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D4.1 System architecture and design specification

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Abstract

The PRECIOUS project addresses the challenge of providing reliable, cost-effective, continuous, pervasive and non-intrusive preventive care services for individuals under risk of non-communicable diseases, namely: cardiovascular diseases and type 2 diabetes. To that end, the aim of this deliverable D4.1 is to specify the design of a pervasive communication infrastructure between sensors and rest of internal processing units in the system, such as, the virtual individual model (VIM) system, the risk analysis and motivational system and the

actuators used to interact with the user. The PRECIOUS architecture specification provides an overall plan on how the different work packages will work towards a common unified architecture within the project and guidelines for interaction between different components of the architecture. Specifically, the architecture provides a coherent framework (both technical and non-technical) for the work to be carried out in the second half of the project in WP2-WP4, as well as, WP5 System Validation.

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Acronyms

2G	Second Generation
3G	Third Generation
3GPP	Third Generation Partnership Project
3GPP2	Third Generation Partnership Project 2
4G	Fourth Generation
AAA	Authentication, Authorization and Accounting
AHD	Application Hosting Devices
AP	Access Point
API	Application Programming Interface
BAN	Body Area Network
BCT	Behavioural Change Technique
BIT	Behavioural Intervention Technologies
BMI	Body Mass Index
BP	Blood Pressure
CDMA	Code-Division Multiple Access
CoAP	Constrained Application Protocol
CSVCC	Collaborative Semantic Vocabulary Creation Cycle
CVD	Cardiovascular Disease
DPU	Data Processing Units
DVU	Data Visualisation Units
ECG	Electrocardiogram
EEG	Electroencephalography
EMG	Electromyography
EMR	Electronic Medical Record
EPC	Evolved Packet Core
EPR	Electronic Patient Records
ETSI	European Telecommunications Standards Institute

E-UTRAN	Evolved UMTS RAN
GCF	Global Certification Forum
GPS	Global Positioning System
GSM	Global System for Mobile communication
GSMA	GSM Association
GW	Gateway
HAN	Home Area Network
HDP	Health Device Profile
HIPAA	Health Insurance Portability and Accountability Act
HL7	Healthcare Layer 7
HRN	Health Reporting Network
HRV	Heart Rate Variability
HSPA	High Speed Downlink/Uplink Packet Access
HTTP	Hypertext Transfer Protocol
HU	Helsinki University
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineering
IHE	Integrating the Healthcare Enterprise
IMT	Institut Mines-Télécom
INR	International Normalized Ratio
IoT	Internet-of-Things
IP	Internet Protocol
IPSec	IP Security
ISO	International Standards Organisation
IT	Information Technology
ITU	International Telecommunications Union
JSON	JavaScript Object Notation
LAN	Local Area Network

LTE	Long Term Evolution
M2M	Machine-to-Machine
MBAN	Medical BAN
MD	Major Depression
MI	Motivation Interviewing
MME	Mobility Management Entity
MQTT	formerly acronym for *Message Queue Telemetry Transport*
MTC	Machine-Type Communications
N/A	Not Applicable
NCD	Non-Communicable Disease
NFC	Near Field Communications
NFV	Network Function Virtualization
OA&M	Operations, Administration and Management
ODP	Open Distributed Processing
OS	Operating System
OSGi	formerly acronym *Open Services Gateway initiative*
PA	Personal Assistant
PAN	Personal Area Network
PC	Personal Computer
PCD	Point of Care Device
PDA	Personal Digital Assistant
PHD	Personal Health Device
PRECIOUS	PREventive Care Infrastructure based On Ubiquitous Sensing
QoS	Quality of Service
RAN	Radio Access Network
REST	Representational State Transfer
RF	Radio Frequency
RM-ODP	Reference Model Open Distribution Processing

RPC	Remote Procedure Call
SSL	Secure Sockets Layer
SOA	Service-Oriented Architecture
SOAP	formerly an acronym for *Simple Object Access protocol*
SDO	Standards Development Organisation
SpO2	Peripheral capillary oxygen saturation
T2D	Type II diabetes
TAN	Touch Area Network
TB/IMT	Telecome Bretagne/ Institut Mines-Télécom
TCP	Transport Control Protocol
TLS	Transport Layer Security
UDP	User Datagram Protocol
UE	User Equipment
ULE	Ultra Low Energy
UMTS	Universal Mobile Telecommunications System
UNIVIE	University of Vienna
UPnP	Universal Plug and Play
UTRAN	UMTS RAN
VA	Virtual Agent
VHIR	Vall d'Hebron Research Institute
VIM	Virtual Individual Model
WAN	Wide Area Network
WHO	World Health Organization
WSDL	Web Service Description Language
WOT	Web of Things
XML	Extensible Markup Language

Executive Summary

The aim of this deliverable is to specify the design of the pervasive communication infrastructure between sensors and rest of internal processing units in the system such as food analysis system, virtual individual modeling system, the risk analysis and motivational system and the actuators used to interact with the user. Moreover, the deliverable specifies the architecture that will include the information gathering system based on sensors or end user input, providing core data management services and health guides and multimodal end-user interaction. To that end, the architecture specification intends to draw an overall plan on how the different work packages will work towards a common unified architecture within the project and will provide guidelines for interaction between different components of the architecture. Focus on designing the system in a way that it can be reliable, cost effective, non-intrusive and transparent.

Therefore, the PRECIOUS system architecture as specified within this deliverable D4.1 provides a framework for the many design and implementation activities carried out in the second and third years of the project. To that end, the PRECIOUS system architecture specification is based on an architectural framework known as the Reference Model Open Distribution Processing (RM-ODP) which found use in many research projects and health enterprise IT design processes. The RM-ODP framework facilitates the depiction of the 'big picture' PRECIOUS architecture with different perspectives or viewpoints that provide viewing angles for mixed set of system users (e.g. software developers, health practitioners, network engineers, etc.). For this purpose, the PRECIOUS architecture is specified with five viewpoints classical RM-ODP viewpoints, namely: enterprise viewpoint, computational viewpoint, information viewpoint, engineering viewpoint and technology viewpoint.

The definition of each PRECIOUS architectural viewpoint is further complemented by the so called Behavioural Intervention Technologies (BIT) model, which provides conceptual and technological definitions from clinical aim to technological delivery for behavioural change interventions.

The architecture specification process has enabled the consortium to further identify and highlight interdependencies that exist within the PRECIOUS system concept and solidifies the framing of the system implementation work that is carried out in the second half of the project.

Part A: Background

1. Introduction

1.1 Background and objectives

1.1.1 Background on the PRECIOUS project

The PRECIOUS project aims to develop a preventive care system to promote healthy lifestyles with a particular focus on the environmental, socio-psychological and physiological factors linked to two common non-communicable diseases: Type 2 Diabetes (T2D) and cardiovascular diseases (CVD). Each of these conditions has individually modifiable risk factors that include, for example, physical activity level, stress, sleep quality, food intake and substance use, as well as living environment. As such behavioural interventions and motivation for lifestyle changes play a major role in reducing an individual risk to T2D and CVD.

Therefore, the PRECIOUS project aims to provide new innovations in preventive health care that include:

- A new automated service that analyses user health and ambient data to identify present and future risk factors
- A novel motivational system that boosts the required user actions to reduce unhealthy habits and promote healthy ones
- An innovative gamified user interface, including key motivation elements from the gaming industry to trigger and maintain behavioral change

1.1.2 Specific objectives of deliverable D4.1

The objective of deliverable D4.1 is to specify the design of a pervasive communication infrastructure between sensors and rest of internal processing units in the system such as food analysis system, virtual individual model (VIM) system, the risk analysis and motivational system and the actuators used to interact with the user. Moreover, the deliverable specifies the architecture that will include the information gathering system based on sensors or end user input, providing core data management services and health guides and multimodal end-user interaction. Specifications will cover, for example, functional modules per system and their logical interfaces.

The architecture specification should draw an overall plan on how the different work packages will work towards a common unified architecture within the project and will provide guidelines for interaction between different components of the architecture. Focus on designing the system in a way that it can be reliable, cost effective, non-intrusive and transparent.

1.2 Purpose, context and scope of this deliverable

It is generally acknowledged that every system has an architecture, whether created deliberately through a formal design process or gradually as a result of other less managed processes over a period of time. The system architecture specification (viewed as art form) is a process of painting a 'big picture' that allows us to view many properties of a system, such as, the functional behaviour, emergent behaviours, complexity, flexibility, and so on. As such, the system architecture finds relevance in many processes, including design, operation and management of the system.

To that end, this deliverable provides a detailed exposition of the PRECIOUS system architecture. The PRECIOUS system architecture is underpinned by the lessons and insights from the preceding work in PRECIOUS WP2 *Requirements Identification and Socio-Economics* and WP3 *Virtual Individual Model and Building Motivation*, as well as, the ongoing work in WP4 *System, Sensors and Feedback*. Going forward the intention of the architecture is to provide a coherent framework (both technical and non-technical) for the work to be carried out the second half of the project in WP2-WP4, as well as, WP5 *System Validation*.

1.3 Organisation of the deliverable

The deliverable D4.1 is split into two major parts: *Part A Background* and *Part B Specification of the PRECIOUS System Architecture*.

Part A provides a technology-focused state-of-art overview of the notable project, industry initiative and prevalent standards and protocols in the two main application domains: personal connected health and smart home, which encapsulate the PRECIOUS system use cases. Wherever, possible the review tries to underline the relevance to PRECIOUS and provide an assessment of technologies for further consideration within the PRECIOUS framework.

Part B describes the PRECIOUS system architecture design process and presents the PRECIOUS architecture from five different perspectives or viewpoints. The former process includes the specification PRECIOUS system requirements (both functional and non-functional) and the consolidation of the requirements as inputs that inform the PRECIOUS architecture design.

2. Review of Personal Health System Standards, Initiatives and Projects

Personal health systems are implemented end-to-end so as to interlink the end-user (patient or monitored individual) domain and the care provider domain (e.g. hospital, fitness centre etc.). The end-user domain essentially covers the end-user's personal space and their immediate surroundings, which could usually be their place of abode (home environment) or physical workspace (e.g. office). The personal health system integration has been greatly hampered by closed incompatible proprietary solutions by competing vendors, each with their own data formats, data exchange protocols and so on. In a bid to realize economies of scale and drive-up adoption of personal health system solutions, there have been efforts to address the aforementioned fragmentation by pushing for personal health system designs based on commonly-agreed standards. This Section provides an overview of the most widely accepted standards for implementing interoperable personal health system within the mobile framework.

2.1 Standardisation and Industry Initiatives

2.1.1 IEEE 11073 PHD standards

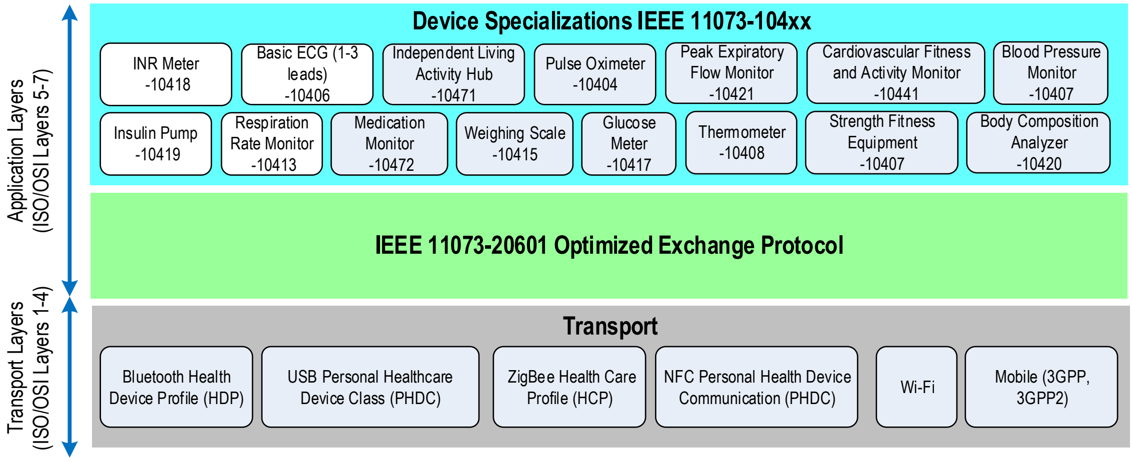
The Institute of Electrical and Electronic Engineers (IEEE) defines the IEEE 11073 personal health device (PHD) family of standards[1] to enable seamless connectivity and mutual information exchange between PHDs and data managers or gateways. The term PHD is used to draw a distinction with the point-of-care devices (PCD) interoperability originally standardised as IEEE 11073 PCD for devices used in the hospital environment. The PHD category includes personal or domestic devices such as heart rate monitors and connected weight scales which collect personal measurements and send the information to a gateway (e.g. a smartphone, PC, etc.) for the purpose of collection, display, and further transmission for additional analysis (e.g. healthcare centres). Generally the gateways can communicate with a plurality of PHDs simultaneously using separate point-to-point connections.

Figure 1 depicts the high-level view of the IEE 11073 PHD protocol stack. This includes the following main layers:

- *Device specialisations (IEEE 11073-104xx)*: Each PHD type has a specialized IEEE 11073-104xx standard (where xx is any number from 01 to 99) that specifies how it utilizes the IEEE 11073-20601 standard (described in next bullet point) to fulfil its function. For instance, IEEE 11073-10407 defines how blood pressure (BP) measurement data is exchanged between a BP measurement device and a smartphone. Currently over 15 PHD specialization standards are either defined or are in the definition process, and this list will grow gradually as more vendors adapt the IEEE 11073 standard.
- *Optimised Exchange Protocol (IEEE 11073-20601)*: The baseline IEEE 11073-20601 standard defines application layer services (e.g., connection management, reliable data transfer) and a transport-independent optimized data exchange protocol that specifies the commands, device configuration information and interoperable data format for the interface between PHDs and gateways.

[1] http://standards.ieee.org/develop/wg/PHD.html

- *Transport layer*: Implements actual data transport between using existing lower-layer communications protocols. Thus, transport layers specifications are out of the scope of IEEE 11073 standardisations, but other SDOs have been working on additional specifications for their standards to more effectively support health device connectivity with IEEE 11073. These customized protocols include: the Bluetooth Health Device Profile (HDP) [1], the ZigBee Health Care Profile (HCP) [2], and the USB Personal Healthcare Device Class (PHDC) [3].



Notes: ECG = Electrocardiography, INR = International Normalized Ratio, 3GPP = Third Generation Partnership Project, 3GPP2 = Third Generation Partnership Project 2.

Figure 1 IEEE 11073 PHD protocol stack [4]

2.1.2 Continua Health Alliance Reference Architecture

Continua architectural overview

The Continua Health Alliance[2] is an open industry group providing interoperability guidelines, testing and certification programs for the personal health system device implementers and system integrators. The current Continua guidelines specify an end-to-end harmonized Continua reference architecture (see Figure 2) based on a suite of standards that enable implementation of interoperable personal health system devices and system interfaces. The Continua design guidelines have also been adopted by the International Telecommunications Union (ITU) as the first global standard for personal connected health devices and systems [5]. The end user-owned devices in the defined Continua reference architecture are the Touch Area Network (TAN), Personal Area Network (PAN) and Local Area Network (LAN) health monitoring devices and the Application Hosting Devices (AHD) which in most cases is physically located in the end-user's domain (see Figure 2).

2 http://www.continuaalliance.org/

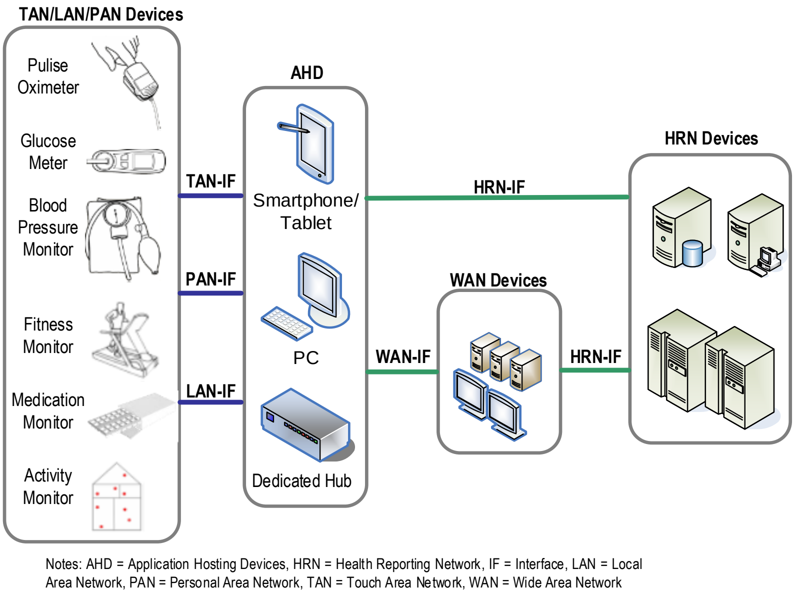


Figure 2 High-level view of the Continua reference architecture [4]

The TAN, PAN and LAN monitoring devices are essentially health sensors or actuators, which may be worn, implanted or carried by the monitored individual, or alternatively deployed within their home environment. The PAN devices are within the range of an individual and are typically connected using short range, radios such as, Bluetooth Low Energy and IEEE 802.15.6 Medical BAN (MBAN). The LAN devices covers the areas beyond the PAN (e.g., entire home or office environment), typically in a range of few tens of meters using short-to-medium range wireless technologies, such as, Wi-Fi and ZigBee. The TAN devices where introduced in later revisions of Continua guidelines to cover Near Field Communications (NFC)-based health devices.

The AHDs include devices, such as, smartphones and dedicated personal health system hubs, that aggregate data from monitoring devices and provide a connectivity gateway towards remote WAN or Health Reporting Network (HRN) devices. Moreover, the Continua reference architecture also allows for the Continua AHD to be integrated with in the same unit with some health sensing or actuation functionality. For instance, smartphones may have integrated sensors and health monitoring apps while also carrying out the function of interfacing to PAN devices as well as sending health data to WAN devices via the mobile network. The WAN and HRN devices are deployed and managed in the care provider domain. For instance, a WAN device could be a web server platform that receives aggregated health data from an end user's Smartphone (AHD device) and uses it to provision a personalized health service (e.g., medicine reminder service). The HRN devices sit on the edge of the personal health system and provide long-term information storage (e.g., Electronic Medical Records in hospital data servers).

Continua interface specifications

The Continua TAN, PAN and LAN interfaces (TAN-IF, PAN-IF and LAN-IF) uses the baseline IEEE 11073-20601 for higher layer functions (see Figure 1), such as, connection management, device configuration information exchange and abstract to transmission data format conversion. The IEEE 11073-compliant data transport over the TAN, PAN and LAN interfaces is currently specified for Bluetooth, Universal Serial Bus (USB), ZigBee (IEEE 802.15.4) and NFC [5]. Additionally, Wi-Fi (IEEE 802.11x) and mainstream mobile technologies standardized by 3GPP (Third Generation Partnership Project) or 3GPP2 (Third Generation Partnership Project 2) may be used for health data transport in the case that AHD(s) are physically deployed in long distances away from the monitoring devices. To that end, Continua Health Alliance has produced a supplementary set of implementation guidelines for Continua-certified personal health device vendors with embedded 3GPP or 3GPP2 communication modules for operation in the mobile environment [6].

The WAN and HRN interfaces describes the connection between personal devices (TAN, PAN, LAN and AHD devices) and devices in the clinical domain (WAN and HRN devices). For both interfaces, the Continua alliance opted for alignment with the Integrating the Healthcare Enterprise (IHE) initiative that is the leading promoter of standards from bodies, such as, Healthcare Layer 7 (HL7)[3], for use in the clinical domain.

For the WAN interface, Continua uses the PCD-01 transactions of the IHE Device Enterprise Communication (DEC) profile to transform IEEE 11073 data from personal health devices into the widely used HL7 2.x message format (while retaining IEEE 11073 semantics) and then uses Web Services (from IHE IT Infrastructure standard) for sending the data to target WAN device(s) [5]. The HRN interface uses IEEE 11073 or other semantics (e.g., SNOMED-CT) and the XML-based HL7 Clinical Document Architecture (CDA) with a customized Performance Healthcare Monitoring Report (PHMR) document format to accommodate personal health device monitoring [5]. The actual data transport in the HRN interface may be based on Web Services (IHE Cross-Enterprise Document Reliable Interchange, XDR) or simply email (IHE Cross-Enterprise Document Media Interchange, XDM) [2]. Therefore, data exchange protocols for WAN- and HRN-Interfaces are transport-independent and may utilize Wi-Fi, mobile or fixed technology standards for connectivity between devices in the end-user domain (monitoring devices and AHDs) and WAN or HRN devices [5].

2.1.3 GSMA High Level Reference Architecture for Mobile Health

Mobile networks provide the kind ubiquitous coverage, service manageability and security features that add significant value in the implementation of personal health systems. This has seen the increased commercialization and rapid adoption of so called mobile health or mHealth solutions. This has prompted mobile equipment and device vendors, mobile operators, and mobile industry bodies, most notably, the GSM Association (GSMA), to identify potential opportunities for deeper integration of mobile networks and healthcare systems. To that end, the GSMA has proposed a High Level Reference Architecture for Mobile Health, which defines in detail how existing capabilities in mobile networks (connectivity, security management, identity management, billing platforms, etc.) can be effectively leveraged to add value to mobile health systems (see Figure 3) [7]. The GSMA

[3] http://www.hl7.org/

reference architecture identifies both existing and missing logical architectural components from existing open standards, such as, the standards underpinning the Continua reference architecture.

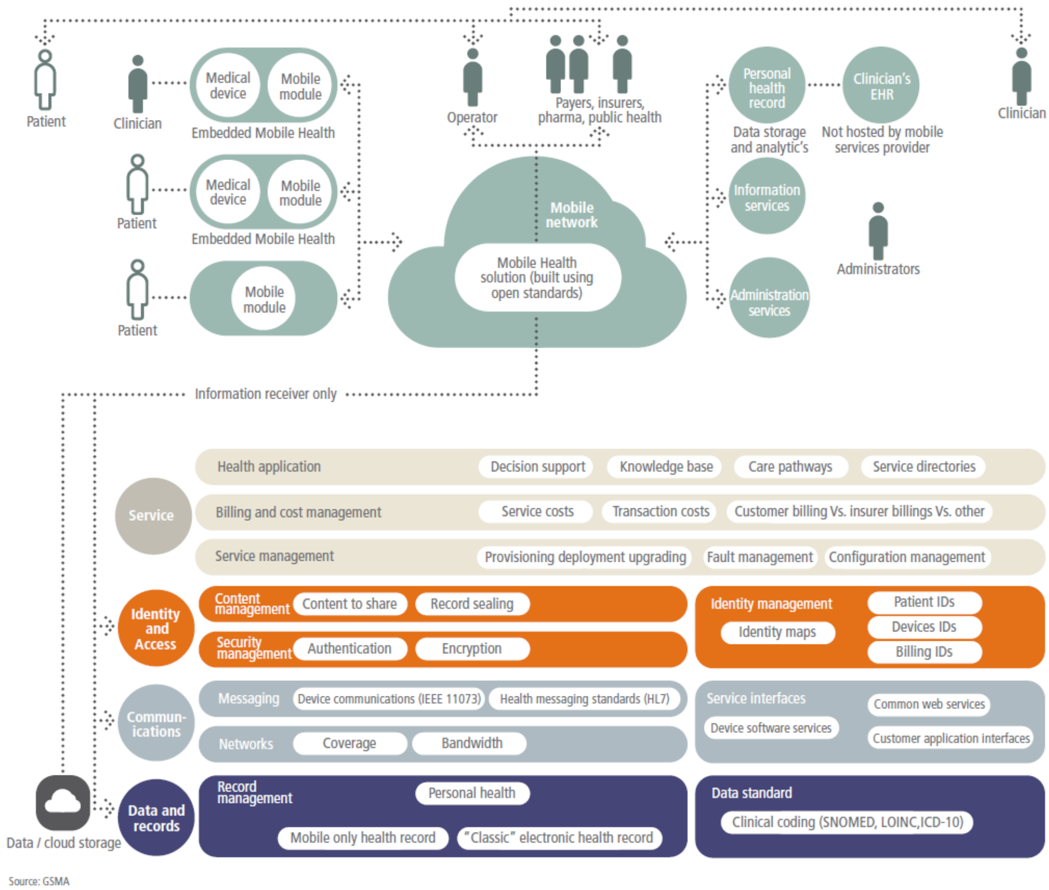


Figure 3 GSMA high level reference architecture for mobile health [7]

A summary of the future areas of focus for the development of the GSMA reference architecture is shown in Table 1.

Table 1 GSMA mobile health architecture roadmap [7]

Area of focus	Now	Short term	Long term
Areas where partial standards already exist	Complete assessment of the Continua guidelines to identify if this is the approach that the Mobile Industry will support and back.	Engage with standards developers to fill gaps, in particular IEEE 11073 and HL7 standards groups to raise awareness of the needs of the mobile industry.	Encourage a move to a single certification process that encapsulates Device, Healthcare and Telecoms approval.
	Document the encryption and security standards used within mobile industry as a USP of partnering with the mobile industry.	Engage with the IHE working groups to raise awareness of the needs of the mobile industry and Continua Mobility task force.	
	Document how patient data that is stored on a device, in transit or at rest in storage could be protected.	Investigate the capabilities used in other vertical markets such as the financial sector and if these standards can be applied to mobile health.	
Areas of low architectural complexity	Identify existing mobile solutions that could be reconfigured to support element of Mobile Health.	What are the implication on Mobile Health products and service that LTE/4G will introduce.	
Areas where new technologies have solved old problems	Document the capabilities of on-SIM value added services that could be used in Mobile Health solutions to encourage adoption. Document how NFC capabilities can be used in Mobile Health solutions to encourage adoption and simplify connectivity.	What are the new technical requirements that tablets will introduce vs mobile handsets. Continua Tap and Go interface is being defined as transport agnostic, GSMA should push the use of NFC.	Look to the gaming industry, finance industry, automotive industry for new procedures and technologies to support adoption.
Areas within control of the mobile industry	Identify that the introduction of the Bluetooth Health Device Profile (HDP) and LE would encourage the roll out of Mobile Health devices and services.	If suitable, promote the inclusion of the HDP and LE into all new mobile devices.	Identify if there is a requirement from the mobile industry to manage Quality of Service (QoS) on the RAN to support Healthcare device and submit into 3gPP for inclusion into future releases of GSM standards.
Driving a standardisation approach	Develop a reference architecture for the integration of Mobile Health solutions into a Mobile Network Operator.	Define the outline requirements of a Mobile Health gateway component and its required capabilities.	

2.1.4 Mainstream MTC/M2M communications standards

Mobile networks are increasingly expected to support not just person-to-person communications, but generally communications between (and among) people and "machines" or "things". The terms machine-to-machine (M2M) communications, machine-type communications (MTC) and Internet of Things (IoT) are commonly used to describe this paradigm shift that will enable numerous meaningful uses cases in alleviating congestion of transport systems, smart grids, environmental monitoring as well as remote person-centric healthcare [8]. Therefore, standardisation bodies have incorporated mobile health use cases in within the MTC/M2M general standardisation frameworks.

The MTC/M2M communication standards are currently being developed by, among others, the 3GPP and the European Telecommunications Standards Institute (ETSI). The MTC standardization activities in 3GPP are closely aligned to those of ETSI M2M, but with the 3GPP standards having a narrower scope by focusing mostly on 3GPP radio access networks and mobile core networks [8]. The mHealth use cases have been described in both 3GPP MTC [9] and ETSI M2M working groups [10], and are considered to be one of the main drivers for MTC/M2M in addition to smart grids, intelligent transport systems, public security, and so on. Additionally oneM2M standards initiative has defines comprehensive service layer solutions to accelerate development and reuse of MTC/M2M/IoT data and applications across diverse verticals application areas, networks, and devices.

Exemplifying the emerging synergies across different SDOs in this area, ETSI has teamed up with a number of leading standard bodies (e.g. Continua alliance) and industry consortia in the oneM2M Partnership Project[4] with the objective of developing universal end-to-end specifications for an M2M management system for applications, such as, health. A recent notable result of this synergy has been showcase demonstration from Lamprey Networks and Interdigital that showed how multiple off-the-shelf Continua-certified devices could collect and transmit data via a Continua/oneM2M compliant gateway to remote WAN devices (see Figure 4) [11].

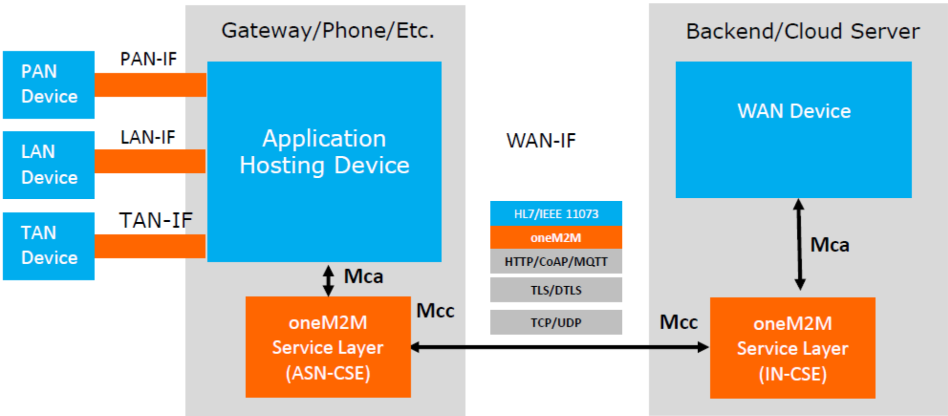


Figure 4 Example scenario of oneM2M over the Continua WAN-IF

2.1.5 Open mHealth

Open mHealth is a non-profit organisation that has been developing an open software architecture to address the interoperable sharing of data across multiple mHealth applications and links to electronic health records [12]. The architecture consists of open source software modules with Application Programming Interfaces (APIs) based on a minimal set of common metadata that allow independently developed reusable software components or blocks to be mixed and assembled like building blocks. To that end, Open mHealth as developed InfoVis that provides the necessary architectural scaffolding for analysing and visualising the building blocks created by the Open mHealth developer community.

The main types of reusable software blocks in Open mHealth (see Figure 5) are the data processing units (DPUs) and the data visualisation units (DVUs). In addition data storage units are the blocks that manage the input/output data of DPUs and DVUs and specific to particular health data storage solutions. Each low-level DPU and DVU block performs one specific task that can be composed to produce higher-level functions. For instance, low-level DPUs can be used to transform time-series accelerometer readings from a wearable sensor into a set of user states (sleeping, walking, cycling, etc.) derived from the data readings. The

[4] Note: OneM2M description is revisited again in Section 4.2.5 within the smart home context

DPU and DVU blocks are reusable across multiple mHealth applications, disease types, user demography and so on.

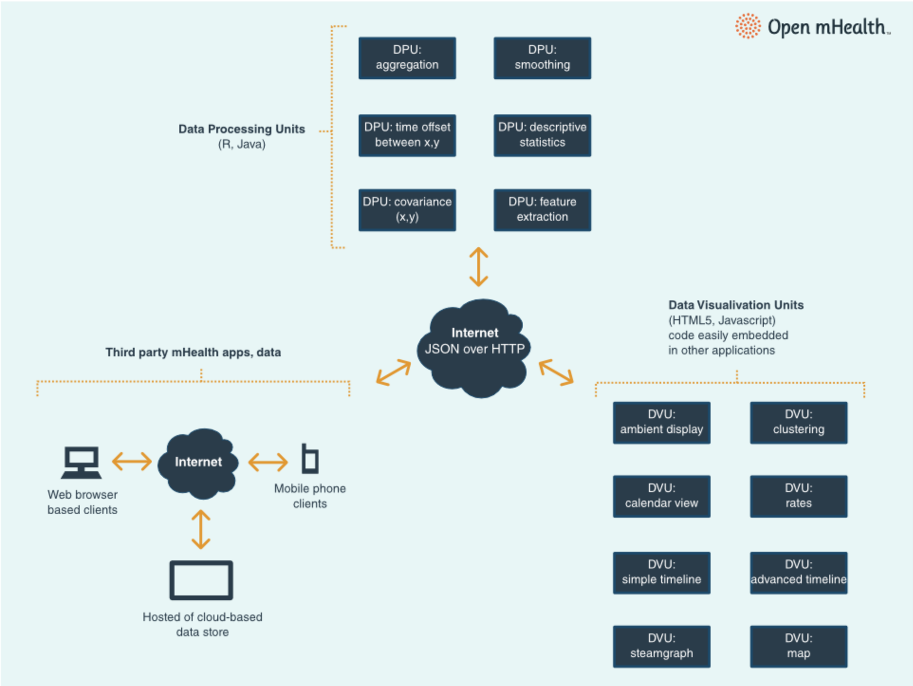


Figure 5 Open mHealth InfoVis concept

2.1.6 Other standards

ANT/ANT+

The communication ANT/ANT+ is proprietary [31] and designed for low powered consumption devices. At the beginning, it has been realized for sport, fitness and well-being related devices. It works in the ISM band at 2.4 GHz. As Bluetooth and ZigBee, ANT has also several device profiles: Weight scale, Heart rate monitor, blood pressure, etc.

Z-Wave

Z-Wave is low-power low bit rate wireless technology (by the Z-Wave industry alliance)[5] designed originally for remote control applications but now also supporting use cases in smart home and assisted living for elderly persons (connected ageing). For the latter use cases, Z-Wave is finding increasing use in activity monitoring devices for persons in their home environment.

[5] http://z-wavealliance.org/

2.2 Exemplary Personal Health System Research Projects

2.2.1 EC FP7 REACTION (2010-2014)[6]

Vision

To develop an integrated approach to improved long term management of diabetes; continuous blood glucose monitoring, clinical monitoring and intervention strategies, monitoring and predicting related disease indicators, complemented by education on life style factors such as obesity and exercise and, ultimately, automated closed-loop delivery of insulin.

Approach

The project proposed an interoperable peer-to-peer communication platform based on a service oriented architecture (SOA) – all functionalities, including devices, are represented as services and applications consisting of a series of services orchestrated to perform a desired workflow. The FP7 REACTION platform also features a Model Drive Application Development environment based on extensive use of dynamic ontologies and advanced Data Management capabilities with algorithms for clinical assessment and rule-based data processing.

Relevance to PRECIOUS

Criteria	**Description**
Architecture style	Service-oriented architecture (SOA)
Interoperability	IEEE 11073
Motivational system	n/a
Communication technologies, protocols, middleware	Hydra middleware
Multimodal user interface	PC, PDA, smartphone
Sensing and actuation	Continuous blood glucose monitoring, tight glycaemic control (for insulin therapy)
Test in lab/Field test	In-hospital and out-of-hospital environments

2.2.2 EC FP7 SimpleSkin (2013-2016)[7]

[6] http://www.reaction-project.eu/
[7] http://www.simpleskin.org/

Vision

To put functional clothes on the mainstream, much like today smart, sensor-enabled phones. The "sensor ready" garments become part of a wearable computing system, by adding hardware, that allows self-organizing, dynamic and adaptive processing of input signals converting the specific garment into a general wearable sensor with a dedicated high-level sensing interface.

Approach

Project pursues a new approach for creating smart textiles and functional garments. The basic idea is to separate sensing textile production, garment manufacturing, the hardware platform, and the software implementation by well-defined abstractions and interfaces. The major innovation is the development of a mass-producible generic sensing fabric, which will allow capacitive, resistive or inductive modes, to measure movement, electrical body signals, activities, and change in body capacity. The sensor density and intelligent signal processing will compensate the simplicity of single sensors. Based on these fabrics "sensing ready" garments can be produced, that are with respect to their properties, looks, production process and price virtually undistinguishable from today's standard garments.

Relevance to PRECIOUS

Criteria	**Description**
Architecture style	*yet to be specified in deliverables*
Interoperability	*yet to be specified in deliverables*
Motivational system	n/a
Communication technologies, protocols, middleware	Garment Operating System (OS) provides APIs for apps in user devices to access of sensors and actuators on clothing
Multimodal user interface	Smartphone, eye-glass displays, smart watches
Sensing and actuation	Resistive or capacitive arrays in the clothes for sensing pulse rate, body posture, skin temperature, muscle activity, etc.
Test in lab/Field test	Currently only lab environment

2.2.3 EC FP7 eHealthMonitor (2011-2014)[8]

Vision

To provide a service-oriented platform used in the process of generating a Personal eHealth Knowledge Space (PeKS) as an aggregation of all knowledge sources relevant for the provision of individualized personal eHealth services.

Approach

The platform is realised by integrating service-oriented architecture, knowledge engineering, multiagent systems, and wearable/portable devices technologies. The platform supports end users in two hospital-based scenarios – covering dementia and cardio-vascular domain as well as one prevention-based scenario in the health insurance domain.

Relevance to PRECIOUS

Criteria	**Description**
Architecture style	SOA
Interoperability	Interfaces exposed as web services or REST API. Semantic Integration of data sources using eHealthMonitor Ontology Suite developed by the project.
Motivational system	n/a
Communication technologies, protocols, middleware	Bluetooth, mobile radios
Multimodal user interface	Smartphone
Sensing and actuation	Continuous ECG recording
Test in lab/Field test	In-hospital and out-of-hospital environments

2.2.4 EC FP7 SPLENDID (2013-2016)[9]

Vision

To develop a Personalised Guidance System to help and train children and young adults to improve their eating and activity behaviour by detecting subjects at risk for developing

[8] http://www.ehealthmonitor.eu/
[9] http://splendid-program.eu/

obesity or eating disorders and offering them enhanced monitoring and guidance in order to prevent further disease progression.

Approach

Project will monitor key parameters of eating and activity, such as food intake, meals structure, snacking, daily physical activity during real life; evaluate in real-time and offer guidance towards recommended behaviours. Four studies in Sweden and Netherlands will evaluate:(i) a screening programme conducted at school settings during daily meals, with the aim to assess the children's eating behaviour, and (ii) the capability of the system to offer correct and effective guidance on eating/activity behaviour.

Relevance to PRECIOUS

Criteria	Description
Architecture style	*yet to be specified in deliverables*
Interoperability	*yet to be specified in deliverables*
Motivational system	Interfaces for presentation of behavioural recordings and feedback notifications
Communication technologies, protocols, middleware	Short range radios, mobile radios
Multimodal user interface	Smartphone, tablet, desktop
Sensing and actuation	Connected weight scales, accelerometers, chewing sensors
Test in lab/Field test	Out-of-hospital environments (e.g. in schools)

2.2.5 EC FP7 INTERSTRESS (2010-2013)[10]

Vision

To design, develop and test an advanced ICT based solution for the assessment and treatment of psychological stress.

Approach

[10] http://www.interstress.eu/

Project used a new concept for eHealth - Interoperability – integrating assessment and treatment within a hybrid, closed-loop empowering experience, bridging physical and virtual worlds: (a) behaviour in the physical world influences the experience in the virtual world; (b) behaviour in the virtual world influences the experience in the real world.

Relevance to PRECIOUS

Criteria	Description
Architecture style	Project-defined mobile pervasive architecture
Interoperability	Project-specific data fusion module on smartphone for common communication language between local sensor interfaces and remote analysis module.
Motivational system	Feedback from tracking user in real world influences his/her experience in the virtual world (aspect, activity and access)
Communication technologies, protocol, middleware	Bluetooth, mobile radio, Wi-Fi
Multimodal user interface	Smartphone (linking user's life to virtual world)
Sensing and actuation	Wearable band for monitoring heart rate variability (HRV), breathing rate, physical motion. Wearable ECG monitor. Camera and Accelerometer-Based Activity Recognition (CBAR). Virtual relaxation and biofeedback training
Test in lab/Field test	Testing and validation by teachers and nurses in clinical settings

2.2.6 EC FP7 Help4Mood (2011-2014)[11]

Vision

To significantly advance the state-of-the-art in computerized support for people with Major Depression (MD) by monitoring mood, thoughts, physical activity and voice characteristics,

[11] http://help4mood.info/

prompting adherence to computerised cognitive behavioural therapy (CCBT), and promoting behaviours in response to monitored inputs.

Approach

Project develops a Virtual Agent (VA) which can interact with the patient (as an avatar) through a combination of enriched prompts, dialogue, body movements and facial expressions. Monitoring combines existing (movement sensor, psychological ratings) and novel (voice analysis) technologies, as inputs to a pattern recognition based decision support system for treatment management.

Relevance to PRECIOUS

Criteria	**Description**
Architecture style	Custom project-defined architecture
Interoperability	Interoperability ontology based SNOMED-CT concepts
Motivational system	Mood enhancements via personal avatar feedback system
Communication technologies, protocol, middleware	Short range radios (Bluetooth, SimpliciTI), Wi-Fi, mobile radio
Multimodal user interface	Smartphone, laptop, desktop PC
Sensing and actuation	Sleep sensors under mattress, wearable and pocket movement/activity sensors, speech sensors
Test in lab/Field test	Patient home, clinical site

2.2.7 EC FP7 ICT4DEPRESSION (2010-2013)[12]

Vision

To develop a system targeting major depression but that is flexible and can easily be adapted for treatment of other mental diseases.

Approach

12 http://www.ict4depression.eu/

Project developed an ICT-based system for use in primary care, which includes 1) devices which monitor bio-signals in a non-intrusive and continuous way, 2) treatments for depression and automatic assessment of the patient using mobile phone and web based communication, 3) computational methods for reasoning about the state of patients, progress of therapies, and the risk of relapse and 4) a flexible system architecture for monitoring and supporting people using continuous observations and feedback via mobile phone and the web.

Relevance to PRECIOUS

Criteria	**Description**
Architecture style	SOA
Interoperability	Use of formal temporal language for qualitative and quantitative expression of complex temporal properties of patients and therapies
Motivational system	Motivational messages and therapy information provided to patient based on translation of results from mood sensors
Communication technologies, protocol, middleware	Short range radios, Wi-Fi, mobile radios
Multimodal user interface	Smartphone, laptop, desktop
Sensing and actuation	Wearable sensors for heart rate, sympathetic nervous system responses, respiration rate and movement (accelerometer)
Test in lab/Field test	Out-of-hospital environment with students (Sweden) and general population (Netherlands)

3. Review of architectures and initiatives : Smart Home Domain

In this chapter, architectures and initiatives related to the smart home domain are described. Moreover, some projects listed here have also application in the health domain. The table of the previous chapter is also used to describe the relevance of projects to PRECIOUS.

3.1 Exemplary research and open industry projects

3.1.1 AMIGO European project (2004-2008)

Vision

The European project AMIGO (IST-004182) focused on user services and proposed a middleware solution to interconnect heterogeneous devices at home [13]. AMIGO wants to allow ambient intelligent services in the home environment.

Approach

The AMIGO middleware allows connections of heterogeneous devices and services in such a way that it is transparent. AMIGO defines a Service-Oriented Architecture (SOA). The reference architecture defines three layers: platform layer, middleware layer and application layer.

To solve the interoperability issues between home automation devices the OSGi framework has been used. The "Amigo Domotic Abstract Reference Architecture" has been proposed to integrate home automation heterogeneous devices. It is composed by several components: bus controllers, proprietary device factories and discoverable device factories [14]. All these components work together to create a transparent layer for AMIGO services. Consequently, home automation devices are exposed as services in AMIGO.

Relevance to PRECIOUS

Criteria	**Description**
Architecture style	SOA
Interoperability	Interoperability managed at different levels: middleware, semantic-based service interoperability, Amigo Domotic Abstract Reference Architecture (OSGi-based), OWL-S
Seamless communication	Middleware service communication component
Motivational system	N/A
Communication protocol	Messages and messages formats exchanged are defined by the service communication component. (e.g., SOAP, RMI). Lower level protocols are managed by

	the platform layer (e.g. Bluetooth, 802.15.4, etc.).
Multimodal user interface	Voice, gesture, dialog manager
Test in lab/Field test	End user tests: Home Care and Safety [15]

3.1.2 EC FP7 SM4ALL (2008-2011)

Vision

The EC FP7 project SM4ALL (FP7-224332) project objective was to develop a middleware for pervasive embedded systems in user environments [16].

Approach

The SM4ALL project based is approach on a middleware solution. It is composed by three layers:

- Pervasive layer: allow to integrate devices, sensors, actuators. The interoperability is managed by an OSGi gateway.
- Composition layer: manage and control the different devices
- User interface layer: allows having interfaces between the system and users.

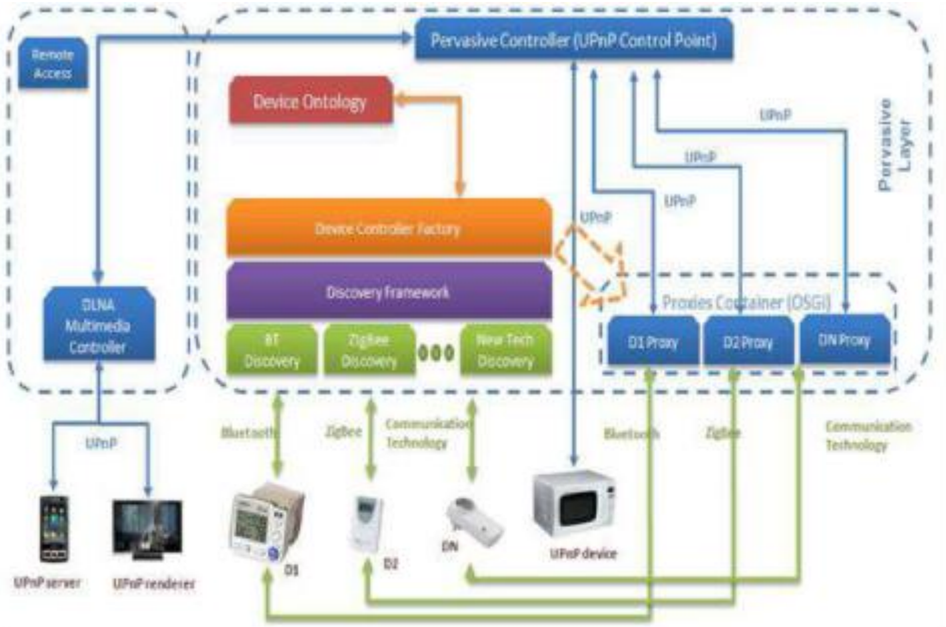


Figure 6: SM4ALL middleware pervasive layer [17]

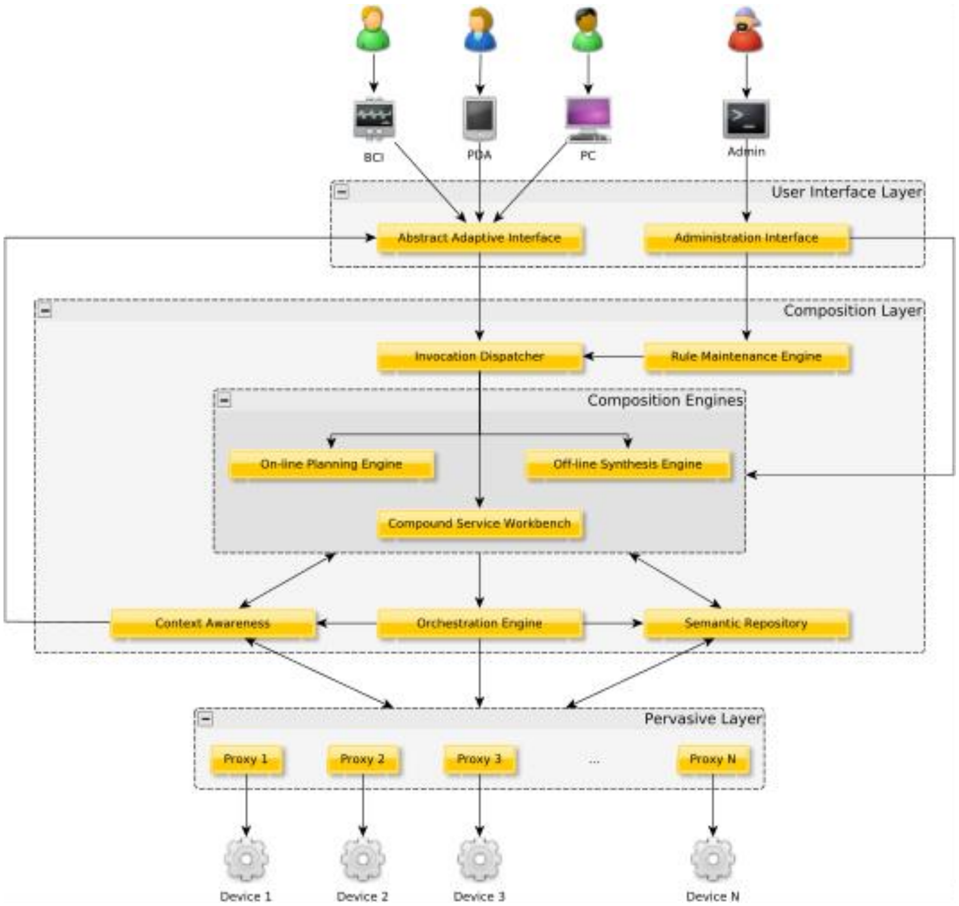


Figure 7: SM4ALL architecture

Relevance to PRECIOUS

Criteria	**Description**
Architecture style	N/A
Interoperability	SOAP based services: Web service interface, UPnP interface Semantic repository
Seamless communication	SM4All middleware pervasive layer manage communications protocols with SM4ALL proxy (OSGi-based)
Motivational system	N/A
Communication protocol	- Low-level: Bluetooth, KNX for proof of concept - High-level (inter communication between components): UPnP

Multimodal user interface	BCI, PDA, PC
Test in lab/Field test	x

3.1.3 OPENHAB open source project

Vision

The open source project OpenHAB [18] wants to allow interoperability between all the existing protocols in smart home/home automation. OpenHAB provides a gateway which is based on OSGi.

Approach

The OpenHAB project focuses on home automation protocols and interoperability between them. Some more elaborate scenarios are provided. OpenHAB is an architecture based on OSGi where each home automation protocols are integrated by bundles. Inside the architecture an asynchronous event bus allows to share events between bundles.

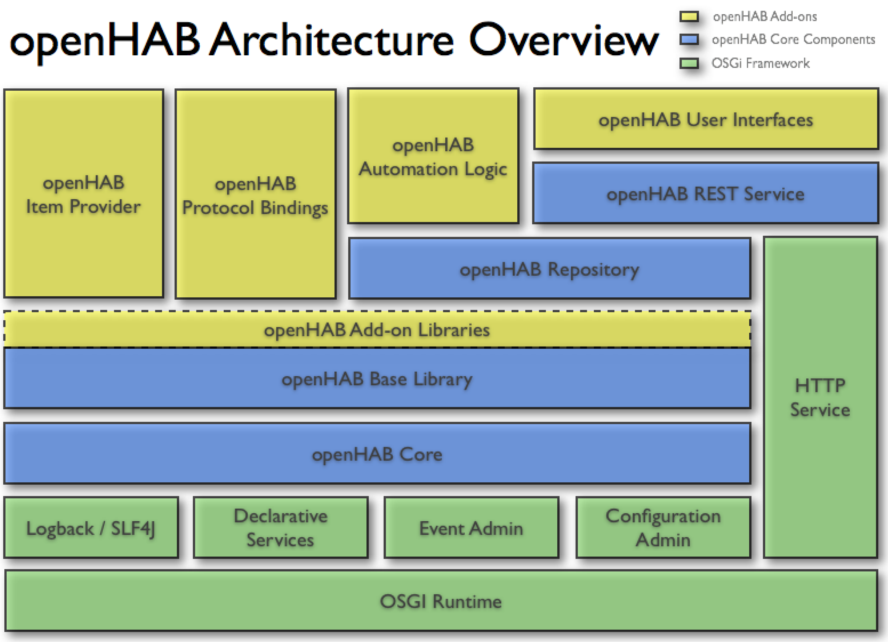


Figure 8: OpenHAB architecture [18]

Relevance to PRECIOUS

OpenHAB is a popular solution (an important open source community) to manage interoperability inside a house. It is only focused on the interoperability of home automation devices with a separation between home automation protocols and high-levels protocol. However, the interoperability is managed in a central piece of hardware running OSGi. In that case, all the functionalities of a home automation system will be centralized in one gateway.

Criteria	Description

Architecture style	OSGi-based
Interoperability	OSGi-based + OpenHAB event bus
Seamless communication	OSGi-based
Motivational system	x
Communication protocol	Home automation protocols (e.g. KNX) and high-level protocols (e.g. MQTT)
Multimodal user interface	Web UI
Test in lab/Field test	x

3.1.4 DOG gateway open source project

Vision

The open source project DOG gateway [19] proposes a centralized solution to resolve the problem of interoperability in the smart home domain. Like OpenHAB the solution is OSGi-based and supplies different well-known home automation protocols to allow interoperability.

Approach

The project DOG gateway allows connecting several heterogeneous devices. Protocols are integrated in the same gateway with OSGi. Unlike other solutions, Dog gateway proposes to manage the interoperability of devices with ontologies.

Relevance to PRECIOUS

The DOG gateway is close to the OpenHAB project but currently less popular in the open source community. Consequently, one of the successes of a new project not standardized is also the popularity in the open source community. Nevertheless, DogOnt [20] is an interesting ontology-based context modelling. It could be a good starting point to develop automata in the smart home related to the usage scenario proposed in PRECIOUS.

Criteria	**Description**
Architecture style	OSGi-based
Interoperability	OSGi-based and DogOnt
Seamless communication	OWL-based device abstraction layer
Motivational system	N/A

Communication protocol	Home automation protocols bindings, REST API for applications access
Multimodal user interface	Web UI
Test in lab/Field test	N/A

3.2 Smart home domain standards and industry initiatives

The smart home domain copes with a lot of standards, alliances, consortium and associations. And all of them propose a specific protocol of communication not interoperable with another. In the following, we will describe some of them judged as well deployed, popular or promising.

3.2.1 ULE Alliance

The ULE (Ultra Low Energy) alliance[13] is a non-profit organization that promotes the ULE DECT standard for home control, security and healthcare applications. DECT (Digital Enhanced Cordless Telecommunications) is an existing standard widely deployed in the world for wireless phones at home. The DECT ULE using DECT frequency bandwidth is a new end-to-end protocol (January 2013) with a star topology (point-to-multipoint). It allows long range communication.

Specifications:

- Carrier frequency: 1.9 GHz (USA), 1.8 GHz (Europe)
- Channels: 5-10 radiofrequency channels
- GFSK modulation
- TDMA
- Throughput: ~1Mb/s
- Security: Packet authentication and encryption.
- Number of nodes: > 400

It is a promising solution because the DECT bandwidth is only used for DECT devices, so interferences with other solutions can be avoided and because a long battery life time is expected. However, it is a new standard and not yet widely deployed. The success of this solution is not yet guaranteed.

3.2.2 KNX

KNX[14] (or Konnex) is an international standard ISO/IEC 145-43-3. It is supported by the KNX association. It is the result of three standards: EHS, EIB, Bâtibus. It is widely deployed in building and home environment. However, a KNX installation is generally costly.

[13] http://www.ulealliance.org/
[14] http://www.knx.org/knx-en/index.php

KNX uses several communication channels: twisted-pair, powerline, radio frequency and IP. The twisted pair is more frequently used and the IP is used as backbone. The configuration of a KNX network is realized through ETS, dedicated proprietary software.

3.2.3 EnOcean

The EnOcean protocol is part of the EnOcean Alliance[15]. It is a proprietary protocol focused on devices working without batteries and without wires. It is dedicated to home automation including smart homes and buildings automation. The protocol follows the standard ISO/IEC 14543-3-10 which has been defined for wireless communication using energy harvesting.

Specifications:

- Frequency: 868.3 MHz or 315 MHz
- Modulation ASK
- Throughput: 125 kbits/s
- Bandwidth: 280 kHz
- Range: 30m in buildings and 300m in free field
- Repeater: yes
- One way or bidirectional communications
- Topology: point-to-point, mesh and star.
- Security: rolling code

Inside the EnOcean network, devices are categorized:

- Controller device
- Sensor device
- Actuator device.

3.2.4 Zwave

The Zwave protocol is defined by the Zwave-Alliance. It is a proprietary wireless communication protocol dedicated to home automation devices. The radio protocol has been designed for low powered devices and it uses a bandwidth at 868.42 MHz (Europe). The PHY/MAC layer is defined by the specification of the standard ITU-T G.9959.

The Zwave Alliance has proposed to categorize devices:

- Basic Device
- Generic Device
- Specific Device

3.2.5 X10

X10 is an old protocol for command/control home automation devices. There is a power line version and a wireless version. One way or two devices are available. X10 has been popular and still present in the market. However, new solution more reliable and offering more

[15] https://www.enocean-alliance.org/en/home/

possibilities (e.g. more nodes) are now available. X10 will be probably not used anymore in the next years

3.2.6 X2D/X3D

X2D/X3D is a proprietary protocol designed by DeltaDore. The protocol has been created to be simple and energy efficient. The protocol can use two different channels: power line or radio at 868 MHz The protocol has the advantage to be well deployed because DeltaDore has a well impact in the home automation domain especially in France and in Europe for energy management and comfort, etc.

3.2.7 ZigBee Home Automation

Like ZigBee Health Care, there is a ZigBee Home Automation profile. It is dedicated to classical home automation devices: lights, security, switches, appliances, heating/cooling, etc.

3.3 Discussion

As shown Table 2, there is no dominant standard in health and home automation domains. Moreover, it exists protocols which are domain specific Health or Home Automation but also the both (e.g. ZigBee).

In eHealth and mHealth domain, new start-ups propose generally the same infrastructure where data are stored in the so-called cloud server. For instance, a new well-being sensor appears on the market, it has a Bluetooth connection, the user’s smartphone is used has a dashboard to see data but also to push data to the start-up server. Finally, if the company opens its API to have access to user data, developers of new applications access data only via the server in the cloud. This schema is common to almost all new devices appearing on the market as we can see Table 15. The same architecture and business model is used for new devices appearing for home automation systems, especially applications concerning home environment measurement as shown Table 16.

Protocols	**Freq.**	**Range**	**Data rate**	**Security & Privacy**	**Topology**	**Domain**	**Proprietary, standard, …**
ZigBee	868 MHz (Europe), 2.4 GHz	~ 0-100m	20 kb/s, 250 kb/s	yes	Star, tree, mesh	Health & Smart Home	Standard
Bluetooth	2.4 GHz	~ 0-100m	24 Mbit/s	yes	Master-slave (Scatternet, Piconet)	Health & Smart Home	Standard
ANT+	2.4 GHz	~ 0-30m	20 kb/s,	yes	Broadcast, Star, Peer-To-	Sport, Well-	Proprietary

			1 Mbit/s		Peer, …	being	
ULE	1.9 GHz (USA), 1.8 GHz (Europe)	-	~1Mb/s	Security: Packet authentication and encryption	Yes	Smart Home	Standard
KNX	Bus, Radio, Powerline or Ethernet	Local area network	-	-	No	Smart Home	standard ISO/IEC 145-43-3
EnOcean	868 MHz or 315 MHz	~ 0-100m	~ 125kb/s	yes	Point-to-multipoint	Smart Home	Alliance
Zwave	868.42 MHz (EU), 908.42 MHz (US)	~ 0-100m	9.6 kb/s, 40 kb/s	yes	Mesh	Smart Home	Alliance
X10	120 kHz for powerline, 310 MHz (US) and 433.92 MHz (EU) for radio	Local area network	~ 20 bit/s	No	Point-to-multipoint	Smart Home	-
X2D/X3D	868 MHz	~ 0-100m	-	yes	Point-to-point	Smart Home	Proprietary

Table 2: Comparison of low-level protocols

4. Supplementary Review of Other Relevant Projects and Initiatives

4.1 Introduction

In this chapter, the idea is to list projects or initiatives which are not dedicated to a specific domain: health or home automation. We will describe project including health and home automation devices as well as more general architecture. Indeed, machine to machine communication or the IoT paradigm aims to be not domain specific. Consequently, architecture developed with those paradigms in mind will be necessary in integrating health and ambient assisting living domains.

4.2 Research and open industry projects

4.2.1 EC FP6 HYDRA (2007-2010)

Vision

The aim of the EC FP7 HYDRA project [21] was to develop a middleware solution for embedded network systems and ambient intelligence for heterogeneous devices. The middleware is usable for three vertical domains: home-automation, eHealth and agriculture.

Approach

Like the Amigo project, HYDRA separates the devices in non-hydra-enabled devices, hydra-enabled devices and gateways. The interoperability between devices is realized by a gateway using the OSGi framework and centralizing all the home automation networks in the same central hardware.

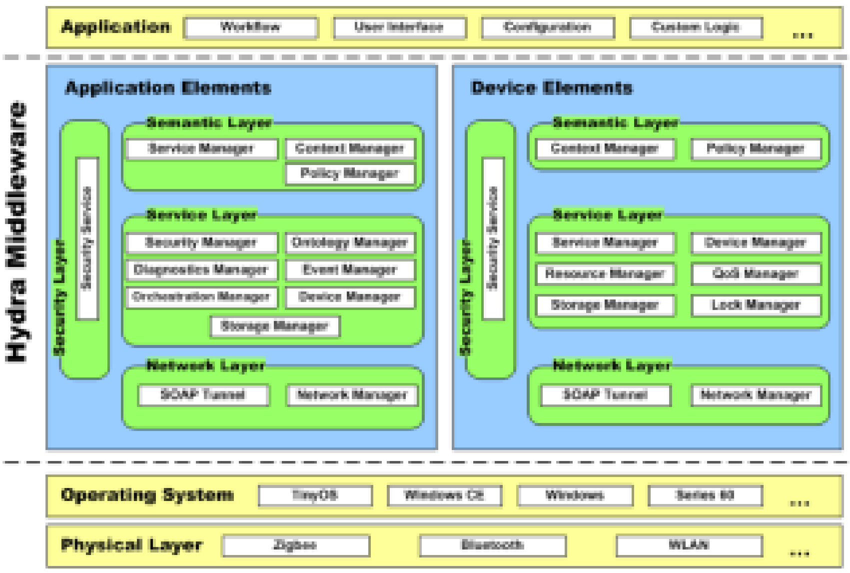


Figure 9: HYDRA middleware [22]

As explained in [22], the middleware proposed to integrate heterogeneous devices to allow an easy creation of more elaborate services. The HYDRA middleware acts like a layer between smart devices and the developer of new services or applications. The HYDRA middleware is now called LinkSmart Open Source Middleware [23]. The middleware defines three layers: Network, Service and Semantic.

Relevance to PRECIOUS

The HYDRA project is relevant for the PRECIOUS project. Several aspects have been handled by HYDRA such as ethical issues, interoperability of smart devices (interoperable distributed systems), business models, and healthcare usage scenarios. Hydra proposes a solution which is not domain specific.

Criteria	**Description**
Architecture style	Service-oriented architecture and semantic based model driven architecture
Interoperability	Services based on open standards, HYDRA middleware Middleware semantic layer
Seamless communication	Middleware Network layer
Motivational system	x
Communication protocol	SOAP and low-level protocols (e.g. ZigBee, Bluetooth)
Multimodal user interface	x
Test in lab/Field test	Healthcare scenarios, Diabetes monitoring

4.2.2 EC FP7 UniversAAL (2010-2013)

Vision

The EC FP7 UniversAAL project [24] is in fact a consolidation of several existing European project. The main objective was to allow, technically and economically, the creation and deployment of new services in the Ambient Assisted Living domain. The project is based on previous European project in the same domain:

- FP6: PERSONA, M-POWER, SOPRANO and AMIGO
- FP7: OASIS, GENESYS, VAALID and AALIANCE

Approach

UniversAAL used a middleware based on OSGi. In Figure 10, we can see that the system is separated in several layers. The communication between UniversAAL nodes is realized through three different buses:

- Service: communication bus with a pattern request/response between applications
- Context: communication bus to share information about the context (e.g., ”User is in

the kitchen")
- UI: communication bus between components in charge of HMI between the system and user.

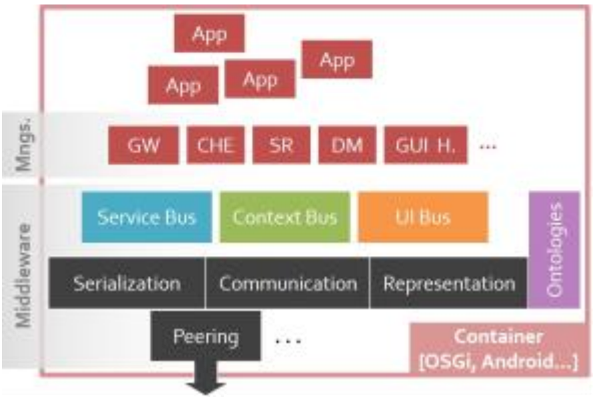


Figure 10: Layers representation of the UniversAAL system

The middleware manage the communication between the UniversAAL nodes with several components:

- Communication: allows to communicate on the different buses
- Serialization: allows analysing messages and processing encryption.
- Representation: defines ontologies.

UniversAAL defines also gateways to plug sensors and actuators to the middleware. The gateway is realized with a "Technology Driver" and the "Exporter" to interface device network and the UniversAAL middleware. There are several "Exporter" for different protocol: KNX, ZigBee, etc.

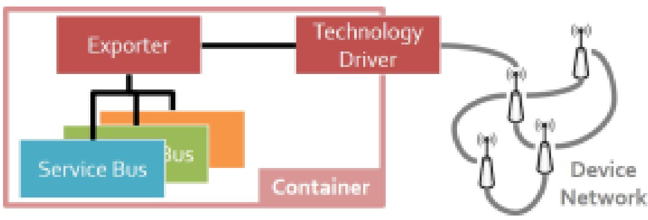


Figure 11: UniversAAL and device network

Relevance to PRECIOUS

Criteria	**Description**
Architecture style	OSGi-based
Interoperability	UniversAAL middleware, Ontologies
Seamless communication	UPnP, R-OSGi and gateway to interface home automation protocol like ZigBee, KNX,

	etc.
Motivational system	N/A
Communication protocol	UPnP, R-OSGi
Multimodal user interface	Realized with the UI Bus
Test in lab/Field test	yes

4.2.3 EC FP7 IOT-A (2010-2013)

Vision

The purpose of the EC FP7 IOT-A project was to propose a guideline to design architecture for the IoT paradigm [25].

Approach

The project proposes to build an architecture following the IoT paradigm for a specific domain. All the vision is based on a state-of-the art about existing architectures & solutions as shown Figure 12.

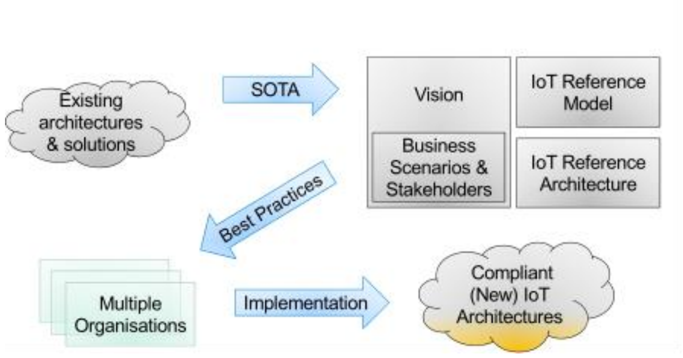


Figure 12: IoT-A architectural reference model building blocks

Inside the IoT Reference Model a sub-model is called IoT Domain Model and it is described in the Figure 13. The model defines several concepts of internet-of-things and their relations. Three important concepts are described [26, 27]:

- Device: physical component with communication capabilities
- Resource: software component representing functionalities of one or several physical entities (sensors and actuators)
- Service: software component which allows to access resources and which can be orchestrated by other services (not necessary IoT services).

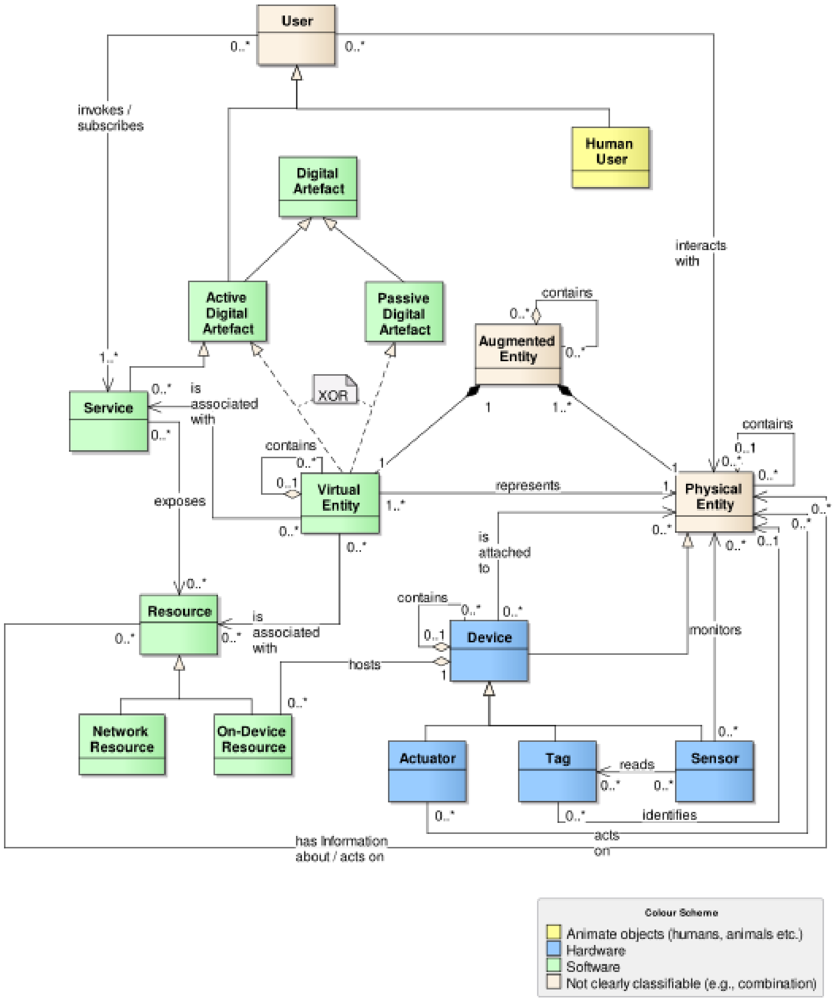


Figure 13: IoT domain model [26]

Relevance to PRECIOUS

Criteria	**Description**
Architecture style	Architectural Reference Model
Interoperability	Integrated in the model description
Seamless communication	yes
Motivational system	N/A
Communication protocol	Rules to build interoperable stack
Multimodal user interface	N/A
Test in lab/Field test	N/A

Guides with best practices delivered by the IoT Reference architecture should be compared with the PRECIOUS system. Moreover, the IoT-A architecture explained in [22] have an interesting description of based concept especially related to RM-ODP.

4.2.4 EC FP7 BUTLER (2011-2014)

Vision

The EC FP7 BUTLER project is described as the first European project to emphasise **pervasiveness**, **context-awareness** and **security** for IoT [28].

Related to the PRECIOUS project, BUTLER focuses on smart health and smart home domains.

Approach

The architecture of the BUTLER project is based on the IOT-A project. Three different platforms are defined: SmartObject/Smart Gateway, Smart Mobile and Smart Server. Interoperability over IP has been advised. However, authors remarks that using an IP stack inside a small sensor device is not feasible for energy consumption reasons. That is why, a gateway (SmartGateway) is necessary and it is dedicated to the following tasks:

- Manage resources
- Caching
- Security
- Subscribe and notifications of objects

The SmartServer connect object all together, process data and manage user connections. SmartServers provide APIs for SmartObject/Gateway and SmartMobile. More precisely, an architecture REST and a data model using JSON has been choices done by the project. The communication between devices (low-level) is realized by the communication layer [25] [26]. It manages the connection and the communication between SmartObjects/SmartGateway, SmartMobile and SmartServer. However, an adaptive layer is needed to include different protocols/standards existing like ZigBee or KNX.

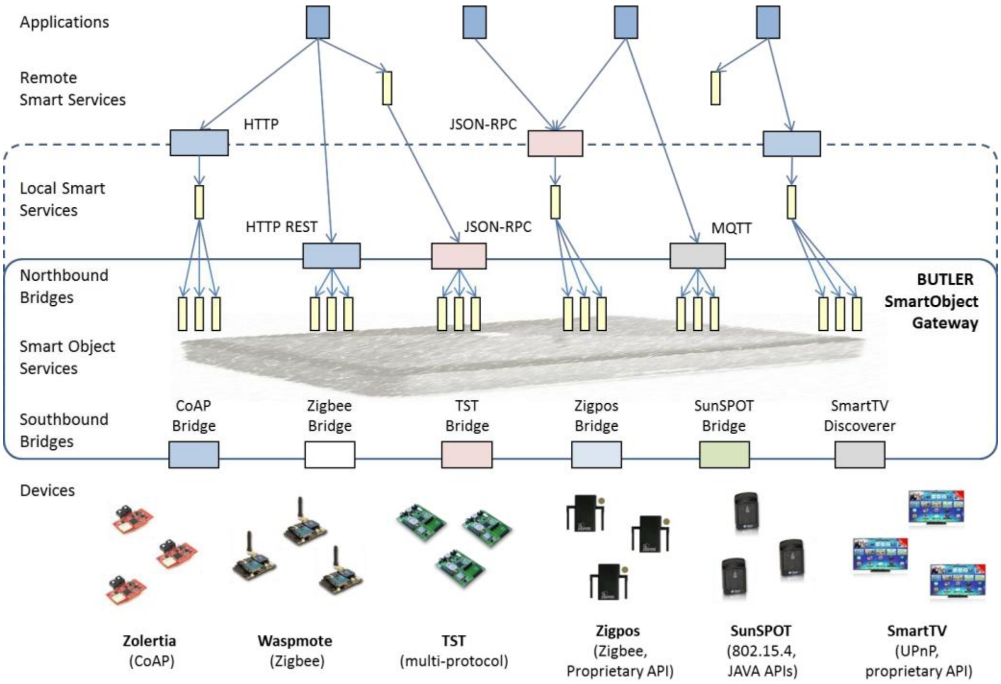


Figure 14: Overall BUTLER architecture [29]

Exchange of data between objects and gateway is realized by the layer “Device Access API” as shown Figure 15. It plays the role of adapters between home automation devices (Southbound bridges): ZigBee, NFC, KNX, etc. Consequently, the “Device Access” API creates a transparent layer and common access to the protocols: CRUD operations, Subscription/notification, etc. Northbound bridges allow communicating with services or applications from outside. For instance, HTTP REST, JSON-RPC or MQTT are protocols used in BUTLER.

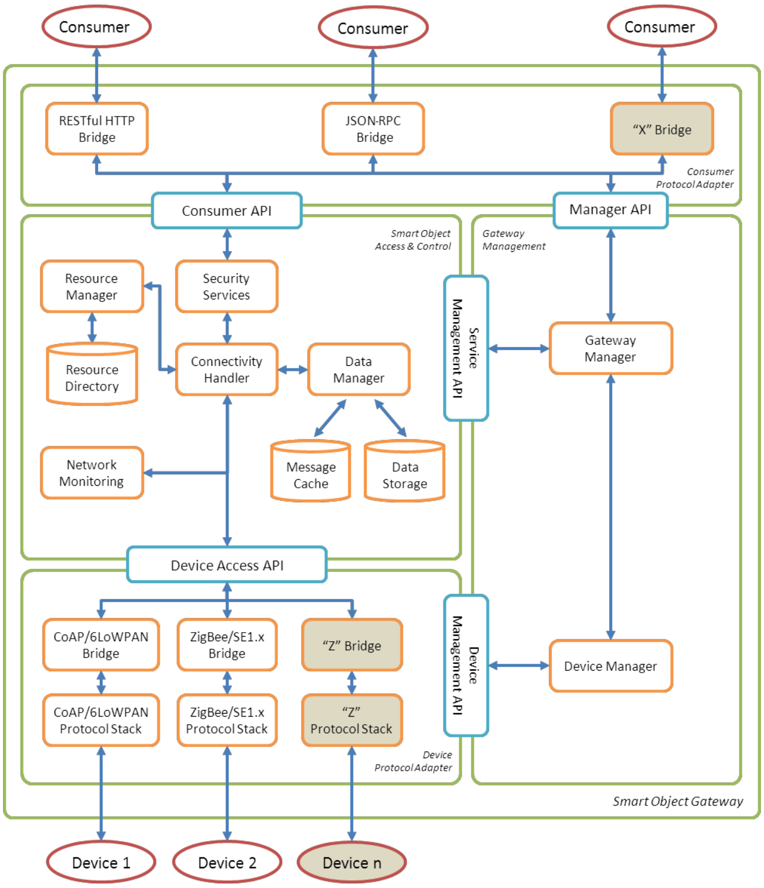


Figure 15: Smart Object Gateway [30]

Relevance to PRECIOUS

The Butler project is highly relevant to the PRECIOUS project regarding the architecture description. The overall architecture for smart home and smart health domains provide an interesting description of the communication between small devices and high-level services that can be used in different domains.

Criteria	**Description**
Architecture style	OSGi-based, API
Interoperability	Interoperability over IP Semantic interoperability
Seamless communication	Yes
Motivational system	N/A
Communication protocol	CoAP, ZigBee, 802.15.4, UPnP, etc.

Multimodal user interface	yes
Test in lab/Field test	Use case in smart home (multimedia everywhere) and smart health domains (personalize diabetes self-healthcare) [28]

4.2.5 OneM2M, ETSI Smart M2M

Vision

OneM2M[16] is a global organization created in 2012 by several important standards organization in the world. ETSI Smart M2M is a partner of OneM2M. The idea is to propose a framework in order to achieve interoperability between devices and services used in M2M applications and the Internet of Things. Several use cases are proposed and more precisely in the mHealth and smart home domains.

Approach

OneM2M is based on a REST Architecture. One of the objectives is to standardize interfaces in order to enable interaction between several vertical technologies to talk with another. Several bindings have been specified, namely: CoAP, HTTP, and MQTT.

Relevance to PRECIOUS

Criteria	**Description**
Architecture style	REST Architecture
Interoperability	Interoperability over IP. Define interfaces and API in order to enable the development of application and services.
Seamless communication	Yes
Motivational system	N/A
Communication protocol	-
Multimodal user interface	No
Test in lab/Field test	No

[16] http://www.onem2m.org/

5. Review of General Higher-Layer Protocols

5.1 Rationale

We have dedicated a special chapter concerning high-layer protocols because we think that it is a necessary separation to understand the choices in terms of architecture. Vasseur & Dunkel [35] explain why interconnecting smart objects with IP is a good solution to develop interoperability. But it is currently not feasible to deploy a full IP stack on small and smart devices. That is why, it is necessary to find a compromise between a low-level network focus on power consumption, physical size & cost and high-level protocols. Consequently, low-level protocols dedicated to devices with constrained resources need a gateway, e.g. to push data towards services or external applications.

High-layer protocols dedicated to layers higher than IP (Transport, Application, etc.) can be used in different ways. Indeed, some of them are used in LAN or PAN to solve interoperability issues (e.g., xAP/xPL, UPnP, etc.). And others are used to share data between the LAN/PAN and a wide area network WAN (that is, M2M protocols).

5.2 Review of relevant protocols

5.2.1 AgoControl (AMQP)

Agocontrol is a framework dedicated to home automation. It defines a lightweight protocol based on Advanced Message Queuing Protocol (AMQP). Devices are identified by an UUID and described by schema.

5.2.2 xPL/xAP

xPL is a network protocol which is a fork of xAP. Both share the same basic protocol relaying on a network bus (UDP). xPL is dedicated to a home area network. The description of devices is type based (i.e., x10.basic). A discovery mechanism allows knowing devices alive in the network with a heartbeat (UDP broadcast).

Pros:

- Widely used in home automation
- Simple text based protocol (JSON like)
- Single transport (IPv4 UDP broadcast)

Cons:

- Loosely type handling
- Transparent gateway (xPL)
- Mix type and address (xAP)
- Overloaded target filtering
- Non-standard text format

5.2.3 UPnP

UPnP is a set of networking protocols to establish functional network services for data sharing, communications, and entertainment. It is widely used and dedicated to home area network.

Pros:

- Used in home automation products
- Standards implementations
- Strong and clear specifications

Cons:

- Mixing a lot of protocols
- Events are hard to tailor
- Too big to feet in embedded devices

5.2.4 DPWS

Device Profile for Web Services (DPWS) is a standard (Rev2 of UPnP specifications). It is a Service-oriented architecture (SOA). The description is realized with WSDL and discovery by WS-Discovery.

5.2.5 MQTT

MQTT (Message Queue Telemetry Transport) is a lightweight M2M publish/subscribe protocol mostly designed for resource constrained devices. Recently, It has been standardized by OASIS [31]. MQTT uses TCP/IP as transport layer and it needs a broker where topics are used by publishers and subscribers. A topic is a URI (e.g. /sensors/temperature) where a publisher pushes its data and where several subscribers subscribe to get data when available.

MQTT define three levels of QoS to manage the reliability of a link:

- 0: message delivered at most once without acknowledge
- 1: message delivered at least once
- 2: message delivered exactly once

MQTT is a simple asynchronous protocol. It is language agnostic and it exists a lot of different implementation (e.g., Python, Java, Javascript, etc.). The payload of a MQTT message is also agnostic. This means that it is possible to defined its own messaging protocol over MQTT.

MQTT do not take in charge security aspects. However, solutions are possible: SSL/TLS, username/password to identify client and encryption of the MQTT payload. Finally, an OASIS MQTT Security Subcommittee provides guidance in order to apply security to systems using MQTT.

5.2.6 CoAP

CoAP is a RESTful protocol defined by the IETF CoRE working group [32]. CoAP has been designed for resource-constrained devices. Unlike MQTT, a request/response model pattern is used. It supports a built-in discovery mechanism. The description of each resources (or devices) is done by a Uniform Resource Identifier.

5.2.7 HTTP/REST

HTTP/REST protocols have nowadays a lot of success. Guinard in [33] describes the Web-of-thing (WOT). The idea behind the concept of WOT is to use web standards to manage heterogeneity between Internet-Of-Things devices. Four layers have been defined:

- Layer 1, Accessibility: allow access to objects
- Layer 2, Findability: search and localize objects
- Layer 3, Sharing: share object on the wed (web social)
- Layer 4, Composition: Service composition ("Physical mashup")

HTTP/REST is based on a request/response model that is why when a device wants to push data (i.e., to take into account events), it is not directly feasible. Consequently, Guinard have proposed tPusher [33] (RESTful API, Websocket and Comet server) in order to push data. Moreover, like it is not feasible to directly address some tiny devices from the Web, smart gateway between one subnet of tiny devices and the Web is still necessary.

5.3 Discussion

It exists also a lot of different protocols to manage interoperability between devices in a local area network as well as for M2M communications.

xPL/xAP, UPnP and AgoControl for instance are dedicated to home area network and control/command applications. MQTT is a protocol dedicated to M2M communication. HTTP/REST protocol is more dedicated to web application or services. But, with the recent Internet-of-things paradigm new protocols appeared like CoAP (HTTP-like) or HTTP/REST Web-of-things [33] more dedicated to constrained devices. However protocols like CoAP, MQTT or HTTP/REST do not use the same communication model. Generally, pub/sub pattern and request/response pattern are opposed. As it is shown in the Butler project [28], hybrid solution offering the choice between the best patterns (HTTP, MQTT, XML-RPC) for a specific application might be a good solution.

In general, common mechanisms (or functionalities) are used to achieve interoperability. Indeed, most of the solutions have similar components or functionalities (see Table 3) that are essential for a system including heterogeneous devices:

- *Addressing* is an essential functionality to send/receive information to/from devices. Several techniques can be employed, e.g., UUID, IP address, etc.
- *Description* gives information about the functions available on a device
- *Discovery* mechanism gives information to the system about the available devices.
- *Communication protocol* is the way a device shares its functionality or information.
- *Security and privacy* are essential to protect user information.
- *Store/cache* data are essential for sensors that are not queryable, or to verify the state.

Table 3 Comparison of high-layer protocols

Protocols	**Description**	**Discovery**	**Communication layer**	**Event**	**Security**
xPL/xAP	Type based	Heartbeat broadcast	UDP broadcast	UDP broadcast	x
AgoControl	Schema	Device announce	AMQP	Yes	SSL (AMQP)
UPnP	XML	SSDP	SOAP	GENA	TLS
DPWS	WSDL	WS-Discovery	SOAP/HTTP, SOA/UDP	WS-eventing	WS-Security
CoAP	URI	Built-in	UDP, SMS, TCP (possible)	Asynchronous notification	DTLS
MQTT	MQTT topic	Pub/Sub	TCP/IP	Pub/Sub	SSL

6. Overall Conclusions of the Review

Interoperability is needed to produce new services for users. Especially, in the home automation and personal connected health domains, it appeared to be essential to share communication and information (that is, data) to have a more elaborated view of the user and its context. It is also essential to interact with the user with targeted feedback.

6.1 Personal connected health domain perspective

A standards-based approach is essential addressing the interoperability challenge in the personal connected health ecosystem. Personal connected health systems constitute a wide range of personal devices and gateways, that increasingly monitor many health conditions and wellness attributes. Moreover, the systems require data transfer across multiple domains (e.g. personal/home to clinical domain), across different locations and/or across different regulatory domains. As a result, no single SDO can cover the end-to-end needs of a personal health system, but rather the system is implemented with multiple solutions each with potentially overlapping and sometimes gaps in the standards. This makes interoperability within personal health systems a significant challenge. Interoperability here is viewed at several levels including: technical interoperability; semantic interoperability; and legal and regulatory interoperability [34].

Therefore, some organisations are adopting the approach of consolidating best-of-breed standards for messaging, security, semantics, transport and so on, in personal health systems so as to obtain a single certifiable solution. To that end, the Continua interoperability guidelines (reviewed in Section 2.1.2) is now increasingly acknowledged as providing the standard approach for achieving interoperability in personal health systems. This view is supported by some notable projects, bodies and initiatives including:

- SDOs and industry bodies in the telecommunications sector (e.g. GSMA[7], ITU[5]);
- Umbrella alliances, such as the Personal Connected Health Alliance (PCHA)[17];
- EC 2010 roadmaps on eHealth interoperability [34] and recent published EC public consultations which further echoed opinions from stakeholders for inclusion Continua interoperability guidelines in the EU eHealth Interoperability framework [35];
- Top-down initiatives through adoption of Continua guidelines in various national eHealth/telehealth action plans (e.g. Denmark [36]);
- Inclusion of Continua-compliant Bluetooth HDP in the Bluetooth APIs[18] of the Android platform, which is now the most widely adopted mobile OS;
- A certification program which now has a global footprint including China and Japan.

It should however be noted that the personal connected health landscape is being transformed by the entrance of large device and platform vendors into the ecosystem. Some of vendor solutions, such as, Apple's HealthKit[19] may have a significant impact on the solution adoption trends which could also influence the dominance of the de facto standards in the personal connected health domain.

[17] http://www.pchalliance.org/
[18] http://developer.android.com/guide/topics/connectivity/bluetooth.html
[19] https://developer.apple.com/healthkit/

6.2 Smart home domain perspective

The home of a user is a special space where different vertical domains are present: personal health devices, home automation devices, entertainment devices, etc. Recent works about IoT domain architecture proposed horizontal interoperability between vertical silos: eHealth, home automation, agriculture, etc. One can cite the HYDRA [21], IOT-A [25] or BUTLER [28] European projects. There is also a recent effort to standardize M2M communication with the OneM2M initiative.

Gateways between devices constrained network and BAN/PAN, HAN & WAN it still needed. Even if protocols like CoAP or MQTT are dedicated to small devices, there is still a gap because of devices: power consumption, memory foot print, etc. Moreover, security & privacy of user data is absolutely a necessity which is a problem for small devices because it increases the general complexity of such systems.

The home automation domain is still a special case where interoperability issues between devices are very strong. In a home area network, the interoperability over IP seems to be a good solution to enable the communication between gateways. Gateways are essential to offer an access to home automation networks (ZigBee, ZWave, KNX, etc.). In the last decade, several solutions to fight interoperability issues in this domain have been proposed:

- Middleware solutions. The interoperability is managed in a centralized gateway generally based on OSGi: e.g. OpenHAB, Dog Gateway, etc.
- Interoperability over IP around a protocol of communication: xAP/xPL, UPnP, AgoControl, etc.
- Interoperability with an architecture/framework: e.g. SM4ALL, UniversAAL, BUTLER, etc.

All of these solutions play around common functionalities to solve interoperability issues in the home area network as discussed in the Section 5.3.

Finally, in the smart home domain, the interoperability over IP inside the home area network has to be proposed to the user. And an access to the home area network realized by M2M communications appeared also as a common model to offer access to external services in different domains: eHealth, home automation services, etc. In that case, several choices are possible according to the application between different models: pub/sub, request/response, etc.

Part B: Specification of PRECIOUS System Architecture

7. Process of the PRECIOUS system architecture design

7.1 Definition of key terms for architecture specification

Architecture (of a system): Set of rules to define the structure of a system and the interrelationships between its parts (ISO/IEC 10746-2).

Other definitions:

- A means for describing the elements and interactions of a complete system including its hardware elements and its software elements (SEI)
- The conceptual model that defines the structure, behaviour, and more views of a system (Wikipedia)

Interface: Named set of operations that characterize the behaviour of an entity. The aggregation of operations in an interface, and the definition of interface, shall be for the purpose of software reusability. The specification of an interface shall include a static portion that includes definition of the operations. The specification of an interface shall include a dynamic portion that includes any restrictions on the order of invoking the operations (ISO 19119:2005).

Interoperability: Capability to communicate, execute programs, or transfer data among various functional units in a manner that require the user to have little or no knowledge of the unique characteristics of those units (ISO 19119, ISO 2382-1).

Open Architecture: An architecture whose specifications are public. This includes officially approved standards as well as privately designed architectures whose specifications are made public by the designers (Wikipedia).

Reference Model: Framework for understanding significant relationships among the entities of some environment, and for the development of consistent standards or specifications supporting that environment. A reference model is based on a small number of unifying concepts and may be used as a basis for education and explaining standards to a non-specialist (ISO).

Service: Distinct part of the functionality that is provided by an entity through interfaces (ISO 19119).

System: Something of interest as a whole or as comprised of parts. Therefore a system may be referred to as an entity. A component of a system may itself be a system, in which case it may be called a subsystem (ISO/IEC 10746-2).

Viewpoint: Subdivision of the specification of a complete system, established to bring together those particular pieces of information relevant to some particular area of concern during the design of the system (ISO/IEC 10746).

7.2 Overview

The PRECIOUS system architecture is designed in a way that allows for iterations so as to take into account any evolving user and system requirements as well as the ongoing rapid ICT technological progress in the personal health and wellness market and standardisation. Such changes require a dynamic architecture design that cannot be captured in one a step design. This iterative architectural design approach is based on the architecture design process pioneered by the FP6 ORCHESTRA (Open Architecture and Spatial Data Infrastructure for Risk Management) project that has since been adopted in many other EC projects [37].

The architectural design process includes two main phases, the analysis phase which designs the framing conditions for the architecture design and the actual architecture design phase. Figure 16 illustrates the dynamic cycle between the analysis and the design phases.

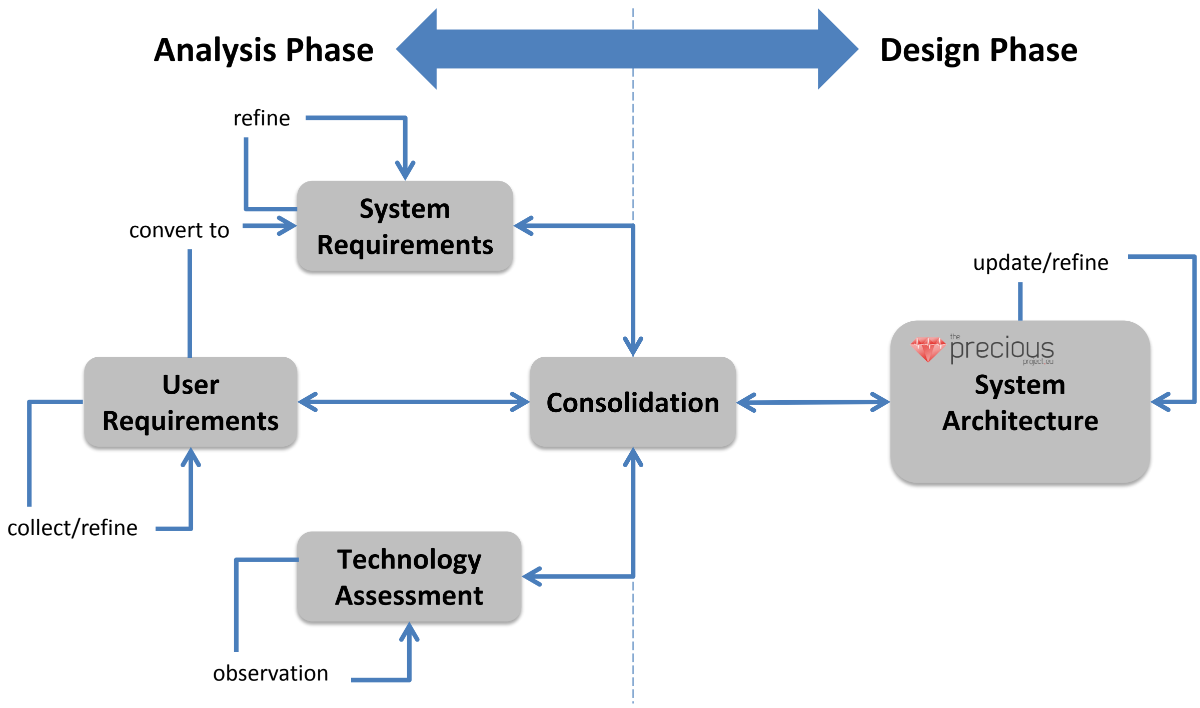


Figure 16 Dynamic PRECIOUS analysis and design processes

The *user requirements* for the PRECIOUS system architecture incorporate all aspects that users of the PRECIOUS system expect to see reflected in personal preventive health and wellness system. The collection and initial refinement of the PRECIOUS user requirements has been previously done in WP2 and is reported in deliverable D2.2.

The *system requirements* for the PRECIOUS Architecture encompass all functional and non-functional aspects that need to be factored in order to reflect the user requirements on the system architecture design. A mapping of the user to system requirements is presented in the subsequent section. It is noted that the specification of the PRECIOUS system requirements is open to further future refinements beyond what is specified in this document.

The *technology assessment* process is also an iterative process, by means of which it is ensures that the system requirements can be fulfilled with the current available technology, based as much as possible in interoperable and open standards. Moreover, it allows for incorporation of any emerging technology developments to impact on the architectural design process.

The *consolidation* process sits in-between the analysis and design phases. To that end, it ensures that, at given point in time, there is a common understanding of the user requirements, the system requirements, and an assessment of the current technology as a foundation to design the PRECIOUS system architecture.

7.3 System requirements

7.3.1 Background on system requirements

The effective adoption and usage of the PRECIOUS system is dependent on the system implementation meeting the PRECIOUS end-user requirements (specified previously in deliverable D2.1). Therefore, a list of system requirements is derived from user requirements so as to address the PRECIOUS system implementation challenge and fulfil user needs and expectations. It should be noted that it is not the intention of this deliverable, to cover all possible requirements of the PRECIOUS system, but rather to outline the requirements important to the PRECIOUS system designers.

The PRECIOUS system requirements defined in this deliverable are grouped in the following categories:

- *Functional requirements*: Requirements that are intended to define specific system behaviour or functions.
- *Non-functional requirements*: The requirements that provide a defining of the criteria that can be utilised for judging the operation of the PRECIOUS system

The requirements documented in this report are expressed in *structured natural language* which provides a compromise between natural language (informal requirements) that are easily understandable to the user and formal specifications or graphical notation that is usually preferred by system designers.

In order to bring some rigor to the structured natural representation, a requirement template is used as follows:

Req_Id	[Req_Type]R[Number]
Concise expression of the requirement	
Expression...	
Rationale	
Explanation….	

Compliance Classifier	Mandatory
Related user requirement(s) as specified in deliverable D2.1	
URx:….	

- Requirement Identifier (Req_Id): Identifier of the requirement in the form [Req_Type]R[Number], where, [Req_Type] is F and NF for functional and non-functional system requirements, respectively. [Number] is the unique number assigned to that requirement of type [Req_Type].
- Concise Requirement Expression: Description of the requirement in a short and concise manner. Italics may be used to highlight the keyword in requirement expression.
- Rationale: Short description to justify, if needed, the requirement. "N/A" (Not Applicable) is used if no justification is needed.
- Compliance classifier: Level of compliance expected for the requirement. One of Mandatory (M), Recommended (R) or Optional (O).
- Related user requirement(s) as specified in deliverable D2.1: Wherever relevant, the user requirement(s) from D2.1 to which the system requirement is linked. "N/A" (Not Applicable) is used when no strong link exists with any of the user requirements.

7.3.2 Functional requirements

Req_Id	FR1
Concise expression of the requirement	
System must be able to monitor at least one risk factor or lifestyle aspect of a user.	
Rationale	
The main capability of the PRECIOUS system is to provide feedback to the user and motivate behavioural changes based on quantitative or qualitative measures of user's risk factors or lifestyle aspects. Therefore, for the system to function at least one of those attributes has to be monitored.	
Compliance Classifier	Mandatory
Related user requirement(s) as specified in deliverable D2.1	
UR1: Measurement of risk factors / lifestyle aspects (food intake, physical activity, stress and sleep)	

Req_Id	FR2

Concise expression of the requirement	
Any communications between distributed components of the system, or between any system component and component(s) from an external system must be authentic, protected and confidential.	
Rationale	
The PRECIOUS system user data includes personal medical and activity/contextual data, which is sensitive and the users would wish to keep private and protected. This requires authentication mechanisms for any entity, both internal (e.g. PRECIOUS cloud server) or external (e.g. social media channel), that intends to communicate with a PRECIOUS system component, protection of user data (e.g. with data encryption) and guaranteeing of user confidentiality, typically through anonymisation of their data. Deliverable D2.4 provides an extended set of ethical and privacy guidelines from a PRECIOUS persective.	
Compliance Classifier	Mandatory
Related user requirement(s) as specified in deliverable D2.1	
UR2: Options to control data sharing and privacy settings UR4: Connections to social networks UR8: Ability to interact with groups of users who have a common goal(s)	

Req_Id	FR3
Concise expression of the requirement	
Any transmission, processing or storage of user data by the system must only be done with prior user consent.	
Rationale	
The legislative terms for user data protection (particularly in the health domain) require that any transfer, processing or storage of the user data is done with the knowledge and consent of the user. Any data handling without user consent is not permitted by law. Deliverable D2.5 provides a summary review of the legislative frameworks that impact on usage of PRECIOUS system.	
Compliance Classifier	Mandatory
Related user requirement(s) as specified in deliverable D2.1	

UR2: Options to control data sharing and privacy settings UR4: Connections to social networks UR8: Ability to interact with groups of users who have a common goal(s)

Req_Id	FR4
Concise expression of the requirement	
System must provide user with options to control data sharing and privacy settings.	
Rationale	
The user data may be accessible to relevant actors (personal doctor, family member, etc.), devices, platforms or applications with a key and valued role in promoting the user's health and wellbeing. Therefore, system should provide the user the ability to customise their data access control settings so that their data could be consumed by actors, devices, platforms or applications that the user deems useful for promoting their health and wellbeing.	
Compliance Classifier	Mandatory
Related user requirement(s) as specified in deliverable D2.1	
UR2: Options to control data sharing and privacy settings UR4: Connections to social networks UR8: Ability to interact with groups of users who have a common goal(s)	

Req_Id	FR5
Concise expression of the requirement	
System should provide sufficient levels of customisation for different user device interfaces	
Rationale	
A user would typically own one or more devices (smart watch, smartphone, tablet PC, smart television, etc.), each with different form-factors, screen resolution, power sources (grid or battery), and so on. The system should therefore allow for user interaction with the system for all the different interfaces that are provided by those diverse device types.	
Compliance Classifier	Recommended

Related user requirement(s) as specified in deliverable D2.1
UR3: Provision of different format options for displaying data e.g. numbers, pictures UR7: Able to access / interact with service through multiple channels e.g. smart TV, smart phone, smart watch, laptop, tablet

Req_Id	FR6
Concise expression of the requirement	
System should provide seamless synchronisation with user's calenders	
Rationale	
The PRECIOUS system behavioural and lifestyle monitoring and feedback should be logical (timewise) and in sync with the user's personal and/or work calenders. The requires system to work synchronise with multiple calendar formats.	
Compliance Classifier	Recommended
Related user requirement(s) as specified in deliverable D2.1	
UR5: A calendar/organiser that seamlessly syncs with work and/or personal calendars	

Req_Id	FR7
Concise expression of the requirement	
System should keep track of user location	
Rationale	
PRECIOUS system feedback is highly dependent on user context and user location is one the most key pieces of the contextual data that in understanding user activity level (e.g. jogging route) and formulating user feedback (e.g. recommendation of food choice based on restaurent). As such, the utilisation and sharing of user location subject to user privacy preferences and consent.	
Compliance Classifier	Recommended
Related user requirement(s) as specified in deliverable D2.1	

UR2: Options to control data sharing and privacy settings UR4: Connections to social networks UR6: Use of location data to suggest local amenities, activities etc that help the user to meet their objectives

Req_Id	FR7
Concise expression of the requirement	
System should keep track of user location	
Rationale	
PRECIOUS system feedback is highly dependent on user context and user location is one the most key pieces of the contextual data that in understanding user activity level (e.g. jogging route) and formulating user feedback (e.g. recommendation of food choice based on restaurent). As such, the utilisation and sharing of user location subject to user privacy preferences and consent.	
Compliance Classifier	Recommended
Related user requirement(s) as specified in deliverable D2.1	
UR2: Options to control data sharing and privacy settings UR4: Connections to social networks UR6: Use of location data to suggest local amenities, activities etc that help the user to meet their objectives	

Req_Id	FR8
Concise expression of the requirement	
System must provide feedback to users on risk factors or lifestyle aspects	
Rationale	
The main capability of the PRECIOUS system is to provide feedback to the user and motivate behavioural changes based on quantitative or qualitative measures of user's risk factors or lifestyle aspects. Therefore, for the system function to valid feedback based on any monitored attribute (risk factor or lifestyle aspect) should be provided back to the user.	
Compliance Classifier	Recommended

Related user requirement(s) as specified in deliverable D2.1
UR9: Receive feedback on risk factors / lifestyle aspects

Req_Id	FR9
Concise expression of the requirement	
System must provide feedback to users on risk factors or lifestyle aspects	
Rationale	
The main capability of the PRECIOUS system is to provide feedback to the user and motivate behavioural changes based on quantitative or qualitative measures of user's risk factors or lifestyle aspects. Therefore, for the system function to valid feedback based on any monitored attribute (risk factor or lifestyle aspect) should be provided back to the user.	
Compliance Classifier	Mandatory
Related user requirement(s) as specified in deliverable D2.1	
UR9: Receive feedback on risk factors / lifestyle aspects UR12: Educates the user towards healthier behaviours UR13: Motivates the user to make behavioural changes UR15: Gives rewards for healthier choices and/or encouraging others to make healthier choices	

Req_Id	FR10
Concise expression of the requirement	
System monitoring and feedback must be customisable for the user	
Rationale	
The PRECIOUS system should be customisable for the feedback provided (and health values derived or perceived) to be relevant to the user. Customisation may be done directly by user interventions in adjusting settings or automically by the system based user profile, context, history and so on.	
Compliance Classifier	Mandatory
Related user requirement(s) as specified in deliverable D2.1	

UR10: User receives only information that is relevant to their goals UR14: Setting of personal goals

Req_Id	FR11
Concise expression of the requirement	
System could represent the user with an avatar	
Rationale	
When it comes to providing feedback and motivating behavioural change, avatars are an considered a tool that is more approachable and relatable compared other visual interfaces or human counterparts.	
Compliance Classifier	Optional
Related user requirement(s) as specified in deliverable D2.1	
UR16: Representation of self with an avatar	

7.3.3 Non-functional requirements

Req_Id	NFR1
Concise expression of the requirement	
System must meet or exceed levels of security as specified by relevant legislation for data protection.	
Rationale	
PRECIOUS system handles signifanct amounts of user monitored and context data that places stringent demands in terms of privacy preservation and access controls.	
Compliance Classifier	Mandatory
Related user requirement(s) as specified in deliverable D2.1	
UR2: Options to control data sharing and privacy settings	

Req_Id	NFR2
Concise expression of the requirement	

System must have *flexibility* to adapt to variable usage contexts, environments as well as, to support changes in business rules or business policies.	
Rationale	
A flexible system allows for ease in reconfiguration or adoption on response to varying user requirements and system.	
Compliance Classifier	Mandatory
Related user requirement(s) as specified in deliverable D2.1	
UR2: Options to control data sharing and privacy settings UR10: User receives only information that is relevant to their goals UR14: Setting of personal goals	

Req_Id	NFR3
Concise expression of the requirement	
System must have *scalability* to perform under increasing or expanding data volumes or workload.	
Rationale	
The PRECIOUS system may have to respond to increased monitored data traffic, user number, device number, number of actice applications and so on. The system scaling typically involves making available more memory, more processors, faster processors etc. locally or in the cloud.	
Compliance Classifier	Mandatory
Related user requirement(s) as specified in deliverable D2.1	
N/A	

Req_Id	NFR4
Concise expression of the requirement	
System should have *portability* to easily adopt to different operating environments.	
Rationale	
The PRECIOUS system would be deployed on devices or machines of different capabilities, different platforms etc.	

Compliance Classifier	Optional in the project timeframe, but Mandatory for future realisations of the system.
Related user requirement(s) as specified in deliverable D2.1	
UR3: Provision of different format options for displaying data e.g. numbers, pictures UR7: Able to access / interact with service through multiple channels e.g. smart TV, smart phone, smart watch, laptop, tablet	

Req_Id	NFR5
Concise expression of the requirement	
System must have *extensibility* for adding new features or capabilities.	
Rationale	
The PRECIOUS system design philosophy is one of on open architecture that favors system extensibility with the aim of facilititating evolutionary or incremental developments by a broader developer ecosystem.	
Compliance Classifier	Mandatory
Related user requirement(s) as specified in deliverable D2.1	
UR1: Measurement of risk factors / lifestyle aspects (food intake, physical activity, stress and sleep)	

Req_Id	NFR6
Concise expression of the requirement	
System must make *efficient* use of computational/or and communications resources.	
Rationale	
PRECIOUS system must be designed within the resource and cost constraints of devices and distributing computing platforms.	
Compliance Classifier	Mandatory
Related user requirement(s) as specified in deliverable D2.1	
N/A	

Req_Id	NFR7
Concise expression of the requirement	
System must have acceptable levels of *availability*, *reliability and robustness*.	
Rationale	
PRECIOUS system will experience many error conditions during operation (invalid data, sensor failures, software defects etc.) and must be able to tolerate these error conditions, without failure or significant disruption, and operate reliably over time with high availability. The system's availability is the amount of time that the system is operational and available for use.	
Compliance Classifier	Mandatory
Related user requirement(s) as specified in deliverable D2.1	
N/A	

Req_Id	NFR8
Concise expression of the requirement	
System must be easily *maintanable or serviceable*	
Rationale	
PRECIOUS system must have the ability to allow alterations in devices, services, features or interfaces to the extent that such changes are required when adding or changing functionality, correcting defects or supplementing new business requirements.	
Compliance Classifier	Mandatory
Related user requirement(s) as specified in deliverable D2.1	
N/A	

Req_Id	NFR9
Concise expression of the requirement	
System must be acceptable levels of *usability* for its intended users.	
Rationale	

PRECIOUS system design must incorporate the capacity for the system to be understood, learned, and used by its intended users.	
Compliance Classifier	Mandatory
Related user requirement(s) as specified in deliverable D2.1	
UR2: Options to control data sharing and privacy settings UR3: Provision of different format options for displaying data e.g. numbers, pictures UR7: Able to access / interact with service through multiple channels e.g. smart TV, smart phone, smart watch, laptop, tablet UR10: User receives only information that is relevant to their goals UR14: Setting of personal goals	

7.4 Overview of the RM-ODP architectural framework

The Reference Model of Open Distributed Processing (RM-ODP) is an international standard jointly specified by the International Standards Organisation (ISO) and the International Telecommunications Union (ITU) for architecting open, distributed processing systems [ITU-T X.901-X.904, ISO/IEC 10746] [38].

7.4.1 Rationale and conceptual description

Open distributed processing (ODP) systems are important due to the great need to interconnect information processing systems, such as, multi-stakeholder personal health systems. However, organisations looking to manage and exploit systems with distributed processing must deal with a number of key attributes of system distribution, such as:

- *Remoteness*: System component interactions may be either local or remote.
- *Concurrency*: Distributed system components may execute in parallel.
- *Lack of global state*: Global state of a distributed system cannot be precisely determined.
- *Partial failures*: A system component may fail independently of other components.
- *Asynchrony*: Communication and processing activities are not driven by a single global clock.
- *Heterogeneity*: Distributed system components are typically built using different technologies (hardware, software platforms, communication protocols, etc.)
- *Autonomy*: A distributed system can be spread over a number of autonomous management or control authorities, with no single point of control.
- *Evolution*: Changes generally occur during a distributed system's due to need for upgrades, need to handle different or new applications, etc.
- *Mobility*: The sources of information, processing nodes, and users may be physically mobile.

In response to the aforementioned complexity, the reference model (RM-ODP) serves to provide "big picture" that organises the pieces of an ODP system into a coherent whole. In this RM-ODP is meant to describe system components without prescribing an implementation or influencing the choice of technology. Based on this understanding of a system, the RM-ODP standards specify an architectural framework for structuring the specification of ODP systems using a concept of viewpoints. The different viewpoints address different aspects of the system that are of concern to a diverse set of system users (e.g. software developers, health practitioners, network engineers, etc.). To that end, the RM-ODP standards define five generic and complementary viewpoints, namely:

- *Enterprise viewpoint*: A viewpoint on the system and its environment that focuses on the purpose, scope and policies for the system.
- *Information viewpoint*: A viewpoint on the system and its environment that focuses on the semantics of the information and information processing performed.
- *Computational viewpoint*: A viewpoint on the system and its environment that enables distribution through functional decomposition of the system into objects which interact at interfaces.
- *Engineering viewpoint*: A viewpoint on the system and its environment that focuses on the mechanisms and functions required to support distributed interaction between objects in the system.
- *Technology viewpoint*: A viewpoint on the system and its environment that focuses on the choice of technology in that system.

The RM-ODP viewpoints provide relevance at various phases of the system lifetime. The enterprise viewpoint allows for specification of community objectives at the inception phase and communication of these objectives to stakeholders (both within and outside the system development team) throughout the system lifetime. The enterprise viewpoint guides the information and computation viewpoints that provide an abstract view of the system that in turn provides the design framework for the system developers. Finally, the engineering and technology viewpoints build on the previous viewpoints to specify the system (hardware and software) tool selection and integration in the system development and implementation.

7.4.2 Example usage in EC research projects and health IT

The RM-ODP standards have been widely adopted in for defining IT architectural frameworks in healthcare industry and EC research projects. In most cases the projects have utilised the five original viewpoints, while others have leveraged the modularity and flexibility of the RM-ODP framework to modify the some of the legacy viewpoints or add some new viewpoints that were not fully addressed by the legacy viewpoints (see examples of Table 4).

Table 4 Example RM-ODP usage in various EC projects

EC Project	Viewpoints used to specify architectural specification					
	Enterprise	Information	Computational	Engineering	Technology	Other
FP7	Yes	Yes	Yes (renamed	Yes	Yes	n/a

EC Project	Viewpoints used to specify architectural specification					
	Enterprise	Information	Computational	Engineering	Technology	Other
PEScADO			Service viewpoint)			
FP7 EnviroFI	Yes	Yes	Yes	Yes	Yes	n/a
FP7 GEOWOW	Yes	Yes	Yes	Yes	Yes	n/a
FP7 PCAS	Yes	Yes	Yes	Yes	Yes	n/a
FP6 DEWS	Yes	Yes	Yes (renamed Service/ Computational Viewpoint)	Yes	Yes	Added Physical and Communication Viewpoints

The RM-ODP standards have for defining IT architectural frameworks in a number of healthcare initiatives. Examples include:

- The international standard (EN/ISO 12967) on Health Information Services Architecture (HISA), whereby, three RM-ODP viewpoints (Enterprise, Information and Computation) are used to describe the HISA architecture [39];
- Australia's National E-Health Transition Authority (NEHTA) which uses three viewpoints (Enterprise, Information and Computation) to define the NEHTA Interoperability Framework [40];

7.5 Application of RM-ODP for PRECIOUS system architecture specification

The RM-ODP standard has been selected for the specifying the PRECIOUS Architecture. To that end, RM-ODP is applied on structuring of ideas, documentation of the PRECIOUS architectural design and presenting the PRECIOUS system from different perspectives using viewpoints as shown in Figure 17. As noted in the examples of the previous section, the RM-ODP framework is generic and allows for flexibility in its usage through removal or addition viewpoints, but also in terms of adoption of viewpoint specifications from models or frameworks entrenched in a community for which the system is intended for.

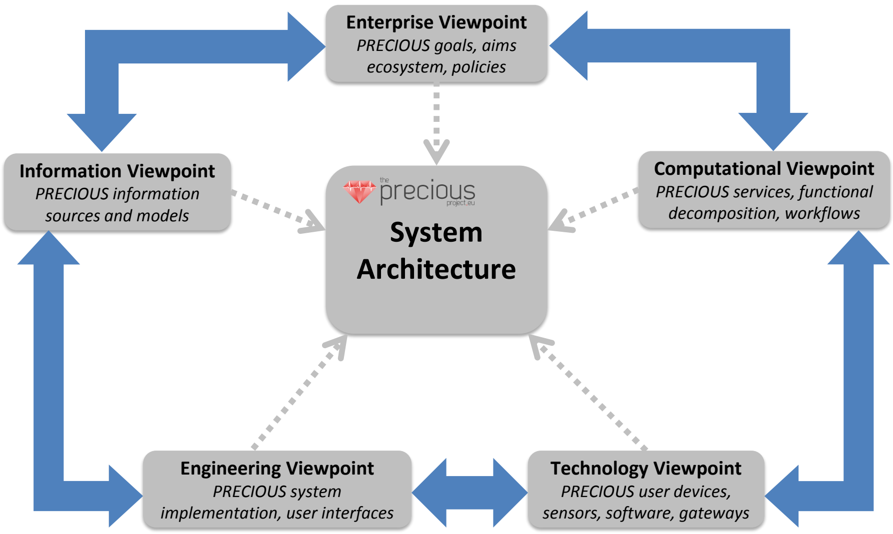


Figure 17 Representation of PRECIOUS architecture using the RM-ODP framework

The PRECIOUS system can considered as a part of a class of Behavioural Intervention Technologies (BITs). The BITs generally constitute a subset of m/e-Health interventions, utilise a broad range of technologies (smartphones, Internet, sensors, data analytics etc.) to support users in changing behaviours and cognitions related to health and wellness [41]. Typically BITs have larger treatment goals which are built on a number of smaller interventions for the user. These interventions may include, promotion or elimination of particular behaviours and the related behavioural change strategies (monitoring of health risk factors, motivation methods, personalised guidance etc.).

A BIT model has recently been proposed by Mohr et al [41] to provide both conceptual and technological definitions of BITs from the clinical aim to the technology delivery framework. To that end, the BIT model address the questions of why, what, how (conceptual and technical), and when for particular BIT implementations. These questions of course echo some of the aspects that are specified by the RM-ODP framework as noted in the previous section. The augmentation of the RM-ODP viewpoints with elements of BIT model adds more relevance to the mapping of the standard RM-ODP viewpoints to the PRECIOUS system architecture. This mapping of the augmented RM-ODP viewpoints to the PRECIOUS architecture is summarised in Table 5:

- The second column provides the standard definition of each RM-ODP viewpoints.
- The third column describes how BIT model augments corresponding RM-ODP viewpoints for more effective use of RM-ODP in the BITs context.
- The fourth column provides the mapping to the DEWS architectural design process according to its needs.
- The fifth column lists the relation between the viewpoints and different PRECIOUS deliverables

Table 5 Summary of the mapping of the RM-ODP viewpoints to the PRECIOUS system architecture

Viewpoint Name	Definition according to ISO/IEC 10746/ ITU-T X.901-904	RM-ODP augmentation by elements of the BIT model	Mapping to the PRECIOUS system architecture	PRECIOUS Deliverables matching
Enterprise	Concerned with the purpose, scope and policies governing the activities of the specified system within the organization of which it is a part.	"Why": The overall *treatment goal* of a BIT which consists of multiple smaller intervention aims. This includes clinical and usage aims. *Clinical aims* refer to the clinical goals of the intervention or treatment (e.g. reduce stress, eat well, sleep better etc.). *Usage aims* refers to usage of the BIT intervention components (e.g. apps, sensors). "How" (conceptual): The *behavioural change strategies* used to attain clinical and usage aims. These include education, goal-setting, monitoring, feedback and motivation enhancement.	Focused on the PRECIOUS overall treatment goal is prevention of two non-communicable diseases: cardiovascular diseases and type-2 diabetes. The clinical aims include behavioural changes to improve diet, physical activity, sleep quality and reduce stress level. Usage aims target acceptance/adoption of PRECIOUS intervention tools, including: PRECIOUS apps on smartphone, tablets etc. and sensors for monitoring user's physiology, activities, context, sleep quality, food intake and environment. Also the description PRECIOUS behavioural change strategies, including: behavioural change and motivation techniques; gamified feedback; goal setting and goal achievement mechanism. This viewpoint also provides overview PRECIOUS service ecosystem and main actors therein. It is presents the PRECIOUS governance framework in the form of ethical and privacy guidelines.	Deliverables D2.1 and D3.1 D3.3 D2.2 D2.4
Information	Concerned with the kinds of information handled by the system and constraints on the use and interpretation of that information	n/a	This PRECIOUS viewpoint lists the parameters for the building the virtual individual model (VIM) provides an up-to-date representation of user's risk to cardiovascular disease and type-2 diabetes. Furthermore, it defines the approach of	Deliverables D3.1 and D4.4

Viewpoint Name	Definition according to ISO/IEC 10746/ ITU-T X.901-904	RM-ODP augmentation by elements of the BIT model	Mapping to the PRECIOUS system architecture	PRECIOUS Deliverables matching
			semantic interoperability and processing of the aforementioned user data.	
Computational	Concerned with the functional decomposition of the system into a set of services or objects that interact at interfaces – enabling system distribution.	"When": Most BITs are intended as a treatment consisting of a series of interventions. The workflow identifies when particular interventions are delivered and possibly how the interventions are sequenced. The workflow could be user defined, frequency-based, rule-based (time, event, task-completion etc.), and so on.	This PRECIOUS viewpoint illustrates the high-level functional decomposition of the PRECIOUS system and the interrelationship between different components. Furthermore, it describes the workflows of different PRECIOUS intervention services (initiation, push, pull, etc.)	Deliverables D4.1 and D4.2
Engineering	Concerned with the infrastructure required to support system distribution.	"How" technical: The required technical implementations to achieve particular characteristic for the BIT platform. This includes the medium (text, video, audio etc.), complexity (of content or tasks), aesthetic (depending user profile and tastes) and personalisation (customisations to increase relevance to a user).	This PRECIOUS viewpoint presents the actual implementation and realisation of the PRECIOUS system. This includes the deployment and interconnection of physical and cloud based components, as well as, the communication channels, protocols and standards utilised. The viewpoint also summarises the PRECIOUS user interface and user experience (UI/UX) design approach for customisation (complexity, aesthetic and personalisation) according to user profile and service or intervention.	Deliverables D4.1 and D4.2 D3.3 and D4.3
Technology	Concerned with the choice of technology to support system distribution	"What": The components or objects (actual technical instantiations) of a BIT intended to implement the behaviour change strategies, which in turn support achievement of clinical and usage aims.	This PRECIOUS viewpoint specifies the technological choices (hardware, software, middleware etc.) for implementing the PRECIOUS system, and for each, summarises their characteristics.	Deliverables D4.1 and D4.3

8. PRECIOUS Architecture: Enterprise Viewpoint

8.1 PRECIOUS goals and aims

Healthier lifestyles – including more exercise, a better diet and reduced stress – are associated with the reduced risk of diseases such as T2D and CVD. However, adopting healthier behaviours is a challenge. Advances in technology have made it easier for individuals to monitor lifestyle attributes (e.g. through smart phone applications and wearable technology); however, one of the main challenges is motivating people to make lifestyle changes before risk factors develop into life threatening and expensive diseases.

To solve this challenge, PRECIOUS aims to improve motivation using a combination of motivational interviewing (MI) and gamification principles, as well as creating a personalised system that adapts to the users' goals and preferences. The system will collect information about the user from a variety of devices and applications (sensors) that measure food intake, physical activity, stress levels and sleep patterns. Links between these key lifestyle aspects will also be important in delivering an overall picture of the users' health status. Furthermore, the system and its sensors should be user-friendly and reduce the burden of recording where possible.

In deliverable D2.1 a study was carried out to understand the user requirements and determine a set of usage scenarios, which will form the basis of the system design. There are many important stakeholders in PRECIOUS, including end users/consumers/patients, health professionals, SME's/service providers/software developers, public healthcare organisations, policy makers and researchers. However, the end user must be central to the design of PRECIOUS and therefore, an early indication of user requirements was essential. The user requirements and usage scenarios identified provides a starting point for development of the PRECIOUS system architecture.

For individually accurate feedback, based on the sensor data and lifestyle intervention recommendations, a Virtual Individual Model (VIM) is constructed from users of the PRECIOUS system. The principal idea of the VIM is to combine data from different sources preferably through ubiquitous sensors in order to build an individual risk profile that can be used to recommend individually tailored services in terms of content, timing, and specificity.

Deliverable D3.1 described the behavioural representation and virtual individual modelling tools that can be used for building the VIM, along with their inputs and outputs. The main building blocks for the VIM were identified as physiological, psychological, nutritional, social and context-related. More specifically, for example data on users' physical activity level, stress, recovery and sleep, diet and food composition, location and environment, psychological distress, physical and psychological wellbeing, and motivational status for behavioural change will need to be utilised for the VIM.

The aim is that, when behaviours that increase the users risk for T2D and CVD are noticed by the VIM, the PRECIOUS system will use various methods to facilitate beneficial lifestyle changes. The VIM will therefore be utilised in the PRECIOUS services that apply motivational techniques and gamification elements to encourage beneficial behavioural change.

The outcomes of the above two reports will help the PRECIOUS team to deliver a system that can provide a preventive health care system that will improve the health of the user, and deliver cost savings in the public health sector.

8.2 Behavioural change strategies

Innovative methodologies for promoting participation in preventive healthcare practices are needed. Recent evidence supports the feasibility and acceptability of using mHealth technology for increasing the odds of users' self-management and participation in preventive healthcare practices. However, the proliferation and efficacy of interventions involving such applications sometimes fails due to the lack of inclusion of a holistic approach that takes into account not only providers' needs but also users' (patients, clients) expectations [42].

Scientific literature has identified seven technical characteristics that a health monitoring and promotion system must have to comply with the established health behaviour change theories and strategies, as well as to be able to deliver effective and innovative interventions. These characteristics are described in the work of Al Ayubi *et al.* [43] as sketched in Figure 18.

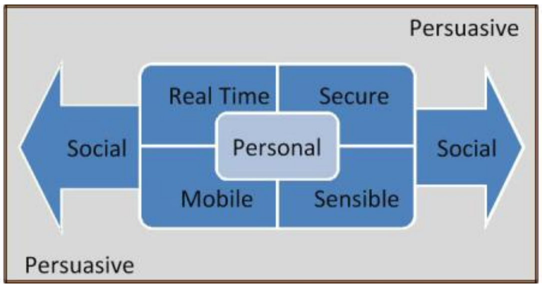


Figure 18 Health monitoring and promotion system characteristics \cite{al2014persuasive}

These authors have also established the relationship between the seven characteristics and some elements extracted from different health behaviour change theories, as illustrated in Table 6.

Table 6 The seven characteristics and health behavioural change theories (source:[43])

Personal	Behavioural intention, self-perceived control, self-efficacy
Sensible	Self-efficacy and perceived behavioural control
Real time	Self-efficacy and cues to action; one important gratification for people to use technology is to get immediate and real-time information
Secure	Supportive and environmental factors, and perceived usefulness (acceptance)
Mobile	Perceived benefit, self-efficacy, cues to action, perceived usefulness and perceived ease of use
Social	Social support, influence of belief and cognition, social categorization, cooperative interdependence, intergroup comparison, social interaction, exchange of personal information, personal attraction through similarity, sense of belonging, social enhancement, and maintenance of interpersonal connectivity
Persuasive	Cues to action, self-efficacy, perceived behavioural control, entertainment, motivation and behavioural triggers

It is important to highlight that most mHealth applications fail to include sufficient and satisfactory educational and motivational elements at once [44]. The added value of the PRECIOUS service is the inclusion of such features in an integrated manner with the expertise of a multidisciplinary approach. The open-minded concept of integrating various kinds of apps will help to focus on motivational techniques tailored to various kinds of user groups in order to increase the impact.

8.2.1 Behaviour change

Within current behaviour change theories, it is common practice to distinguish between three phases of behaviour change: *motivation*, *action* and *maintenance* [45] (see Figure 19). Of these three phases, motivation is perhaps the most crucial, as it determines whether individuals will make efforts to change their behaviour and engage with behaviour change in the first place, and whether this effort will be sustained [46, 47]. At present, many existing digital behaviour change interventions rely exclusively on action-focused approaches and neglect the motivation phase – a fact which may explain the shortcomings of many existing behaviour change interventions.

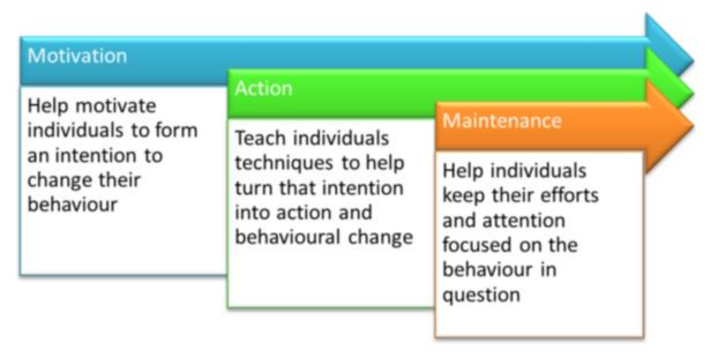


Figure 19 Three phases of behaviour change

8.2.2 Fostering Motivation for Behaviour Change

In the motivation phase, individuals require assistance in forming intentions to change their behaviour [48, 49]. Among the most effective techniques to increase motivation and create intention formation in practice is MI, which has been successfully applied to increase motivation across a wide range of behaviours, among them physical activity [50] and diet [51]. MI has most commonly been applied in clinical settings, where treatment providers can use their expertise to strategically apply various MI techniques and optimally guide individuals toward change. However, in a digital environment, this is not entirely straightforward as digital systems do not yet exist which allow for syntactic interpretation or analysis in real time. Some early steps toward digitizing the processes of MI have been taken by researchers in the Netherlands, who have replicated some techniques of MI using computer tailored algorithms [52].

In essence, digital tailoring may be created by asking users a series of multiple choice questions and providing personalized feedback to users based their responses or asking open-ended questions, and using the answers as a material for future reminders. While not perfect, this method of tailoring based on user input allows for the delivery of a number of core MI techniques, including conveying understanding through the use reflections, emphasizing the idea of patient choice in behaviour change and providing information in a way that is congruent with the principles of MI. Until now, MI has been applied digitally via the internet on PCs and laptops only, and no mobile approximation of these procedures exists.

The PRECIOUS service will therefore be the first to apply MI techniques on mobile devices. While mobile phones ubiquity provides the possibility to interact with the user behaviours in real time, it presents challenges regarding the user interface in digital MI. The main aims of this component will be to extend the scope and content of existing digital versions of MI, integrating results of current research in this area, and to make this new component easily accessible and user-friendly on mobile devices. In this, the aim will be to find a balance on mobile devices between user provided input (more autonomy) and ready-made content (better usability). In terms of Behavioural Change Techniques (BCTs), components of this mobile version of MI will include providing users choice of target behaviours (i.e. emphasizing choice), developing and drawing attention to discrepancies between current and desired states, setting outcome goals, prompting focus on past success and providing information on social norms and health-behaviour links using the elicit-provide-elicit structure.

8.2.3 Translating Motivation into Action

In the second phase of behaviour change, individuals require guidance to help translate their motivation and intentions into action. From a number of systematic reviews examining the effectiveness of interventions to change diet and physical activity behaviours, it is known that BCTs derived from self-regulation theory (control theory) seem central to creating change [53]. BCTs derived from the self-regulation theory include self-monitoring of behaviour, behavioural goal setting, action planning, feedback on behaviour/goal progress and problem solving (coping planning). In addition to BCTs from self-regulation theory, a recent review has identified techniques used in mHealth self-management solutions for T2D [54]. This review examined 13 computer assisted diabetes self-management interventions and found several techniques associated with improved behavioural outcomes, including prompting social support, facilitating social comparison, and prompting review of behavioural goals. The table below outlines how PRECIOUS will make use of these BCTs to improve diet and physical activity from literature on control theory, from this review of Van Vugt et al [54] and from earlier PRECIOUS research.

Table 7 How PRECIOUS utilises BCTs

Behaviour Change Technique	Description
Self-monitoring of behaviour and behavioural outcomes (physical activity)	Data on physical activity will be collected via the smartphone's on-board accelerometer, and translated to user-relevant metrics using existing algorithms (e.g. steps taken, minutes active/sedentary, calories burned).
Self-monitoring of	Data on dietary intake will be collected via (photo-based) food

behaviour and behavioural outcomes (diet)	diaries completed by users, including relevant nutritional intake information (e.g. calories, fat, sugar, sodium).
Behavioural goal setting (physical activity)	Users will have the capability to set physical activity goals in their own chosen metric(s) (e.g. steps, active minutes, limiting sedentary time, burned calories), which are to be presented in a gamified way. Data-driven algorithms will prompt users to set goals that are challenging, yet realistic improvements, in comparison to past behaviour.
Behavioural goal setting (diet)	Users will have the capability to set dietary intake goals in their own chosen metric(s), which are to be presented in a gamified way. Data-driven algorithms will prompt users to set goals that are challenging, yet realistic improvements, in comparison to past behaviour.
Prompt review of behavioural goals	After pursuing a goal, users will have the opportunity to adjust this in deciding which goals to pursue next.
Action planning (physical activity)	Users will be able to plan when, where and how they will be physically active, including any necessary preparatory behaviours (e.g. taking along necessary clothing or footwear). This action plan will be completed in relation to an individual's physical activity goal(s), so that additions to the plan are visualized as progress toward their goals. This may also include integration with user's personal calendars.
Action planning (diet)	Users will be able to plan when and what they will eat, including any necessary preparatory behaviours (e.g. purchasing necessary ingredients, or planning time to prepare meals). This action plan will be completed in relation to an individual's dietary goal(s), so that additions to the plan are visualized as progress toward their goals. This may also include integration with user's personal calendars.
Feedback on behavioural performance (physical activity)	Feedback on physical activity behaviour and progress toward physical activity goals is to be presented in a gamified way, so as to increase user engagement with the process of goal pursuit.
Feedback on behavioural performance (diet)	Feedback on dietary behaviour and progress toward physical activity goals is to be presented in a gamified way, so as to increase user engagement with the process of goal pursuit.
Problem solving (physical activity)	Individuals will be prompted to identify potential barriers to achieving their physical activity goals, and choose solutions to overcome them.

Problem solving (diet)	Individuals will be prompted to identify potential barriers to achieving their dietary goals, and choose solutions to overcome them.
Provide instruction on how to perform the behaviour	If desired by users (in line with MI principles), PRECIOUS will be able to offer suggestions as to the types of behavioural changes an individual might wish to pursue next.
Social comparison/ prompt social support	This component is to be addressed with a gamified running app (conquer the block) in which the users can compete against, or collaborate with, other users.

8.2.4 Sustaining Action over Time

Several factors have been identified as important in creating lasting behavioural changes, including intrinsic, integrated and identified motivations for behaviour, habit strength and automaticity [55, 56, 57]. These factors are to be taken into account within the gamified elements of PRECIOUS. Additionally, the use of follow-up prompts has been identified as a BCT important to maintenance [54] and will be integrated through ongoing feedback within PRECIOUS. Additional motivational and maintenance related factors have been described in the earlier deliverables D3.1 and D2.2, and these will be developed further in the next months.

8.3 Ecosystem

In parallel to the present report, the deliverable D2.2 is focusing on the ecosystem perspective of PRECIOUS. Based on the modular design around a common market sketched in Figure 20, individual business strategies can be explored by PRECIOUS actors. For the PRECIOUS architecture, this means that around a platform with common services and substantial development assistance for app developers, independently apps can be designed.

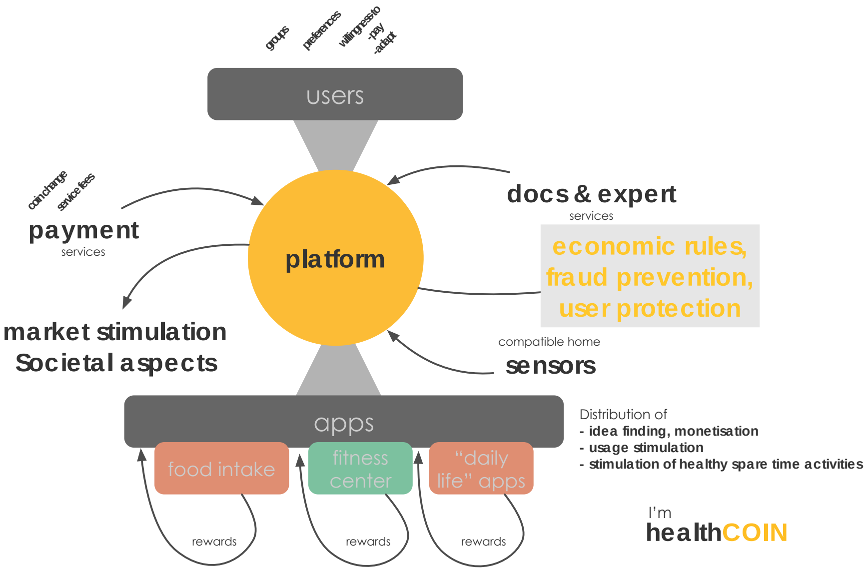


Figure 20: Ecosystem perspective (healthCOIN), ***Source: D2.2***

Common link will be the motivational concept, the sandbox and privacy concept, and the common health data from the VIM. Beyond that innovation shall not be limited in order to allow innovative solutions to be developed and in order to increase the scalability and market reach of PRECIOUS.

healthCOIN further requires external data APIs such as to prominent payment services, e.g. Paypal, and potentially expert services.

Due to the handling of sensitive personal data and monetary transactions (payments, deposits, etc.), the data security and trust in the system has a very high importance. Once the trust relationship is broken, the two-sided nature[20] of the market may lead to a permanently lowered market volume or collapse of the entire marketplace.

8.4 Governing policies

New technology, such as mobile phones and portable electronic devices, offers unprecedented opportunities for preventive health care in a wide range of settings. mHealth apps and solutions have shown a promising potential to improve individual well-being. These new possibilities, however, have an important number of ethical implications that need to be taken into consideration in research and practice. Ethical and privacy issues including data collection and protection have to be carefully considered from planning to implementation of the system architecture.

PRECIOUS integrates technological advancements with understanding from social, behavioural, and nutrition sciences in order to offer evidence-based, customisable motivational support with a focus on diet and physical activity. Physiological sensors, environmental actuators, and self-reports provide data for personalisation and goal

[20] If the consumers suddenly lose interest (even if temporarily), the app providers may also reduce their activities for this platform or may even pull their app from the marketplace. This further increases the downwards movement on the customer side and thus establishes a negative loop.

achievement. The aim is to help individuals to prevent non-communicable diseases by supporting them in healthy life choices. The personal nature of health related behaviours is taken into account in PRECIOUS so that the service will respect individuals' right to self-determination in all sectors. Users have the right to set their own health goals, manage or delete their data, switch on and off service features, and leave the service at any time.

In D2.4 the ethics and privacy considerations for the PRECIOUS system are taken into consideration during the service development. Questions of anonymity, privacy, and overall data protection were taken into special consideration.

The interactive nature of the PRECIOUS service means that it actively monitors the user's health and adapts its functioning with regard to changes. However, the users themselves have control over the service; the service does not enforce activities. Thus, the user has autonomy but also the final responsibility lies with the user. It is crucial to ensure this is conveyed to the users that PRECIOUS is an unregulated, unsupervised service, and that by using PRECIOUS they accept the nature of the service. Furthermore, PRECIOUS will not provide any clinical diagnoses and the service will not be able to reliably take account of food allergies and other medical conditions. The PRECIOUS service only gives motivational recommendations, tips, and information on healthy living following evidence-based recommendations. PRECIOUS only receives the data that the user provides and is therefore not a comprehensive view of the user's health. Users will need to be informed of the limitations of the system.

The risk of psychological harms related to the use of PRECIOUS are minimised through careful planning of the service. For instance, support messages are framed positively, negative feedback is avoided, and the users are guided to set appropriate goals. These measures are taken to increase the experience of autonomy for the users. The core of the service is the customisation; users can modify the privacy settings to decide which information is shared with others. All collected data is handled with great care and with appropriate data protection measures. It can be concluded that the risk for harm to be caused by the PRECIOUS service is small and may be further prevented through careful design of the service.

D2.4 also investigates the implication of data protection regulations. PRECIOUS follows European data protection law, which is two-fold by its legal bases. Firstly, privacy is a human right, regulated by the Council of Europe Treaty No 108 / 1981 (ETS 108). Secondly, data protection is based on the European Union Data Protection Directive 95/46/EC, which introduces data protection also as a mechanism for supporting the internal market. This directive emphasises transparency in processing of personal data, free movement of the data, and ensures the individuals' right to privacy. This is the basis for the security policies of PRECIOUS and it will be implemented in the collection, storage, and processing of the data. Users will be fully informed about all data collected by the service and will be given the opportunity to cease their use of the service, as well as all data collection, at any moment. All users and study participants will be presented with the terms and conditions of the service in order to enable informed consent for the use.

Based on the findings of D2.4 the PRECIOUS system is considered to be a low risk service, however the Partners will continue to assess the ethical and privacy risks of the system. To decrease risks, the service will be designed to offer a tutorial, teaching the user how to use the service in an optimal way and how to take care of the users' safety and privacy.

An investigation is also currently being carried out to investigate the other legislative governing policies that may impact the PRECIOUS system and these will be summarised in D2.5 "Report on Legislative investigations". The aim of this report is to investigate the legislation associated with the design, implementation and use of mobile health applications and considers how these may affect the development of PRECIOUS.

9. PRECIOUS Architecture: Information Viewpoint

9.1 Parameters

This PRECIOUS viewpoint lists the parameters for building the VIM that provides an up-to-date representation of user's risk to CVD and T2D. The key parameters for producing the VIM include information from food intake (foods consumed, energy intake, following of recommendations), physical activity (following of recommendations), sleep quality and recovery (subjective estimates of sleep, and objective recovery and sleep duration measures with sensors), psychological wellbeing (subjective estimates), environment (noise level, light level, temperature, and humidity) as well as motivation towards lifestyle changes.

The Table 8 describes how the risk factors for T2D or CVDs could be monitored and summarises some of the related parameters of interest for the PRECIOUS system. A more detailed discussion on the parameters is provided in deliverable D3.1.

Table 8 Risk factors that could be monitored with different technologies and sensors and utilized for the VIM

PRECIOUS Risk Factor	Risk factor attributes monitorable for (or by) the Individuals	What will be monitored in PRECIOUS	How attribute will be monitored in PRECIOUS
Diet/Obesity	• Trends in body weight, body mass index BMI, waist circumference, waist: hip ratio, body fat percentage • Food intake and food composition • Food quality • Food stocks at home • Shopping routine	• Trends in body weight, body mass index BMI, waist circumference, waist: hip ratio, body fat percentage • Food intake and food composition	• Weight scale (manual) • Food intake sensor (automated, wearable)
Physical Inactivity	• Physiological signals (blood pressure, heart rate etc.) • Exercise caloric burn, distance, elapsed time, etc. • Indoor activity or movement • Outdoor movement or mode of transport car, bicycle, etc.	• Heart rate (RR data) • 3D activity (accelerometer, other) • Spatio-temporal data (location, trajectory, speed)	• Heart rate sensor (automated, wearable) • GPS device (handheld, wearable) • Accelerometer (wearable) • Indoor activity sensor (embedded in home, pervasive)
Home Environment	• Indoor temperature of home environment • Indoor air quality carbon monoxide, nithumidity, molds, etc. • Indoor lighting quality intensity, color spectrum etc. •Indoor noisy environment. This includes noise for instance from home appliances or out of building noise that penetrates indoors. • Other indoor risks/accidents	• Indoor temperature of home environment • Indoor air quality carbon monoxide, nitrogen dioxide, humidity, molds, • Indoor lighting quality intensity, color spectrum etc. •Indoor noisy environment	• Thermometer (networked/automated) • Air quality sensor (networked/automated) • Smoke sensor (networked/automated) • Light quality sensor •Sound/noise sensor
Stress	• Physiological signals: blood pressure, ECG, heart rate variability, galvanic skin response etc. • Stress level, stress appraisal measure, perceived stress level etc.) trends from questionnaires or other user-provided feedback	• Heart rate (RR data) • Other	• Heart rate sensor (automated, wearable) • Other
Sleep Quality	• Physiological signals pulse oximetry, breathing sounds, ECG, etc. • Sleeping posture body movement, sleeping positions, etc. • Trend of sleeping quality indicators e.g. Sleep Efficiency Index	• Heart rate (RR data)	• Heart rate sensor (automated, wearable)

9.2 Semantics

From the semantic viewpoint a major objective is a clear semantic dissemination of all measured and calculated values for the integration into the VIM. In order to achieve this goal, the Collaborative Semantic Vocabulary Creation Cycle (CSVCC) will be introduced. (1) The CSVCC five-step plan helps to systematically collect the required data for the controlled semantic declaration of values, (2) provides common understanding of data to all participants (users, developers, experts, and doctors, (3) maintain the quality of the controlled vocabulary at a high level. The PRECIOUS vocabulary collection phase currently utilises an online vocabulary management system for collecting parameter definitions from PRECIOUS partners (see Figure 21).

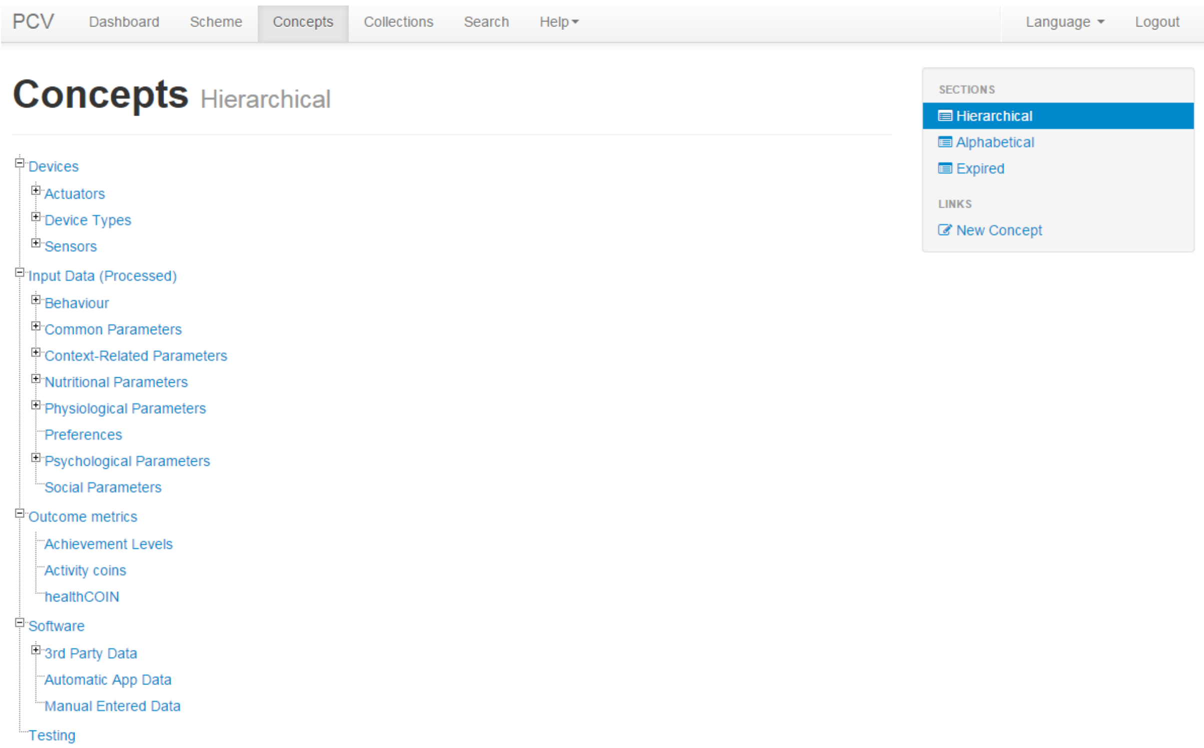


Figure 21 Screenshot of the PRECIOUS vocabulary management system

The development of the CSVCC is ongoing and will be described in more detail in deliverable D4.4.

10. PRECIOUS Architecture: Computational Viewpoint

10.1 Functional decomposition

This PRECIOUS viewpoint illustrates the high-level functional decomposition of the PRECIOUS system and the interrelationship between different components.

On the highest level (see Figure 22) we can distinguish between the module to process raw data in order to fill the PRECIOUS VIM with user-specific data (see left side) and the design of the particular intervention treatment (see right side), which consists of the following two sub-modules: Firstly, the Interference Module acting upon the status of the user (VIM) and predefined set of rules. Those rules may of app-specific, user-specific or general (e.g. provided by the project for all users) form. The intervention module is intended to detect when a certain threshold is reached and initiates the intended intervention. This for instance could be to formulate a request such as to motivate the user to increase exercising rate again. At this point in time, only the need is formulated as a clear request.

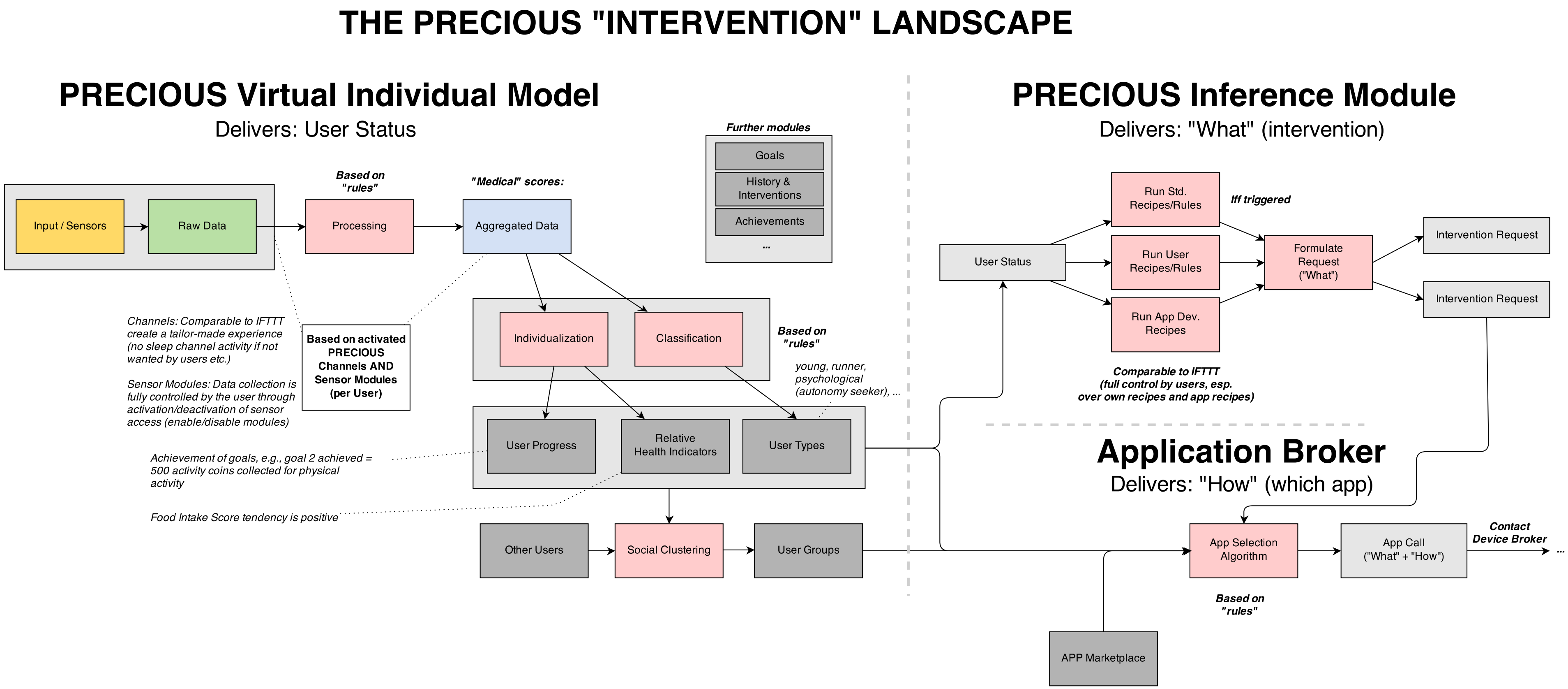


Figure 22: The PRECIOUS functional modules from input data via the processing to tailored interventions

Secondly, the Application Broker matches the intervention request with the available set of apps (e.g. installed by the user). The Application Broker only focuses on maximising the success rate for a particular user while ignoring business considerations. The outcome is a direct request to an application.

In addition to those modules, a device broker may additionally be used, whenever users make use of a series of devices, including ambient devices such as smart lights but also smartphones or tablets apparently. A device broker may select the most promising means for reaching out to the user and may use less capable means of interactions such as lights in order to send signal or notification to the user.

The installed app base will be determined by the user, who can purchase or install apps from the marketplace.

The VIM module is responsible for the individualisation of the entire reasoning by interpreting the collected data for a particular user (individualisation) and classifying users properly (user types w.r.t. motivational or health needs). On that basis, social clustering can be applied that finds similar users to which progress can be compared to for upcoming events, e.g. an app may want to understand whether a workout performance is in line with similar users or might even be an overachievement.

This modular design enables a straightforward adaptation of the reasoning of the entire system by optimising the data quality on the one end or adding new intervention rules on the other end.

10.2 Workflows

There are three main categories of PRECIOUS workflows: the initiation or onboarding of new users, automatically generated push activities, and pull activities initiated by the user. The latter two characterise the system interaction after the onboarding.

Initiation / Onboarding. The onboarding phase is characterised by collecting a first set of information on the new user. If sensor data is available, this information can directly be included in this first phase. So, in the initiation phase the connection of all available sensors is important in order to provide very first feedback to model the user and to automatically suggest goals, if applicable. Otherwise, health goals have to be entered manually. Health goals are critical as the user reveals their intentions for using PRECIOUS and will help PRECIOUS to tailor future interactions (w.r.t. meaningful motivation strategies, appropriate recommendations, suitable interaction design and information visualisation, etc.). Users also have to manually enter some personal information to improve app recommendations.

In the next phase, from an initial list of suggested phase, the user selects a subset they like. If the resulting list is empty or insufficient to target all defined health goals, more apps will be suggested. After the list of apps has been settled, the interaction with the app and recording of data is initiated. This will affect the VIM.

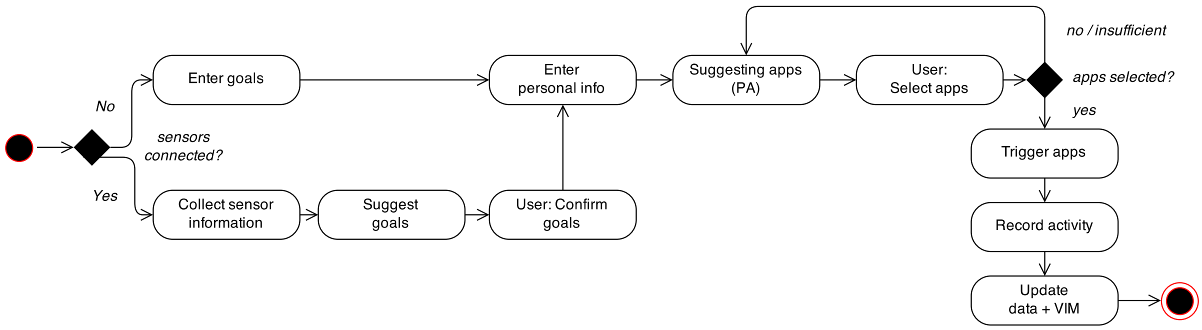


Figure 23: PRECIOUS initiation workflow

Push activity. The VIM data is continuously monitored by the PRECIOUS system. The system remains passive unless dissatisfactory health conditions or insufficient activities are observed (w.r.t. defined thresholds for individual health parameters). When the system becomes active, an intervention needs to be determined, which feeds the app selection process (also see broker `App brokering process'). In the next step, the user is notified, which requires an active device with sufficient capabilities, e.g. a smartphone. An actuator broker takes care of checking the availability of such devices and mobilises them through less capable otherwise, e.g. a lamp signals the user to check their smartphone.

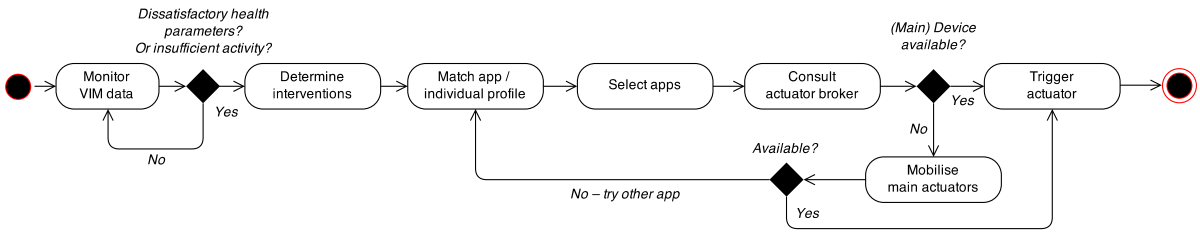


Figure 24: PRECIOUS push workflow

Pull activity. The users can also initiate activities like workouts themselves. They may request assistance by the Personal Assistant (PA), i.e., "Alfred", or may directly call an app of their choice. Once a suggested app is confirmed by the user or manually select by a user, the interaction with the app starts. Any activity is recorded and will affect the user data and the associated VIM.

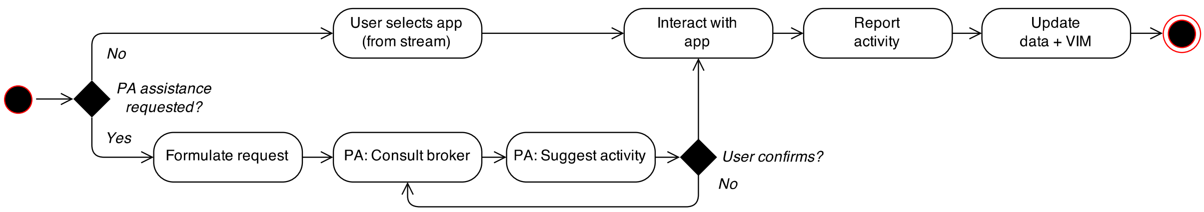


Figure 25: PRECIOUS pull workflow

App brokering process. The selection of the best suited app is a sub-process that is reused in the above presented processes. Based on an intervention request ("increase physical activity now by X") and associated requirements, suitable apps are identified based on their efficacy, the known reviews, the user's preferences for apps, the offered apps and the relationship to the intervention request, and app individual data (e.g. success rate with prior interventions of similar kind). The result is presented as ordered list where the best is presented as first. If a sufficient number of suitable applications are found, the sub-process stops and returns the list. If this is not the case, the marketplace can be queried for other apps or the intervention is altered in the ultimate case.

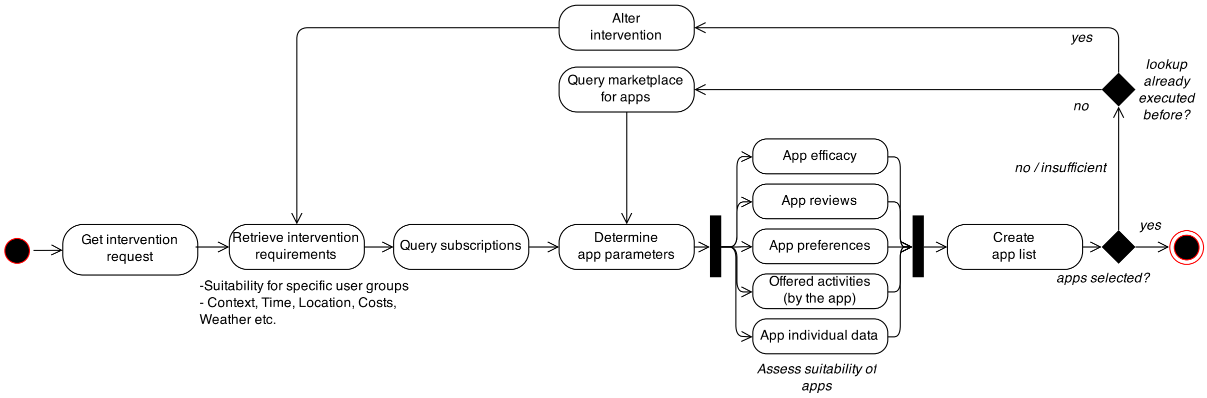


Figure 26: PRECIOUS app brokering workflow

11. PRECIOUS Architecture: Engineering Viewpoint

11.1 System implementation

This PRECIOUS viewpoint presents the actual implementation and realisation of the PRECIOUS system. This includes the deployment and interconnection of physical and cloud based components, as well as, the communication channels, protocols and standards utilised. A high-level diagram of the current PRECIOUS system implementation is depicted Figure 27.

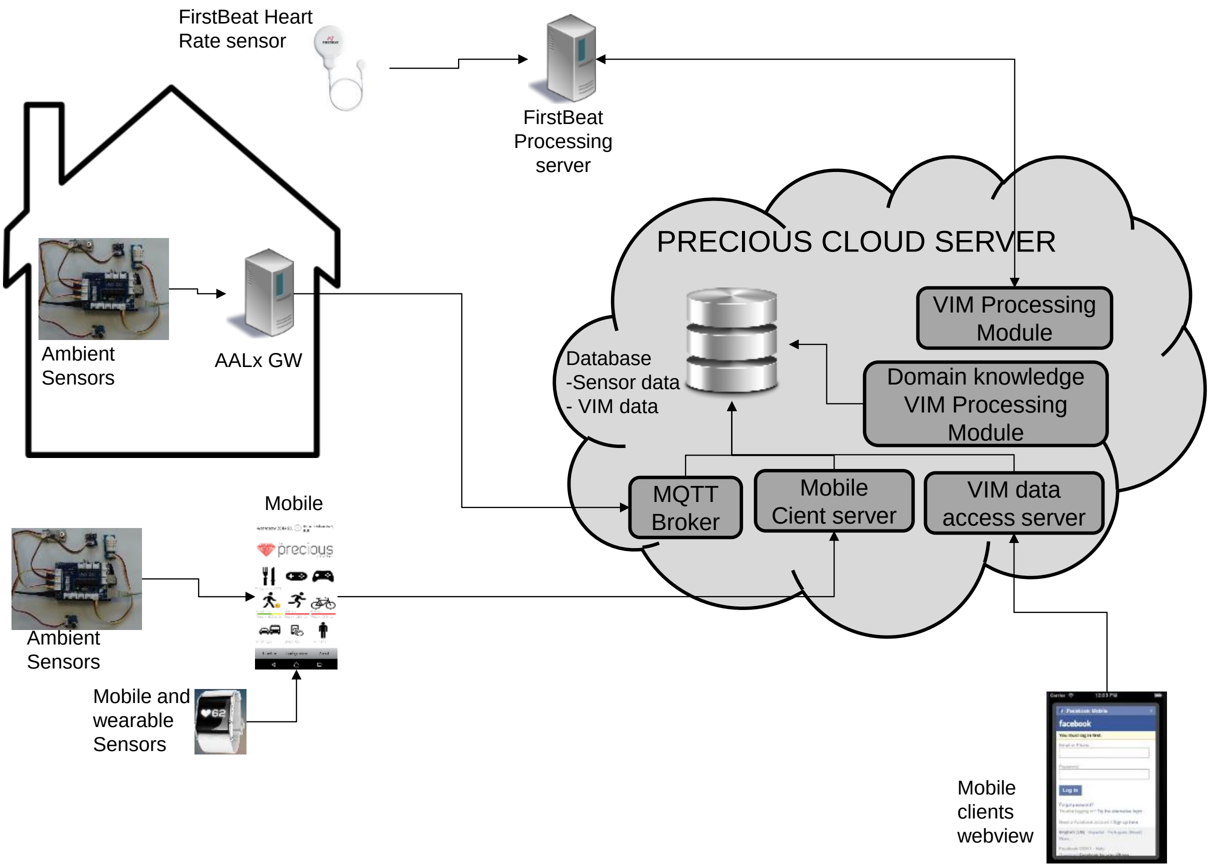


Figure 27 High-level diagram of PRECIOUS system implementation

The system implementation constitutes distribution system components deployed by different partners at their respective sites. These include:

- PRECIOUS cloud server deployed at AALTO
- Ambient sensor and smart home network test-bed deployed at TB/IMT
- Ambient sensor network test-bed deployed at AALTO
- HRV data analytics server deployed at FB
- Development sandbox deployed at UNIVIE
- Mobile clients utilised at various locations and running the PRECIOUS applications

Some of the main deployed are described further in the next sub-sections.

11.1.1 PRECIOUS cloud server at AALTO

Overview

The cloud server would include the modules needed to collect and process data from the sensors to generate the VIM data. In order to collect data from multiple sources different modules are needed in the cloud server to interact with mobile clients or sensor data from AALx gateways, ambient sensors, heart beat wearables, etc.

Cloud server functional components

Database: This module would store the data from sensors before processing. The Database will also store the VIM data resulting from the processing of ambient sensor, mobile and heart beat sensors. The VIM data is structure following the semantic vocabulary, thus the Database will include a set of tables with the vocabulary data structure.

Mobile client server: This module will be listening for incoming messages from mobile devices. This mobile will analyse the received data and store it in the Database. The mobile client server will host a REST based interface that clients can use to report data from sensors and other data collected from wearable devices connected to the mobile device.

VIM access server: This module will be providing interface to third party applications that require access to VIM data. This module will offer sandbox framework for applications to access VIM information while maintaining security and privacy robustness rules.

VIM processing module: This module will analyse the data available in the Database from heart beat sensors and request information from external processing servers (e.g. Firstbeat analytics server) to fill in the VIM model.

Domain Knowledge VIM processing module: This module will analyse all the data from sensor plus information from additional sources in order to complete the VIM model.

11.1.2 PRECIOUS system implementation at the TB/IMT site

Overview

In order to test the PRECIOUS system at the TB/IMT site, a living lab called Experiment'HAAL[21] is used. Home automation devices (sensors/actuators) are connected all together with xAAL in a home area network at the living lab. The PRECIOUS system will offer services to the user to monitor their home environment; get data from well-being dedicated devices (e.g., body weight scale) and then advertise the user in its home environment with notification like blinking a lamp, notification with messages on TV screen or computer screen, and so on.

The system assumes that PRECIOUS services (VIM model, etc.) are located into the cloud. The interaction between a smart home and the PRECIOUS system is organized in the two directions: the communication from the user home to PRECIOUS server (uplink), and the communication from the PRECIOUS server to the user home (downlink). The uplink will push all data considered as useful to the PRECIOUS system. The downlink will be used by

[21] http://www.telecom-bretagne.eu/recherche/plates-formes_technologiques/experiment-haal/

PRECIOUS to activate scenarios inside the user home or to advertise the user with notifications called user feedback.

To realize the uplink/downlink between the smart home and PRECIOUS servers, a publish/subscribe protocol is mandatory. MQTT [31] is M2M communication protocol well adapted to for the communication of data between a smart house and the PRECIOUS servers.

Home area network: xAAL

xAAL is a distributed infrastructure for heterogeneous ambient devices. Communication between devices is realized by a lightweight xAAL messaging protocol working on the so-called xAAL bus. Basically, the xAAL bus is based on existing protocols: multicast IPv4/IPv6 UDP.

Functional Architecture

The functional architecture is presented Figure 28 with different xAAL devices:

- *Native equipment*: Home automation devices communicating natively in xAAL
- *Gateways*: Translate messages between the home automation protocol of a manufacturer and xAAL
- *Schemas Repository*: Each home automation device is described by a Schema which defines how to interact with it and the nature of the equipment.
- *Database of Metadata*: Allow to store Metadata about each xAAL devices like for instance the location, a nickname, etc.
- *Cache*: Allow to store data from devices not queryable.
- *Automata of Scenarios*: Scenarios are advanced home automation services like for instance “send a notification if the humidity level is too low”.
- *User Interfaces*: Allow displaying information for user or administration: PC, tablet, TV, etc.

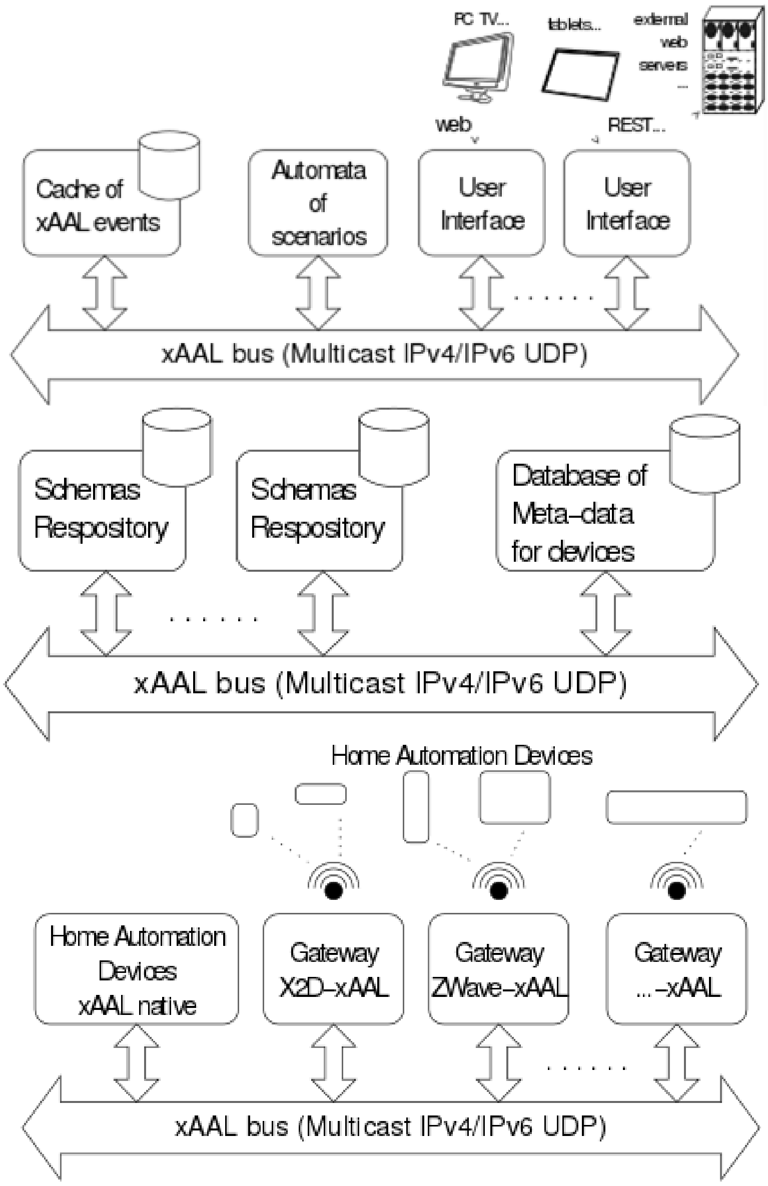


Figure 28: Functional architecture of xAAL

Home Area Network to Wide Area Network communication: MQTT

MQTT[22] is a lightweight protocol dedicated to M2M communications. It is based on a publish/subscribe model and TCP/IP. In term of infrastructure a broker is needed between publishers and subscribers.

xAAL and PRECIOUS services will be connected with the MQTT protocol. The architecture of the whole system is proposed Figure 29.

22 http://mqtt.org/

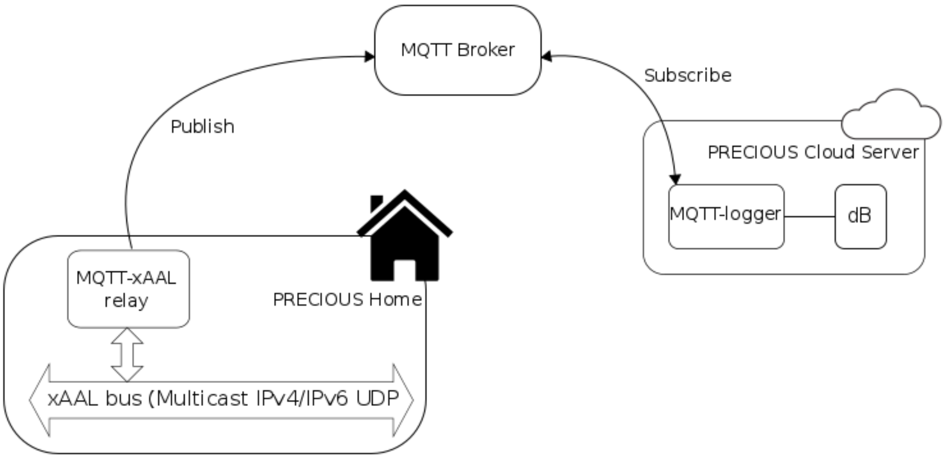


Figure 29 xAAL, MQTT (uplink) and PRECIOUS server: architecture overview

The architecture is composed by several components:

- *MQTT-xAAL relay:* component allowing to publish data
- *MQTT Broker*: component allowing to dispatch published data to the corresponding subscribers
- *MQTT-logger*: component which log data from the smart house to the PRECIOUS database

MQTT message format: specification for PRECIOUS

MQTT only defines a transport layer. Messages need to be defined between publishers and subscribers. For uplink, xAAL message from devices related to PRECIOUS will be directly forwarded. For downlink, the commands for scenario activations will be similar to xAAL commands related to actuators. It means that the message format of MQTT messages will be similar to xAAL messages.

Wide Area Network to Home Area Network: MQTT

The PRECIOUS system allows provisioning of user feedback inside their home environment. It will be enable with MQTT and xAAL. xAAL will offer several scenarios or services inside the house like for instance: "*blink lamp in the living room*", "*notification message in the TV screen*", and so forth. These scenarios will be executable from the PRECIOUS "Actuator Broker" through MQTT. For that purpose, the PRECIOUS Home Agent subscribes to different actuators proposed by PRECIOUS and related to available actuators in the PRECIOUS home. Actuators are in fact PRECIOUS scenarios. Figure 30 describes the architecture with different components:

- *MQTT-xAAL relay*: xAAL device subscribing to PRECIOUS scenarios (i.e., topics) available in the MQTT broker by PRECIOUS and available in the PRECIOUS home.
- *PRECIOUS scenarios*: xAAL device with all the PRECIOUS scenarios subscribed by the user

- *MQTT-actuator*: component in the PRECIOUS Cloud Server allowing the activation of a PRECIOUS scenario

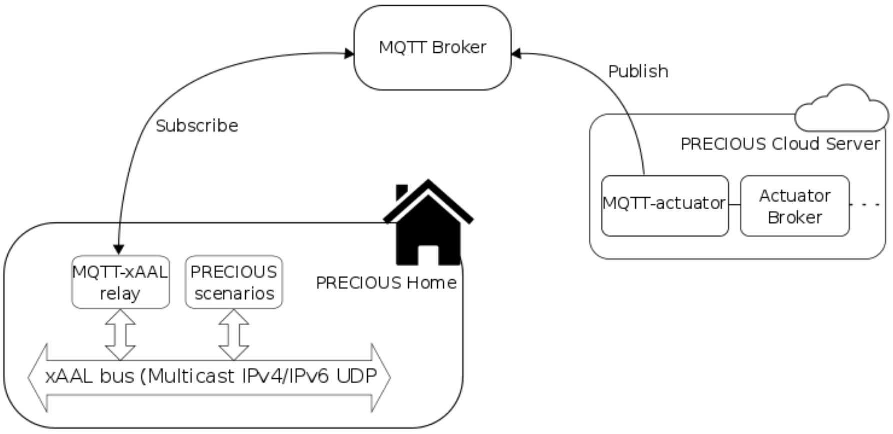


Figure 30: xAAL, MQTT (downlink) and PRECIOUS server: architecture overview

PRECIOUS Sensors/Actuators layer related to home automation domain

The PRECIOUS Sensors/Actuators layer will use MQTT to gather sensor data, related to home automation devices, or to give feedback in the user home environment.

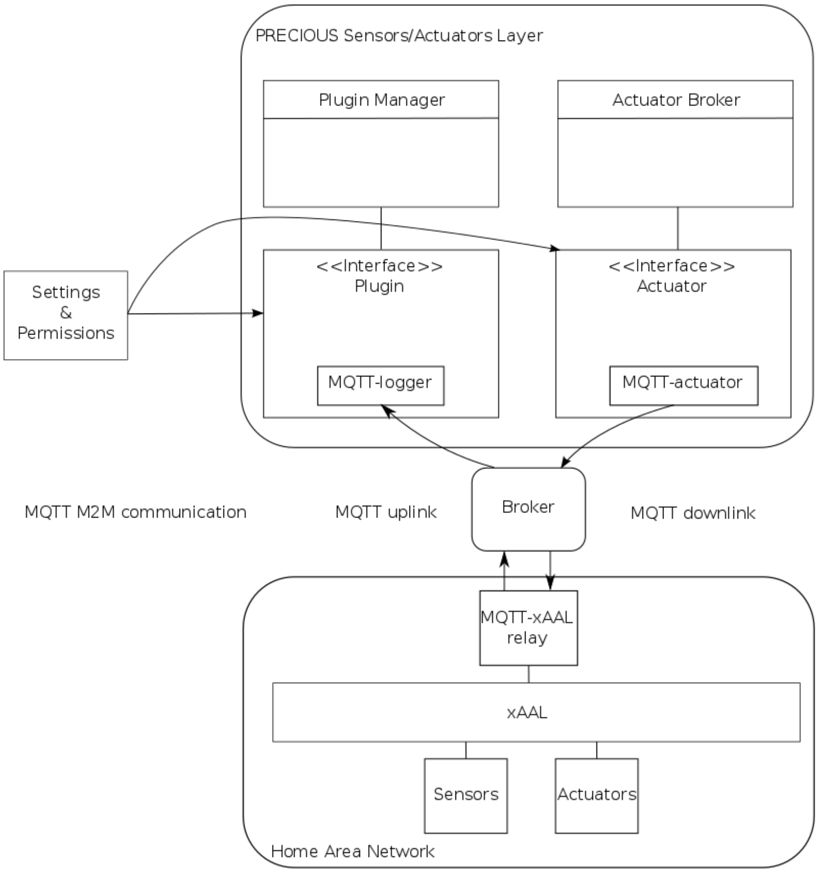


Figure 31: Overview of PRECIOUS Sensors/Actuators layer for the integration of home automation devices

Security & Privacy

MQTT

The communication between PRECIOUS servers and homes of the PRECIOUS users will be realized with MQTT. The MQTT standard does not cover security issues in a normative way. The following section describes the mechanism chosen to secure MQTT in PRECIOUS.

- Transport layer security: encryption of TCP/IP connexions with SSL/TLS.

- Authentication & authorization: username and password. The MQTT broker can identify its MQTT client. Consequently, the broker needs to manage an access list corresponding to the PRECIOUS users. Such an access list specifies which user is authorized to publish/subscribe to which topics. (In the MQTT dialect, a topic is communication channel between publishers and subscribers, and in the PRECIOUS context between home devices and PRECIOUS servers).

Section 5 of the OASIS MQTT v3.1.1 standard is dedicated to security (for guidance only, non-normative). Four security levels (or profiles) are described:

- Level 4: Unsecured
- Level 3: Base Secured
- Level 2: Industry Secured (Base + Industry customizations)
- Level 1: Cyber Critical Secured

According to guides of the OASIS MQTT Security Subcommittee, the PRECIOUS project will match the level 2 security profile. Indeed, TLS provides authentication, integrity and privacy. Moreover in PRECIOUS the TLS client authentication will be used in addition to the MQTT client authentication (username/password).

The Mosquitto software has been chosen as the MQTT broker for PRECIOUS.

xAAL

The xAAL solution is chosen by PRECIOUS to communicate with devices deployed at homes of the PRECIOUS users. The xAAL communications use the home network (wired Ethernet, Wi-Fi, etc.). Therefore, the first security stage is provided by the home network itself (Wi-Fi security key, firewall provided by the ISP box, etc.). So, if somebody or a virus wants to access xAAL devices and data, it needs to get an access to the home area network where the xAAL solution is deployed. Moreover, xAAL communications themselves can be secured. According to the xAAL specifications, the security is possible but optional.

Note that the xAAL protocol is under development. Security aspects are in development and are currently tested in order to fit PRECIOUS requirements. Based on a start-of-the art, solution like Poly1305/ChaCha20 or HMAC-SHA256 are tested.

11.1.3 PRECIOUS ambient sensor network test-bed at AALTO

The AALTO ambient sensor network test-bed is also deployed to keep track of various environmental conditions in an indoor office setting through use of seamless sensing with ambient sensors. These ambient sensors are probed by the sensing application installed on the user's smart phone in a transparent fashion. Figure 32 shows the main components of ambient sensing platform. In this setup, the user and the sensing platform are connected to the same local area network and use UPnP for discovery without user the need for user intervention.

Raspberry-Pi + Grove-Pi Sensing Platform

The ambient sensing platform is created by using Grove-Pi sensors with Raspberry-Pi. A single Raspberry-Pi equipped with Grove-Pi shield hosts a number of sensors for sensing temperature, humidity, light and air-quality in the vicinity of a user. This sensing platform is placed in an indoor locality where user spends considerable time (e.g. their office) and is connecting to the local Wi-Fi hotspot. It also runs UPnP service to announce its TCP sensor-server for users. The TCP sensor-server responds to the requests by sending XML encoded sensor values.

Smart Phone Application

The sensor data is collected by the ambient sensing application on the user's smartphone. The application does not require user input and works transparently. The application keeps searching for the Raspberry-Pi based sensing platform in the background, and after discovering one, periodically probes the sensor it hosts. The discovery process is carried through UPnP by connecting to the local Wi-Fi hotspot. Once a sensing platform is discovered, the application retrieves information of the TCP sensor-server running on Raspberry-Pi using UPnP description requests. A TCP client inside the application interacts with the sensor-server periodically to retrieve the sensor data. Instantaneous and historic data of sensors can be displayed to user in a graph form. It can also be stored in a remote database (PRECIOUS cloud server) for processing at a later time.

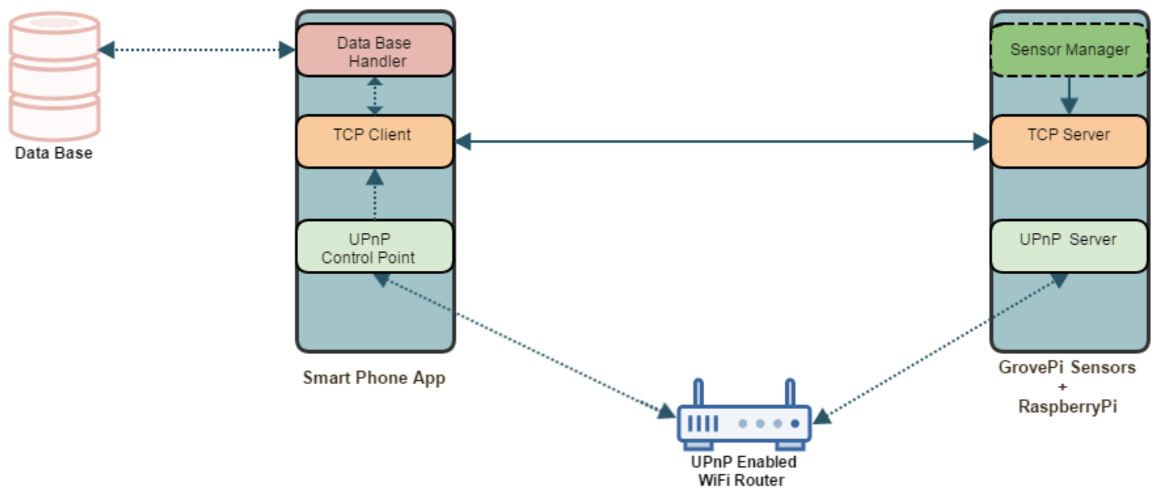


Figure 32 Ambient sensing platform deployed at AALTO

11.2 User interface and user experience

Given a single app as entry point for users into PRECIOUS, design, customisation and personalisation are considered crucial features for the success and acceptance rate among users. PRECIOUS follows a unique approach in this regard, given a highly heterogeneous user group on the one hand, and a specific way of interacting with this group on the other hand. Hence, the user interface needs to be able to address a variety of user types & preferences, while at the same time accessing a unified data infrastructure. This mapping process will be one of the challenges during the development of the system.

Particularly the app-selection process is important to the project, where current techniques overwhelm the user with untailored, lengthy lists and rankings, rendering it nearly impossible for the user to choose the right app for their problem. Hence, during the development several mock-ups of this process will be designed and tested for usability acceptance and potential improvement. Customization and personalization on the other hand can be achieved more easily, as all third-party developed apps will have access to user-defined settings, such as interaction preferences, colour or theme settings, etc. Hence, by adhering to the PRECIOUS framework, all external applications can be formed and shaped to the desire of the user. This approach is unique as to our knowledge, and will be proved in a series of usability tests. We will use both small focus groups (i.e. super users) as well as larger studies during the development phase in order to test for enhancement opportunities. Tools such as AppSee will be used to understand users' natural flows through our application, establish touch heat-maps, find bugs and errors, and to generally gain a more clear understanding of the users' perspective by analysing recordings, duration times on app-screens, failed or succeeded interactions, etc. More details on the UI design will be found within D4.3.

12. PRECIOUS Architecture: Technology Viewpoint

This PRECIOUS viewpoint specifies the technological choices (hardware, software, middleware etc.) for implementing the PRECIOUS system, and for each, summarises their characteristics.

12.1 User devices

A user interested by the PRECIOUS system need to have some devices. At least, a smartphone will be mandatory but a more ubiquitous system will be also available. A non-exhaustive list of user devices is done in Table 9.

Table 9 User devices list

PRECIOUS devices	Mandatory, recommended, optional
TV	Optional
Media hub, Set top box, Mediacenter	Optional
Tablet	Optional
Smartphone	Mandatory
Home environment sensors	Recommended
Home gateway, Home automation box	Mandatory

In the Table 10, a list of user devices (used at the Experiment'HAAL living lab) and corresponding characteristics are presented.

Table 10 User devices characteristics at the Experiment'HAAL living lab

User devices	Hardware	Software
TV	Samsung UE40EH6030W, HD TV 1080p, 40”, 1920x1080	Samsung
Media hub	Neo X8-H, Quad Core Media Hub. ARM Cortex-A9, 2GB DDR3, Gigabit Ethernet, Dual-Band WI-FI 802.11ac	Android 4.4 OS (Kitkat), XBMC MINIX Edition
Smartphone	Archos 50 Hellium 4G, 5”,Quad core 1.5Ghz, 1Gb RAM	Android Jellybean
Tablet	Nexus 7	Android 5.0.2

User devices	Hardware	Software
Tablet	Motorola XOOM, 10.1”	Android 4.0.4
Home environment sensors	Raspberry Pi model B, Shield GrovePi, Grove sensors	Raspbian os, xAAL, GrovePi library
Home automation gateway	Olimex development board OLINUXINO-MICRO, Allwinner A20 dual-core	Debian, xAAL

12.2 Sensors

12.2.1 Heartbeat sensors

For acquiring in-depth physiological data from the user, different heartbeat sensors can be used. Possible heartbeat sensors differ by use case, heartbeat detection technology, and accuracy. We have identified three types of devices: wrist devices based on photoplethysmography (PPG), chest belts, and devices using wet electrodes the latter two being based on electrocardiography (ECG) information. These three device types are described in the Table 11 with their challenges and advantages. The heartbeat data can be used for virtual modelling of the user by delivering the data to an external analytics server via API, analysing the results, and returning them to the PRECIOUS for provisioning of the user feedback together with other monitored attributes. In addition, heartbeat information can be used for example to help the user to perform physical activity at personally suitable intensity for achieving health benefits.

Table 11 Comparison of heartbeat sensor technologies

	PPG (wrist)	ECG (chest belt)	ECG (wet gel electrodes)
Typical sampling	20 Hz – 100 Hz	200 Hz	1000 Hz
Accuracy (best)	< 20 ms	+/- 5 ms	+/- 1ms
HR Accuracy in practise	Poor to good	Good to very good	Excellent
Possibility to analyze HRV	Not possible or low to fair resolution	Yes (5ms accuracy)	Yes (1ms accuracy)
Challenges	Artefacts correction Battery life Mechanical design	Must be placed around the chest Not comfortable for 24h use	Single use electrodes Not optimal for exercising
Main use cases	Casual fitness, recreational use, and lifestyle	Sports and fitness	Professional services Medical use

The possible sensors for PRECIOUS include Bodyguard 2 device (Firstbeat Technologies Ltd, Jyväskylä, Finland) that is a lightweight device for measuring 24h HRV (RR-intervals) and 3-axis acceleration (see Figure 33). The device is designed for robust, accurate and reliable real-life (ambulatory) measurements. The device is attached to a person using two standard electrodes and data is loaded to a PC through USB. The data allows advanced heartbeat analytics for stress, recovery, and physical activity through HRV utilization.

Figure 33 Bodyguard 2 heartbeat sensor

Another sensor considered for monitoring heart rate in PRECIOUS is the PulseOn optical heart rate sensor (PulseOn, Espoo, Finland). The device measures heartbeats from the wrist by using optical light sensors (see Figure 34). This offers a possibility for rather unobtrusive use in the daily life but the challenge with optical sensors are that the technology do not allow as accurate detection of the RR-intervals as ECG-based devices, and are power consuming requiring frequent charging (in continuous use at least daily).

Figure 34 PulseOn wearable heartbeat sensor

Finally, a third type of sensor could be used to monitor heart rate in PRECIOUS with a watch and its heart rate chest belt (see Figure 35). The Suunto Ambit will be used and is different from the others because it offers to measure the heart rate with classical heart rate chest belt. The device is also dedicated to sport activities and it is water proof. Like the PulseOn this device offers a possibility for rather unobtrusive use and can be used for special activities like sport, walk, swimming, and so on.

Figure 35 Suunto Ambit wearable heartbeat sensor

12.2.2 Physical activity monitoring sensors

The physical activity monitoring can be done with previously mentioned heartbeat sensors for acquiring data on real physiological effects of exercise on the user. Physical activity monitoring will also is be done by the PRECIOUS mobile application and which it uses the smartphone's built-in accelerometer. It determines, by applying signal processing over the accelerometer data, if the user is doing of the following activities:

- Step counting.
- Walking.
- Running.
- Riding a bicycle.
- Travelling in a vehicle such as car or bus.
- Using the phone (tilting it).
- Standing still, without movement.

With this data it is possible to estimate the physical activity and the sleeping hours of the user. The current version of the PRECIOUS mobile application already meets all basic requirements for physical activity monitoring and is undergoing further development.

12.2.3 Food intake monitoring sensors

The food intake monitoring will be done by the PRECIOUS mobile application and it includes two parts: the food intake detection (detect that the user is eating) and the food recognition. The first part will be done by a special wristband with built-in gyroscope which, by applying signal processing, will detect that the user is performing a food intake activity. The second part will be done either by a wristband with a built-in camera module or by a smartphone.

The food intake detection can be done in two different methods: by taking a photo of the food or by scanning the barcode of the product. The first method uses digital image processing to detect the food and recognize it by estimating the type of the food using the algorithm illustrated in Figure 36.

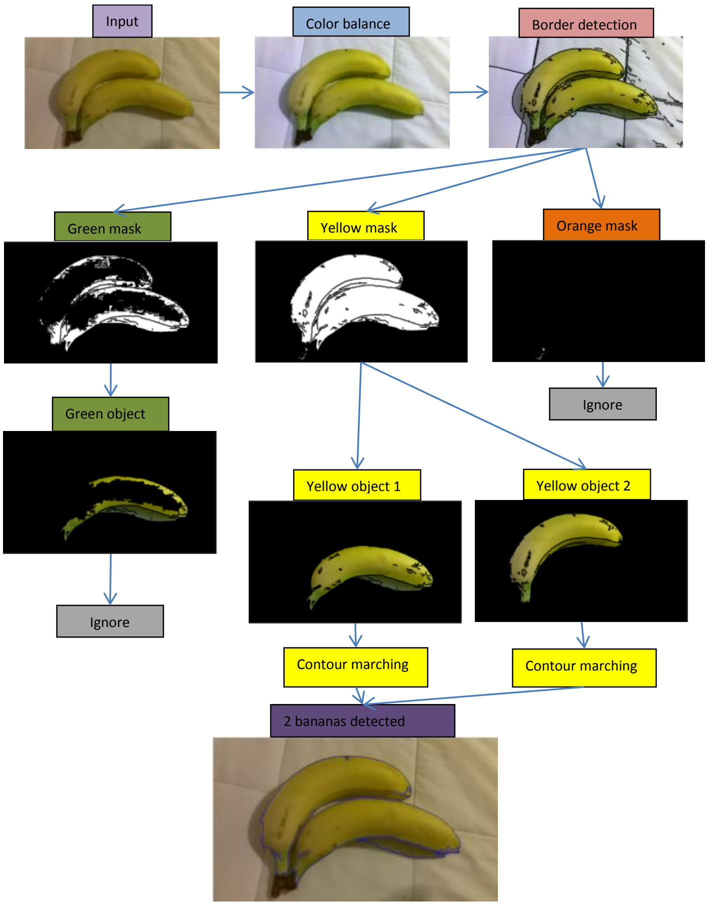


Figure 36 Working principle of the food intake recognition using digital image treatment.

The actual version of the PRECIOUS mobile application meets some of the requirements regarding food intake monitoring, such as the ability to recognize some simple food objects and read products barcodes using an Android smartphone.

12.2.4 Ambient sensors and home automation devices

Home environment sensors at Experiment'HAAL living lab

For a proof of concept, Grove sensors are used to monitor home environment data. A Raspberry Pi will be used as a gateway between Grove sensors and xAAL. The Table 12 describes Grove sensors with a short description of the main characteristics. For a more detailed description of each sensor's characteristics the reader should read the related datasheet and the Wiki page of Seeedstudio[23].

Table 12 Grove sensors with reference and short description of main characteristics

Sensors	Reference	Characteristics
Flame sensor	SEN05082PP	• Spectral bandwidth: 760-1100 nm; Typ. 940nm

[23] http://www.seeedstudio.com/wiki/Main_Page

Sensors	Reference	Characteristics
		• Detection range: 0-1m
Light sensor	SEN11302P	Based on a LDR GL55 series photoresistor
Humidity and Temperature	SEN51035P	• Humidity: 5%-99% RH; resolution: 0.1% RH; accuracy: +/- 2% RH • Temperature: -40 to 80 °C; resolution: 0.1°C; accuracy +/-0.5 °C
UV sensor	SEN00700P	Response wavelength: 200 – 370 nm. Based on a GUVA-S12SD sensor.
Air quality sensor	SEN01111P	Based on the TP-401A Indoor air quality gas sensor
Digital light sensor	SEN10171P	• 0.1 – 40,000 LUX • Based on a TSL2561T sensor
Dust sensor	SEN12291P	Based on a particle sensor: PPD42NS
Loudness sensor	SEN02281P	• Sensitivity: -48~66dB • Freq.: 50~2000Hz • SNR: >58dB Based on a LM2904DR sensor.
NFC reader	Grove NFC 811011001	• Freq.: 13.58 MHz • ISO14443 Type A and Type B

General home automation devices at Experiment'HAAL living lab

As shown in the state-of-the art, there are a lot of open and proprietary solutions for home automation devices at home. Several different, widely used, devices are deployed in the Experiment'HAAL living lab. Table 13 lists sensors/actuators available in the living lab (Experiment'HAAL platform) and other sensors available for testing the transparent sensing platform proposed in the PRECIOUS project and based on xAAL in the home area network.

Table 13 Home automation sensors/actuators at Experiment'HAAL living lab

Type	Manufacturer	Reference	Communication protocol
Motion detector	DeltaDore	IRSX	X2D protocol, Wireless, developed

Type	Manufacturer	Reference	Communication protocol
			and patented by DeltaDore
Open/Close	DeltaDore	MicroCox	X2D protocol, Wireless, developed and patented by DeltaDore
Universal wireless detector for hard-wired contacts	DeltaDore	DTX	X2D protocol, Wireless, developed and patented by DeltaDore
Temperature, indoor	DeltaDore	TYBOX 25	X2D protocol, Wireless, developed and patented by DeltaDore
Temperature, outdoor	DeltaDore	STE2000	X2D protocol, Wireless, developed and patented by DeltaDore
Water flow	Homemade (IMT)	Homemade (GEMS sensor FS-380 + DeltaDore DTX)	X2D protocol, Wireless, developed and patented by DeltaDore
Smoke sensor	DeltaDore	DOFX	X2D protocol, Wireless, developed and patented by DeltaDore
RFID reader	No name	No name	X2D protocol, Wireless, developed and patented by DeltaDore
Temperature	Z-Wave.Me	ZME_ITEMP	Z-Wave protocol
Dimmer	Everspring	AD142	Z-Wave protocol
Relay switch	Fibaro	Fgs211	Z-Wave protocol
Home energy meter	Aeon labs	Aeon labs home energy meter	Z-Wave protocol
Temperature	EnOcean	STM330	EnOcean radio protocol, Wireless (RF 868 MHz)

Type	Manufacturer	Reference	Communication protocol
Energy converter for linear motion. Used has switch	EnOcean	Eco200	Used with PTM 330 transceiver, EnOcean radio protocol, Wireless (RF 868 MHz)
Push button, Batteryless	EnOcean	PTM210	EnOcean radio protocol, Wireless (RF 868 MHz)
Relay switch	X10	-	X10 protocol
Dimmer	X10	-	X10 protocol

Ambient sensors deployed the Aalto test-bed

A list of ambient sensors used in this setup is shown in Table 14

Table 14 Aalto Ambient Sensors

Sensors	Reference	Characteristics
Air Quality sensor	SEN01111P	• Responsive to wide range of gases • Differentiates qualitatively between ranges of pollution
Light sensor	SEN11302P	• Based on a LDR GL55 series photo-resistor
Humidity and Temperature	SEN51035P	• Humidity: 5%-99% RH; resolution: 0.1% RH; accuracy: +/- 2% RH • Temperature: -40 to 80 °C; resolution: 0.1°C; accuracy +/-0.5 °C

12.3 Communication nodes, middleware and servers

12.3.1 Communication tools at the TB/IMT living lab

xAAL protocol

xAAL for home automation interoperability in a home area network. The xAAL protocol and infrastructure is language agnostic. A version in C and Python is currently available.

MQTT protocol

MQTT for home area network to WAN communication. The Paho project provides an open source implementation for several languages.

MQTT-xAAL relay

The *"MQTT-xAAL relay"* component relays data from xAAL sensors to the PRECIOUS Cloud Server with MQTT and from the "mqtt-actuator" to xAAL. It is a xAAL device using the MQTT Paho library coded in Python and the xAAL python stack.

It is not necessary to configure the topics. Indeed, the fact to publish in a topic is enough. For uplink, topics will be generated according to the following pattern:

- /precious/homeId/bus0/devices/xaalUUID/

With the following naming convention:

- precious: the service name
- homeId: a unique number to identified the PRECIOUS home
- bus0: a name defining the xAAL bus
- xaalUUID: a 128 bits uuid corresponding to the xAAL device address

MQTT-logger

The *"MQTT-logger"* subscribe to topics related to a user home. Then, it dumps sensor data to the PRECIOUS database.

MQTT-actuator

The *"MQTT-actuator"* is a component in the PRECIOUS Cloud Server allowing the activation of xAAL devices. More precisely it will allow to actuate PRECIOUS scenarios available and managed by the xAAL device *"PRECIOUS scenarios".*

PRECIOUS scenarios

The xAAL device "PRECIOUS scenarios" will manage the PRECIOUS scenarios to which the user has subscribed.

MQTT Broker

The MQTT Broker allows connecting publishers and subscribers. The PRECIOUS broker will use the Mosquitto broker which open source under a BSD licensed. It supports the MQTT v3.1 and v3.1.1 versions.

12.3.2 Communication tools at the AALTO test-bed

Raspberry-Pi

Raspberry-Pi is a single board computer that is widely used for embedded applications. It does not provide any native sensing framework; however, by using Grove-Pi connector shield, sensors designed for other platforms (such as Arduino) can be used with Raspberry-Pi. Raspberry-Pi provides Ethernet interface to connect to a LAN. A Wi-Fi USB dongle can also be used to achieve the same functionality wirelessly. Raspberry-Pi can run various trimmed down versions of Linux and thus supports a wide spectrum of applications.

Grove-Pi

Grove-Pi is a connector shield that simplifies interfacing of various popular sensors with Raspberry-Pi. Multiple analogue and digital sensors can be connected simultaneously by using a wide array of analogue and digital ports on the Grove-Pi shield.

12.4 Software tools and development environments

12.4.1 Front-End Development

The overall front-end prototype for the intended mobile app framework will be developed on *iOS*[24], that is, Apple's operating system, due to University of Vienna's previous experience on this platform. More specifically, we target iOS 8 due to a number of newly introduced features essential for the development of the sandbox model, in which third-party provided applications can run safely without the possibility for sensitive data to leave the PRECIOUS system. As coding language we will use a combination of Swift, Objective-C and C++, however, mainly relying on Swift due to its simplicity and reading-friendly syntax, which can then be easily transferred to other platforms such as Android.

Overall system design

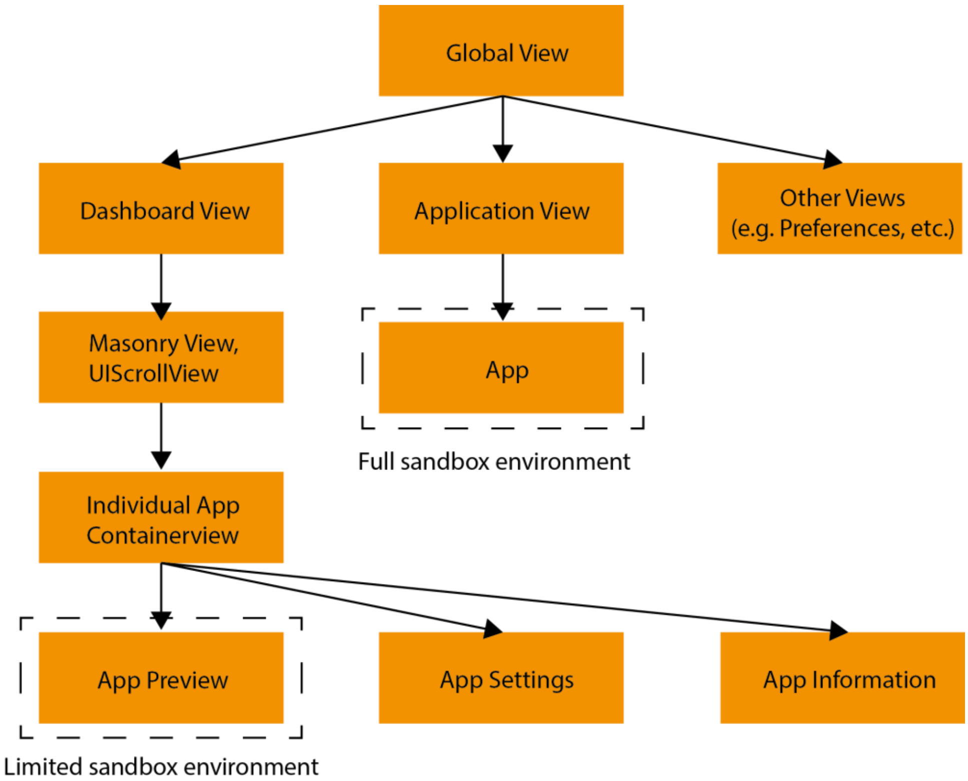


Figure 37 Overview of the front-end development environment

A single global view will hold all app-related content. Three different types of views can be differentiated: the Dashboard, the Application and other general views. The dashboard is the

[24] http://www.apple.com/ios/

main point of entry to the application and will display previews of the Apps that can be run and from which the users can select. A Masonry view will handle the priority in which the apps will be displayed, i.e. the position and size of the apps content. By long-pressing on the respective ContainerView of an App, three different subviews, the App Preview itself, a Quick-Settings View and an App Information View can be selected by additionally swiping left or right. Within the App Preview, we only offer a limited sandboxed environment due to performance reasons and disable user-interactions, i.e. the user is not able to interact with developer-specific content at this stage. By tapping, the user can then open an application within a sandbox in full-screen mode and initiate interactions intended by the respective developer. More details on the development of this application will be found within D4.3 (Development report of mobile applications and feedback tools) which is due month 27 of the project.

Sandbox

For the implementation of the sandbox we will make use of HTML5 and Javascript as the main development environment of external developers. Particularly, we will implement our sandbox on top of Apple's WKWebView class[25], which was introduced in iOS 8. Previous iOS versions used UIWebView[26] for displaying HTML content, however, WKWebView's performance is superior to its predecessor, i.e. by a factor two when displaying WebGL content. The sandbox consists of two main functionalities, which need to be implemented:

- Communication between native code and the sandbox
- Ensuring that external requests, i.e. Ajax requests, are blocked

Two different ways can be distinguished for communication between native code and the sandbox:

1. JavaScript Injection & Communication
2. Communication via a local web-server

WKWebView offers a number of tools for injecting JavaScript into the respective sandbox and hence facilitates the potential communication. Local app bundles containing for instance an HTML file can be loaded into the sandbox through multiple methods, i.e. by URL Request or directly loading the HTML string. After loading the page, communication works as follows: messages from the native code to the sandbox are achieved via Javascript injection, that is, a WKUserScript[27] that calls certain methods of the JavaScript framework. Communicating from the sandbox to the native code is achieved by adding Script Message Handlers and their respective callbacks within the native code to the HTML documents webkit object (see WKUserContentController[28] for instance. As each request or response has a unique ID, requests and response can be easily matched within the Javascript framework. More details

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[25] https://developer.apple.com/library/ios/documentation/WebKit/Reference/WKWebView_Ref/

[26] https://developer.apple.com/library/ios/documentation/UIKit/Reference/UIWebView_Class/index.html

[27] https://developer.apple.com/library/prerelease/mac/documentation/WebKit/Reference/WKUserScript_Ref/index.html

[28] https://developer.apple.com/library/prerelease/ios/documentation/WebKit/Reference/WKUserContentController_Ref/index.html

on this procedure will be found D4.3. The second option is to run a local web-server (see for instance GCDWebServer[29] as a lightweight solution), and to interface native code through a REST API. By calling certain local URLs from the sandbox, the webserver can respond with objects from native code. Both methodologies will be evaluated for performance and other factors during development. Currently, a hybrid approach is chosen, where large objects such as images are transferred via a REST API, while data such as sensor or GPS information is injected into the Sandbox continuously upon request of the developer.

Moreover, external requests can be easily controlled from the sandbox instances, i.e. by implementing the WKNavigationDelegate[30] protocol and either allowing or blocking requests depending on the URL.

Through these implementation steps, we can ensure both safety of the sandbox and an easy, developer-friendly HTML5 interface to both smartphone and PRECIOUS functions.

12.4.2 Software platforms

Android OS

The PRECIOUS project app (*PRECIOUS Project v1.07*) is currently developed for Google's Android operating system that is developed primarily for touchscreen user devices. Apart from the developer tools, the platform provider also gives access to an open market place for distribution of the apps.

Media-Tomb

Raspberry-Pi runs a *Media-Tomb* UPnP server for discovery purposes. UPnP control point for android application is realized using *Cling* Library. Cling provides extensive support for building UPnP based applications for mobile and desktop environments.

Grove-Pi python library

Grove-Pi comes with a simple python library for interacting with sensors. This library was used to create a manager that regularly updates sensor values and provides an interface for other applications to access them.

12.4.3 Developer tools and development environments

Github

The PRECIOUS project employs a Github repository[31] for hosting code and managing the collaboration in the software development.

xAAL library

The xAAL library is provided according the terms of the GNU Lesser General Public License v3.0. The demo applications are provided according to the terms of the GNU General Public

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[29] https://github.com/swisspol/GCDWebServer

[30] https://developer.apple.com/library/prerelease/ios/documentation/WebKit/Reference/WKNavigationDelegate_Ref/index.html

[31] https://github.com/preciousproject

License v3.0. For more details about source code or contribution see the xAAL project webpage[32] and/or the Github repository[33] for the PRECIOUS project.

Eclipse IDE

The PRECIOUS Project v1.07 mobile application is an Android-based program written mainly in Java and available for the compatible Android platform smartphones. It was developed with the *Eclipse v4.2.1* development environment and *Eclipse IDE for Android Developers v23.0.2*, which includes the Android Development Kit and the Android SDK.

13. Conclusions

This deliverable has provided a detailed review of the assessment of relevant approaches and technologies for the personal connected health and smart home domain that together encapsulate the overall context of the PRECIOUS use cases. The review has managed to highlight the developments in the communications and sensing platforms in the two domains, while highlighting common features as well as some differences in the implementation approaches (e.g. interoperability aspects).

The second of the deliverable presented a two phases (analysis and design) approach to the PRECIOUS system architecture design process. The challenge in capturing both the technical and non-technical facets of the PRECIOUS system informed the decision on utilising an architectural framework (RM-ODP) that caters to multiple perspectives or viewpoints. Moreover, leveraging of the BIT model allowed for description of the PRECIOUS architecture viewpoints to be further aligned with contemporary discourse on behavioural intervention technologies in the area preventive care.

The architecture specification has enabled the consortium to highlight interdependencies that exist within the PRECIOUS system concept and further enhances the framing of the work that is carried out in the second half of the project.

[32] http://recherche.telecom-bretagne.eu/xaal/

[33] https://github.com/preciousproject/xAAL

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1. Annexes

1.1 List of commercialized E-health objects related to PRECIOUS

PRECIOUS health indicators	Reference	Protocol of communication	API & SDK
Physical activity	Firstbeat Bodyguard 2	USB	
	Angel	Bluetooth 4.0	Open
	Fitbit	Bluetooth 4.0	
	ihealth		
	Zephyr	Bluetooth	API & SDK
	Withings pulse	Bluetooth	API
	Vivofit Garmin	Bluetooth	
	Vivit medisana	USB	
	Bodymedia	Bluetooth smart	
	Actigraph	Bluetooth smart	
Sleep	Angel	Bluetooth	API&SDK
	ihealth	Bluetooth	API
	Withings pulse	Bluetooth	API
	Vivofit	Bluetooth	
	Vifit		
	Fitbit	Bluetooth	
	Bodymedia	Bluetooth	
Stress	Firstbeat	USB	
Food intake	Hapifork	USB	

Table 15: Non-exhaustive list of commercialized eHealth objects

1.2 List of home environment objects related to PRECIOUS

Reference	Features	Protocol of communication
Alima (now footbot)	Volatile Organic Compound (VOC)	x

Reference	**Features**	**Protocol of communication**
	CO2 Temperature indoor/outdoor	
Netatmo	Temperature indoor/outdoor Humidity indoor/outdoor CO2 Sound level indoor	Wifi 802.11 b/g/n
CubeSensors	VOC C02 Temperature Humidity Luminosity level Atmospheric pression	Communication with a base station (protocol not shared) and a base station related to internet with ethernet
Lapka	Radioactive particule Electromagnetic fields Temperature Humidity	x
SEN.SE	Motion cookie	Proprietary radio protocol
Sense by hello	Smart alarm, sleep score, proximity sensor, ambient light sensor, high sensitivity microphone, temperature sensor and humidity sensor.	Wifi 802.11b/g/n, Bluetooth 4.0, ANT

Table 16: Non-exhaustive list of home environment objects