted by RADIO are domestic homes of elderly people. These homes generally do not have sufficient technological infrastructure to provide ad-hoc ambient assisted living (AAL) services. In order to guarantee that the impact of the RADIO system is not limited by requiring specific communication infrastructure to be prior deployed at the end-users' homes, we consider the infrastructure connecting the RADIO components to be a substantial part of our architecture design.

Specifically, the RADIO communication architecture includes:

- The wide-area communication between each RADIO Home and remote components, such as storage and processing facilities at the hospital or notification functionalities at care-givers' devices. We do *not* delve into any further details here, as this is the subject matter of Task 5.1.
- The local, mostly (or even exclusively) wireless communication of the components deployed within each RADIO Home.

The RADIO Home environment itself comprises subgroups (Figure 8), each fulfilling a different task and designed in response to different requirements:

- Basic smart home: Off-the shelf smart home devices
- Extended smart home: Advanced devices, integrating sensing and low-energy processing, as well as the RADIO Home server
- Mobile platform: Robotic platform, integrating sensors and limited computation functionality
- User interface devices

In order to provide long term support and reliability, the *basic smart home* sensor and actuator devices will be commercial off-the-shelf components such as Z-Wave products. Z-Wave is a wireless communication protocol designed for close range sensor and actuator networks. It does not require a coordinator node as it automatically initializes a full mesh network[4]. However, in the context of RADIO coordinator nodes are used for Z-Wave in order to ensure connection robustness and reliability. This way, it is possible to modularize the architecture and expand it with additional sensors if necessary. There are sensors and actuators for data acquisition in order to react accordingly to user stimuli. However, by contrast to some current smart home architectures, the individual devices should *not* require internet connectivity for their operation. This is due to the privacy requirement that all raw data processing must be carried out within each home and only high-level event logs should be recorded at cloud storage or other remote databases. This includes not only interRAI item recognition logs, but also system operation events (such as using smart home functionalities).

The *extended smart home subgroup* will rely on Bluetooth to connect devices that carry out sensing and local processing in order to recognize daily activities and routines. Such devices cannot be developed for Z-Wave, due to its closed specifications. This creates the requirement for a gateway that interfaces

[4] Z-Wave Alliance. http://z-wavealliance.org/, date of access: August 2015.

between Z-Wave and Bluetooth, in order to allow RADIO to combine the robustness offered by commercial Z-Wave devices with the flexibility to develop new devices offered by Bluetooth. The Bluetooth subgroup consists of devices equipped with the Bluetooth Low Energy (BLE) technology (marketed as Bluetooth Smart). The BLE was adopted to the Bluetooth standard as Bluetooth Core Specification version 4.0 in 2010 aiming in healthcare, security and smart building applications with considerably reduced power consumption.

The Bluetooth subgroup will utilize the wide adoption of BLE by modern consumer electronics and will deliver an ambient environment with interconnected devices and household appliances. Through this extended domestic network coverage, the RADIO project will develop applications that will improve the autonomous living of elders. Indicative applications will be the mapping of the RADIO home space enabling object localization functionalities/services or/and applications requiring mobility support. In that respect an approach affecting the conceptual architecture of the RADIO project, focuses on enabling mesh networking over BLE. This approach overcomes the constraints of one – hop communication that was followed by all the Bluetooth versions so far. The mesh networking over BLE will achieve data transmission between two devices with transmission ranges that do not intersect. The only requirement that must be satisfied is the existence of a full connected BLE network. In that context, the RADIO BLE mesh subgroup abandons the connection – oriented communication of traditional Bluetooth and explores the potentials of the connectionless communication. In the connectionless mode of operation, the BLE modules broadcasts advertisement packets without requesting the establishment of a connection with any other BLE module. In that context, we alter the scope of the advertisement packet which aims on discovering nearby devices and we utilize the limited advertisement packet length (can consist of no more than 31 bytes) as a data carrier packet. The BLE modules will transmit requests and data from source node to destination node through the advertisement packet and if additional payload is required the scan response packet will be also utilized. The link with the rest RADIO environment (e.g. devices equipped with other wireless technologies and the backend server) is the mobile platform that operates as a gateway, responsible for the interconnection of the heterogeneous networked elements of RADIO home and routes data and requests among them.

Finally, the mobile platform establishes its own internal network in order to integrate its various sensing and processing elements, but also needs to connect to the overall RADIO Home. The platform is outfitted with two interfaces, the Bluetooth Low energy (BLE) and the WiFi interface. BLE connectivity is provided to support direct access to devices of the extended smart home and WiFi connectivity for data transfer requirements.

This analysis gives us the architecture in Figure 8 where the Z-Wave network, the Bluetooth network and the TCP network interface at a *central gateway* and where:

- The devices of the basic smart home connect to the Z-Wave network
- The devices of the extended smart home connect to the Bluetooth network
- The mobile platform connects to the TCP and the Bluetooth network

The gateway also serves as the central data processing point, since it is connected to all available devices in the smart home environment. Finally, the gateway interfaces with remote components of the RADIO ecosystem over the Internet.

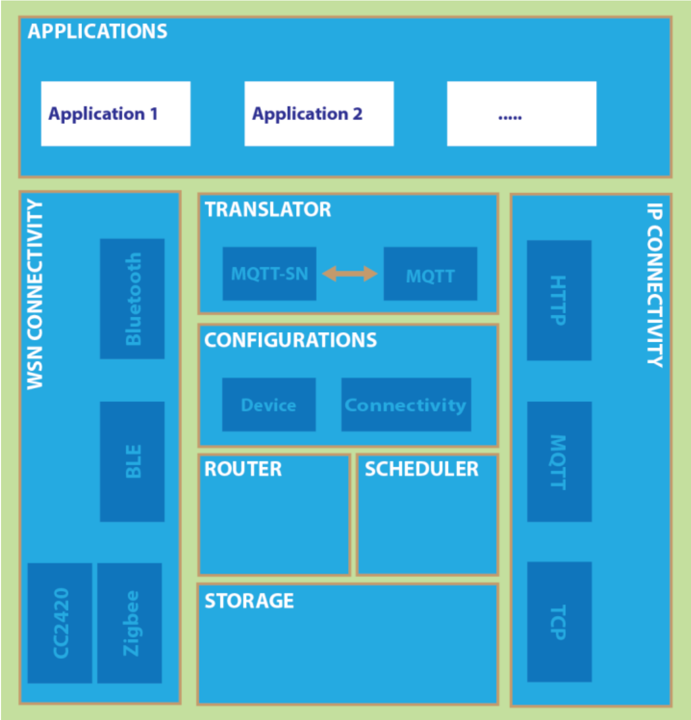

Figure 4: Novel BLE-ZigBee Controller Architecture Approach

Focusing on Bluetooth Low Energy network, novel gateway approaches will be explored able to support heterogeneous wireless communication protocols, such as Bluetooth Low Energy (BLE), 802.15.4, and Bluetooth Class 2, in a homogenized manner (indicated as BLE-ZigBEE Controller). In that respect a critical requirement concerns to the software that will be running on the BLE-ZigBEE Controller which should be lightweight enough, so it can be efficiently supported by devices with limited resources, like Raspberry Pi,[5] easy to be managed and finally secure. From the communication perspective, such as controller must support, widely used backend communication protocols, such as well-known HTTP and more advanced and widely utilized protocols like Message Queue Telemetry Transport (MQTT), for demanding applications. Finally, in order for the envisioned BLE-ZigBEE Controller to be fully operative both offline and online local storage capabilities must be provided.

The proposed gateway architecture is shown in Figure 4. At the top level of this architecture, all user-defined applications that will be run in our Gateway are highlighted. An example of such application, is a monitoring application for the lights of a house. Moving towards to lower layers of the software stack, required networking modules are defined aiming to handle communication requirements as well as a storage module for handling storage requirements.

As depicted in Figure 4, on the left and right hand sides of the architecture scheme, connectivity modules are depicted effectively offering the required heterogeneous communication capabilities on the gateway, for both WSN and IP networks.

On the bottom of the software stack, the storage module is presented providing local storage capabilities to the controller which is particularly important for offline operation. We need a lightweight, embeddable database engine without additional components, which must be scalable, persistent and secure, which are important factors for embedded applications. The storage must provide an easy to use Application Programming Interface (API), able to perform Create, Read, Update, Delete (CRUD) operations.

[5] Cf. https://www.raspberrypi.org

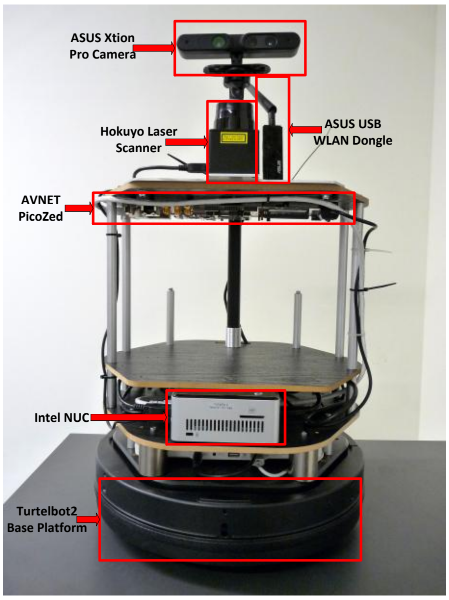

Figure 5: RADIOs robot platform outfitted with camera, laser scanner, the two processing platforms and the WLAN dongle

As an example of such operation, in a localization application, the application can store the current location of the moving object and later retrieve all these locations in order to estimate the new location. Another use of the local storage, is when a network connection is unavailable, and a request is waiting to be executed. The request can be stored to the database and executed when the connection is available again.

On top of storage module, we have the Router and Scheduler modules. The Router module is an embedded mediator in the BLE-ZigBee Controller which is responsible for forwarding messages to the appropriate endpoints in order to be published either to the WSN or to the IP network. The Scheduler module is responsible to carry out repetitive or individual tasks, defined in schedule based or event based conditions.

Finally, two additional modules are defined. The configuration module holds all controller configuration parameters that needed in order to be operational. Finally, the translator module is responsible to translate WSN compatible data to IP compatible data and vice versa.

4.3 Robotic Platform Architecture

Within RADIO, a TurtleBot2 provided by ROBOTNIK[6] is used as robot platform. Out of the box, the TurtleBot2 features odometric sensors for accurate odometric measurements as well as bump, cliff, and wheel drop sensors. One advantage of the TurtleBot2 is the open source philosophy for the firmware and other applications, allowing an easy integration into different frameworks such as the RADIO environment. Since the robot should act autonomously and not be controlled remotely, it needs to be interconnected to the smart home environment. The processing platform is an Intel NUC and is responsible for controlling the base platforms sensors and actuators. Therefore, it is directly connected to the TurtleBot2 base platform via USB.

[6] ROBOTNIK Automation S.L.L. http://www.robotnik.eu/, date of access: August 2015

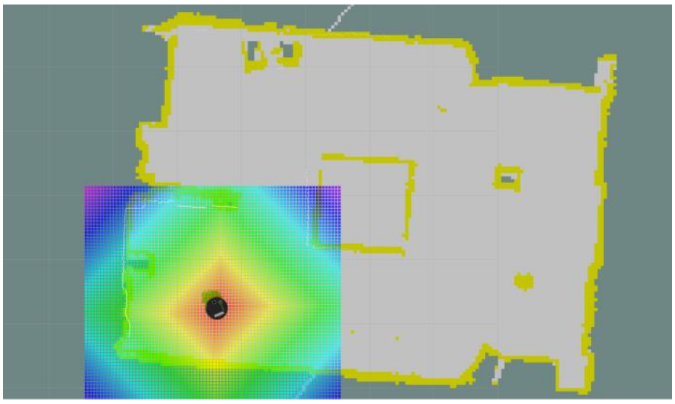

Figure 6: Mapped exemplary room and estimated position of the robot.

Additional devices that are placed on the robot are an Asus Xtion Pro camera and a Hokuyo laser scanner. These two devices are connected to the processing platform. The Intel NUC supports two wireless communication interfaces, the Bluetooth Low energy (BLE) and the WiFi interface. BLE connectivity is used for localization tasks performed by the robot, while the WiFi interface is required to connect the smart home environment and to the IoT platform. The setup of the robot platform is also depicted in Figure 5.

Initial tests showed that the localization performance is reduced when both the BLE and the WiFi interface operate at the same time. This is because the localization task requires requires accurate readings of the received signal strength indication values of the respective BLE devices. Because both interfaces are placed on the same network chip, the Wifi interface interferes with the BLE interface and vice versa. In order to reduce this interference, an external Wifi USB interface is used and connected to the Intel NUC.

The following subsections outline a set of functionalities that must be efficiently executed on the robot platform. This deliverable mainly focuses on the navigation functionality.

One fundamental problem in robotics is *Simultaneous Localization and Mapping (SLAM)*, also known as *Concurrent Mapping and Localization (CML)*.[7] It arises when neither a map of the surrounding, nor the actual position of the robot is known. Several algorithms such as SLAM with *Extended Kalman Filters (EKF)* and with *Particle Filters* address this issue. The robot simultaneously creates a map of the environment and localizes itself relatively to this map. Within the RADIO project, a SLAM algorithm will be implemented in order to allow self-localization estimation of the robot within the smart home. Without this feature, the flexibility of the robot would be limited to a predefined map created before bringing the robot into operation. Based on the results of the SLAM algorithm, the robot is aware of its own position and can further use this information to navigate autonomously through the environment, supporting the unobtrusive monitoring of the patient. This goal creates new challenges for man-machine interaction, as the robot should never become an obstacle for the human. Additionally, the robot is required to autonomously start the mapping process in "out-of-the-box" mode, meaning that it should detect by itself that its surroundings are unknown. When this detection is completed, the robot should start the mapping process. When autonomously mapping the surroundings, the robot will follow a contour (e.g., a wall) and chart the unknown environment with the data of the laser scanner and of its odometric sensors. Figure 6 shows the results of the mapping process.

[7] Thrun, S., Burgard, W., Fox, D. "Probabilistic Robotics", The MIT Press, ISBN 978-0-262-20162-9.

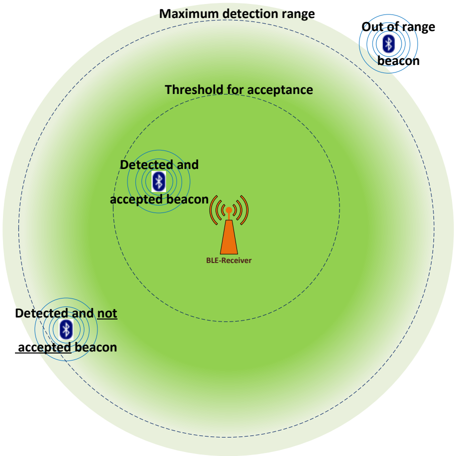

Figure 7: Thresholding of range determined through the RSSI values of BLE beacons

Localization is very important for the cognition task since it provides the most relevant data regarding current distances to obstacles for safe navigation through the environment. The localization task depends on the data from the perception task. For localization within the SLAM algorithm, a particle filter can be chosen since it easily incorporates information from different sensor types, thus enabling sensor data fusion.

With additional sensors, the robot is also able to localize other objects. This can be accomplished with the Bluetooth devices that are positioned within the house. Thus the robot can also help the end-user to search for an item which is outfitted with a BLE transmitter. Because Bluetooth beacons only broadcast their ID, the received signal strength indication (RSSI) is used in order to extract position information out of the beacons signal. The RSSI value can then be converted into a distance measurement. With one beacon, a distance measurement can only define a region of interest in which the receiver is currently located. Through thresholding of the beacons measured distance, simple annotation of regions within an indoor environment is possible. This approach is shown in Figure 7.

5 RADIO CONCEPTUAL ARCHITECTURE

In this chapter, we combine the components described previously into the second version of the RADIO Conceptual Architecture. These components are:

1) The robotic platform
2) Wireless sensor networks
3) Smart Home
4) ADL and mood recognition methods

The Robot is an important element in the RADIO architecture concept. It is an entity that will continuously be in “motion & tracking” elder person activity. The robot is targeted to be the main interface with elderly people, but it is capable to hold computational resources and sensors needed by the recognition methods. Whether or not, the robot will hold them will be decided in future steps within WP4.

The goal of the smart home is to provide means of interaction with different controlled parts of a house, for instance open/close doors, curtains or shuts. Thus, it will provide home automation capabilities at a finger level of the elderly. The smart home thus will be a slave automation component in the RADIO architecture of the applications tailored in WP5. Furthermore, we will complement the data acquisition for the ADL and mood recognition methods, based on the huge amount of off-the-shelf sensors. Sections 2 and 3 provided an initial relation of InterRAI assessment items and RADIO Home data capture capabilities. This initial relation has been provided for the sake of future discussions, and will be updated in next iterations of this document.

All components need to be connected forming the RADIO communication system. RADIO will use common communication technologies between the main components (IP based communications, WIFI or LAN). Section 4 provided an initial overview of main important requirements for the connection of different sensors and actuators in the RADIO architecture, where low power wireless sensor technologies are the target.

Figure 8 depicts the architecture of the RADIO Home communication channels. This architecture does not reflect the physical wireless communication channels which are specified in WP4. It also does not reflect how multiple RADIO Homes, caregivers’ devices, and care services interconnect into the RADIO Ecosystem, developed in WP5.

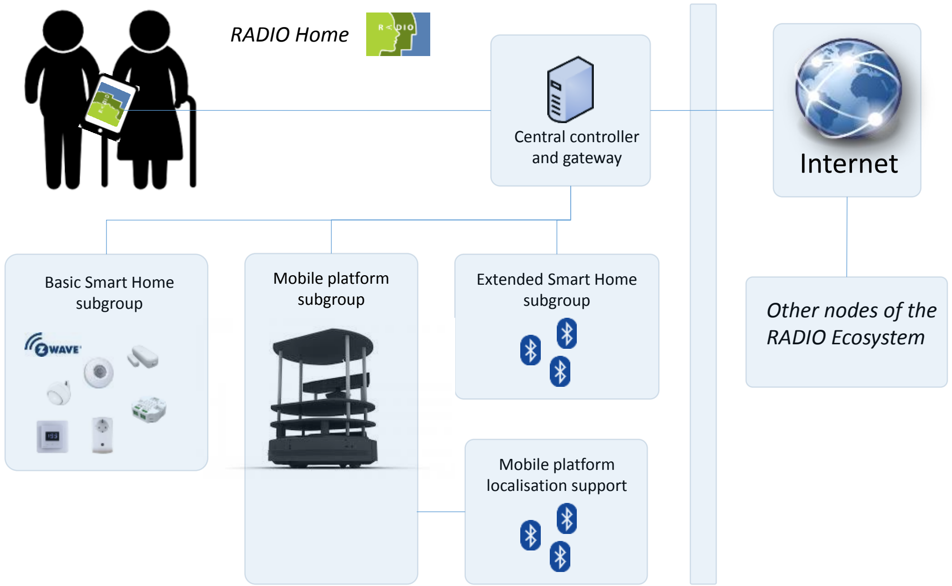

Figure 8: Conceptual architecture of RADIO Home communication channels

5.1 ADL Recognition

Based on our analysis of the ADL recognition methods above, we will now proceed to bundle the relevant components into services and to specify these services' information outputs and requirements. These services will be used as the building blocks of the RADIO ADL recognition architecture.

In our design we foresee the following physical infrastructure:

- acoustic sensors that integrate a microphone with Raspberry Pi
- a mobile TurtleBot2 robot that integrates microphone, depth and colour camera and on-board computer
- a Main Controller, a computer that acts as the gateway to the home and the orchestrator of the overall monitoring and reporting.

There is a single acoustic features interface which publishes a stream of triplets of feature vectors. Each message in the stream contains the current short-term frame feature vector and two mid-term rolling averages of different numbers of frames, to accommodate analyses that require deeper or more shallow acoustic contexts.

This interface was chosen because at our 50 Hz frame rate volume of traffic generated by three floating-point feature vectors is insignificant and this interface lifts the requirement to have a middleware that can latch mid-term feature vectors or synchronize mid-term and short-term feature vectors.

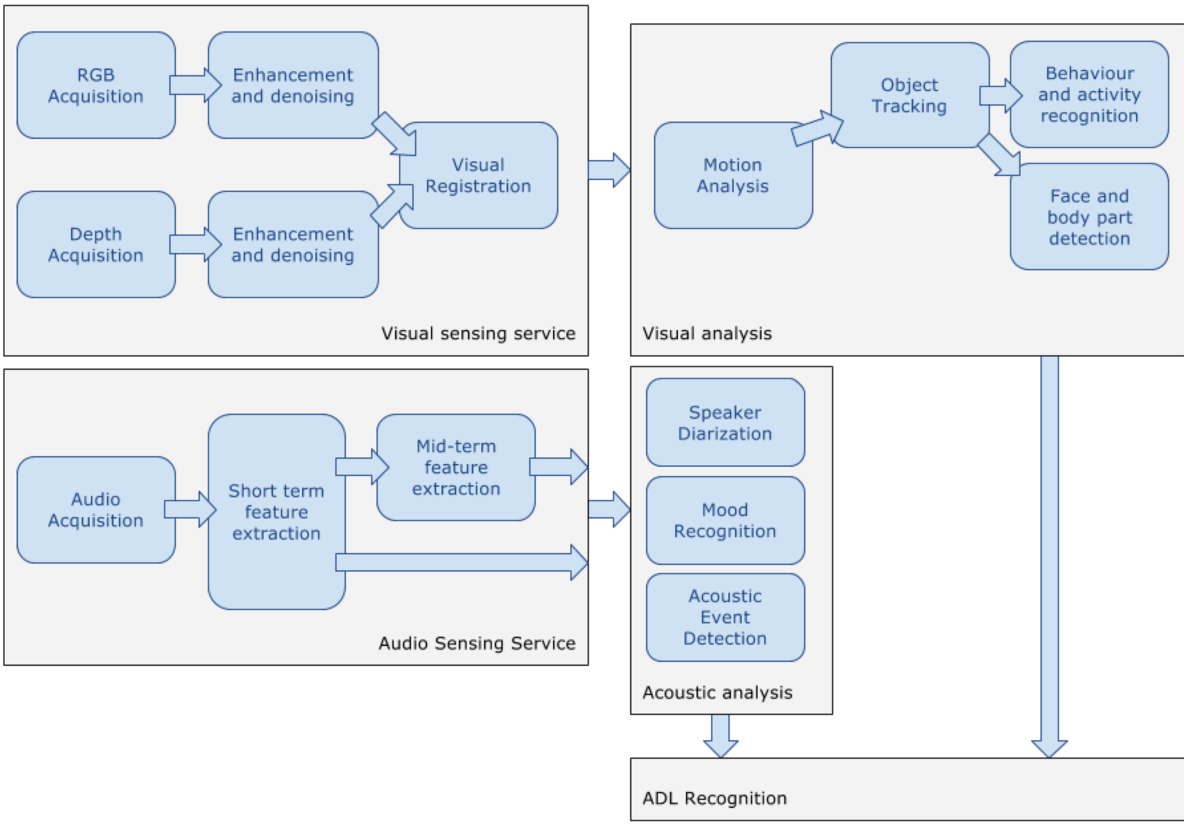

Figure 9: Conceptual architecture of audio-visual analysis

Exposing the complete acquisition-feature extraction pipeline as a single service also allows us to provide a unified acoustic feature service over two heterogeneous implementations:

- The TurtleBot2 implementation comprises a microphone device driver and a feature extraction component that communicate using the ROS middleware. The service end-point is a bridge that simultaneously connects to the robot-internal ROS middleware and to the home WiFi to access robot-external services.
- The Raspberry implementation comprises a microphone device driver and a feature extraction component that communicate using MQTT. The service endpoint is a bridge that simultaneously connects to MQTT and to the home WiFi to access external services.

All instances of the acoustic features service push their vector streams to the audio pattern analysis service. This service implements unsupervised and (previously trained) supervised machine learning methods that recognize ADL events from acoustic feature vectors. The audio pattern analysis service is also distributed, with instances executing at the Raspberry and the robot's computer.

The vision sensing components are analogously implemented as image acquisition, feature extraction, and pattern recognition services. One divergence from the acoustic analysis case is that the graph of dependencies between vision services is not a linear progression from the content to more abstract features and events: motion detection is the only service that constantly consumes features and it triggers more complex analyses as soon as motion is detected. Furthermore, there is no single feature set that is used by all visual analyses and analyses are occasionally stacked more deeply than the features/events/ADLs layers of acoustic ADL detection.

The conceptual architecture is also graphically depicted in Figure 9

5.2 Concluding remarks

The RADIO Conceptual Architecture is a system of services that interact to recognize ADLs from audio-visual sensors. Our design integrates sub-systems which were originally integrated using heterogeneous middleware infrastructures. We have proposed articulation points for re-structuring these existing pipelines into a new set of services. In order to establish the right level of granularity for the functionality bundled under a single service, we used common patterns in the audio-visual analysis literature to identify services that would practically never need to be broken down into finer services.

The most challenging architectural feature to be developed in the remainder of this task is the dynamic handling of early fusion methods. For such methods, the recognition component must have access to both the acoustic and the visual features. In our current design, this is not as issue as in the only situation where this is necessary (scenes captures by the robot) both sensors happen to be on the same ROS middleware and the audio-visual features can be easily consumed by the same component. As this will not be the case in general, we need to investigate how to interconnect early fusion components so that they combine information from different sub-systems (fixed sensors, robot sensors).