A secure 5G eldercare solution using millimeterwave sensors

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Abstract. The world is ageing fast and the need of efficient digital solution enabling elderlies to age at home is getting urgent. Unfortunately there is so far no such a solution which is sufficiently efficient, customizable, secure and reliable. This paper presents a solution called Ageing@home which is efficient, easy to deploy, privacy preserving, unobtrusive and customizable by making use of millimeter wave sensors, 5G network slicing and open unifying IoT platform. The paper provides a detailed description of the advantageous use of the millimeter wave sensors and present the proposed 5G network slicing alternative. An open unifying IoT platform capable of bridging diverse heterogeneous IoT devices from different vendors is also introduced.

Keywords: 5G mobile networks, 5G network slicing, mmWave sensors, unifying IoT platforms, assisted living, elderly care, Home based Elderly Care

1 Introduction

As the world population is getting older every day, challenges are increasing both for the elderly citizen but also for countries all over the world [1]. To meet these challenges multiple digital making use new technologies to provide necessary needs and assistance to senior citizen such that they can age comfortably, safely and securely at their home. This is by far the most economical and sustainable solution for the whole society. In Europe, the *Ambient Assisted Living (AAL) Programme* [2] has as objective the development and use of new technologies to allow elderly and disabled people to live comfortably at home, improving their autonomy, facilitating daily activities, ensuring better security, monitoring and treating sick people. Similarly, in the Nordic countries including Norway, *Welfare technologies* [3] have been proposed to provide better services for the elderly living at home but mostly at nursing homes. Unfortunately, although promising all existing solutions are not adopted because of multiple weaknesses such as instability, configuration complexity, installation difficulties, fragmentation, lack of user centricity, and security and privacy issues. In this paper, we present Ageing@home, a welfare technology solution, which addresses the mentioned weaknesses by combining latest advances in three technology fields namely sensors, mobile communication and Internet of Things (IoT). The paper starts by a summary of the requirements on Ageing@home followed by a clarification of the limitation of current eldercare solution. Next is the conceptual architecture which enables a flexible and adaptable inclusion of welfare technologies and services based on individual needs. The main part of the paper consists of the detailed description of the three fundamental technology components of Ageing@home namely millimeter wave sensors, 5G network slicing and unifying IoT platform. A description of a partial proof-of-concept implemented at the Secure 5G4IoT lab at the Oslo Metropolitan University is also given to complete the presentation of our Ageing@home solution. The paper concludes with some suggestions of further works.

2 Requirements on the Ageing@home solution

The majority of people want to live at home as long as possible because they will have the feeling of independence, comfort, safety, security, joy and happiness. In addition and quite importantly, by living at home, the seniors will put less pressure on the healthcare system at the same time as the incurred costs are by far lower than the ones at the nursing homes. However, in order to be successful Ageing@home must satisfy the following requirements:

- It shall ensure the security and safety of elderly people
- It shall ensure the privacy and dignity of elderly people
- It shall prioritize the well-being and individuality of elderly people
- It shall be affordable to the majority of elderly people

Although reasonable when taken for itself these requirements might be conflicting with others and make the realization of a good Home-based Elderly Care solution quite challenging. For example, to provide adequate security and safety protection might have negative consequences on privacy and well-being. The prioritization of the well-being and individuality of elderly people may raise the costs and make the Home-based Elderly Care solution not affordable to the majority.

3 Limitation of state-of-the art eldercare solutions

There are currently many research activities both in EU and the Nordic countries. As umbrella programme there are Active & Assisted Living (AAL) programme, a European Innovation Partnership with 19 countries and Nordic Ambient Assisted Living coordinated by the Nordic Council of Ministers. In addition to numerous national projects in European countries there are also multiple COST and H2020 projects such as

Sheld-on, Activage, Phara-on, Ghost-IoT, etc. Unfortunately, so far the AAL Digital solutions has still quite low uptake due to the following limitations:

- **Instability:** Most of solutions using Wireless LAN 802.11 experience occasional loss of connection due to interference, channel collision, coverage variation, etc.
- **Configuration complexity:** The usage of Wireless LAN requires also the configuration of several parameters for each installation, which is error prone. Further, security protection requires considerable knowledge and efforts.
- **Installation difficulties:** The installation of sensors and devices at the elderly home could be difficult due to the furniture, time consuming and hence annoying to the users.
- **Fragmentation:** The current digital solutions are "silos" applications that operating in isolation without interworking and interoperability with each other. Consequently, the introduction of additional services will require a full installation of hardware and software which incurs high cost and disturbance to the elderly
- **Lack of user centricity:** The current digital solutions are too much technology oriented [4] consisting of a bunch of technologies that are put together and offered to the elderly without sufficient considerations of the elderly user's preferences or the health personnel's opinions [5].
- **Security and Privacy issues:** Although it is necessary to collect data to provide effective services to the elderly these data are personal data which illegal access constitutes a privacy violation [6]. Unfortunately, the protection of personal data is currently not adequate. Further the use of video camera has been considered as obtrusive by elderly who feels watched.

4 Ageing@home conceptual architecture

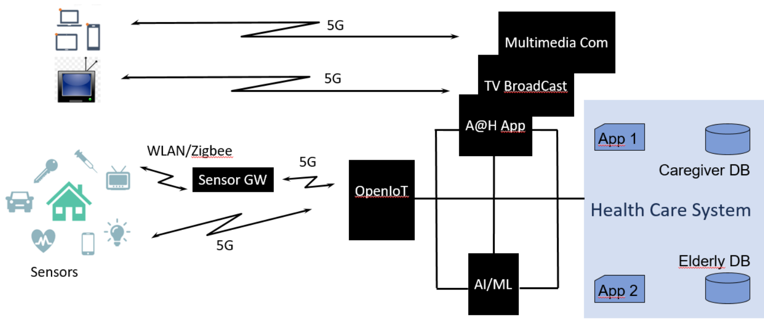

Figure 1 The Ageing@Home conceptual model

To be able to accommodate all the improved welfare technologies described above in a customized, adaptable and scalable way the Ageing@Home end-to-end solution has an architecture represented by a conceptual model shown in Figure 1.

Multiple heterogeneous sensors, both wearable aka on-body and ambient aka off-body with dedicated mission are connected to an open unifying cloud IoT platform

(OpenIoT) directly via 5G or indirectly, first via certain Local Area technologies such as Wireless LAN IEEE 802.11x, Zigbee, Z-wave, etc., to a Sensor Gateway and then via 5G to the OpenIoT. The sensors collect data and upload to the OpenIoT, which can then forward the collected data depending on the need to the Ageing@Home applications (Ageing@Home Apps), the Artificial Intelligence/Machine Learning (AI/ML) Platform or the Health Care System (HCS), where they are consumed in various ways. At the AI/ML Platform they [the data] are in multiple analytic tasks, especially the elaboration of the elderly's profile, which allow for better understanding the elderly and to respond appropriately to their needs and mood. When necessary, the data can be anonymized before being forwarded and stored.

The AI/ML Platform has interfaces with the Ageing@Home Apps and the HCS, which are then enabled to invoke various analytic tasks. The interface between the Ageing@Home Apps and the HCS enables the Ageing@Home Apps to access the HCS user and caregiver database and also other functionality, while the HCS can control the Ageing@Home Apps. The Ageing@Home Apps are essential to the implementation and provision of the targeted welfare technologies such as Digital night vision, Entertainment, Event and vital sign monitoring and detection, etc. Two Ageing@Home Apps, Broadcasting of Physical exercises and Multimodal communication, as communication apps have direct connection with their devices, i.e. TV, PC, tablets, etc.

5 Millimeter wave (mmWave) sensors for Ageing@home

5.1 Brief about mmWave sensors

As their name indicates, mmWave radar sensors or simply radar sensors are active sensors that transmit millimeter waves to detect objects and their changes in the environment such as heat, light, sound or motion, etc. Millimeter waves are electromagnetic radio waves typically defined to lie within the frequency range of 30–300 GHz.

5.2 Advantages with mmWave sensors in eldercare

Compared with the infrared or ultrasonic technology which are commonly used in ehealth applications the mmWave sensors demonstrate with the following advantages:

Higher accuracy, penetration and reliability: By using wavelength in millimeters, mmWave sensors are able to achieve millimeter range accuracy and to penetrate materials such as plastic, drywall, clothing, etc. They are also generally less sensitive to ambient temperature and surrounding environment.

Better privacy protection: The use of mmWave sensors in the monitoring of events and accidents is perceived by elderlies as less intrusive than cameras that are rejected by most elderlies.

More freedom of movement: So far most of the sensors used in ehealth are on-body or wearable sensors that although accurate and reliable have some limitations such as limiting physical movements, detaching and attaching at bath, falling down and loss, etc.

5.3 The use of mmWave sensors in Ageing@home

Ageing@home proposes to use mmWave sensors developed at the Kajiwara lab of the university of Kitakyushu to realise the following welfare services:

- *Health and stress monitoring in living*: includes the monitoring of blood pressure, blood glucose, heart rate, body temperature [7]
- *Health and accident prevention monitoring in bedrooms*: includes heart attack, fall accident, sleep apnea syndrome [8]
- *Accident prevention and early accident detection in bath and toilet room:* requires special sensors that fulfil the conditions of the bathroom e.g. temperature, humidity, pressure, etc. [9]

The wider available bandwidth of the mmWave sensors will offer high range resolution and allow smaller coverages suitable for the deployment at every room in the house as shown in Figure 2. The mmWave sensors are mounted in all rooms and able to capture in a non-contact manner movement data and vital data which are sent to the open unifying cloud IoT platform a gateway via a gateway installed in the elderly home. The data allow not only the detection of vital anomalies upon occurrence but also their prediction prior to occurrence such that doctors can intervene earlier. A sensing algorithm has been developed at the Kajiwara lab.

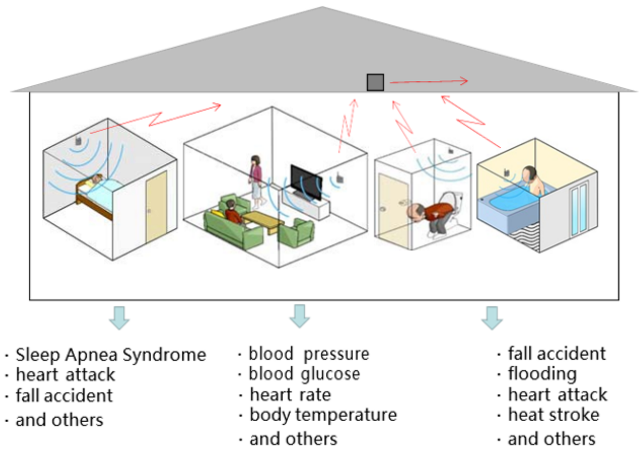

Figure 2 The mmWave sensor monitoring system of Ageing@home

To ensure the reliability and accuracy of Ageing@home it is necessary to study and optimize both the location and number of the sensors for each home to accommodate their different layouts and structures. In addition, in order to cope with presence or absence of different caregivers in the house and also with the visit times which the care are given, it is necessary to consider and optimize the type of data to be collected and the operating hours of the sensors.

By performing these optimizations, it is possible to provide quick and appropriate response to abnormal situations, to prevent occurrence of abnormal situations and to reduce burden on caregivers. If an anomaly is detected, the health care system can be notified and assistance measures can be taken and deployed. There may be a need to consult the location information and the movement flow of elderly dementia who has exited their home and got lost.

Movement on the bed such as getting out of bed, moving, turning over, and vital information such as breathing, electrocardiography, and blood pressure can be continuously monitored without contact.

Accidents in the bathroom can be fatal to the elderly living alone at home. Each year around 17,000 people died from heat shock during bathing and minor accidents that lead to fatal consequences. It is hence necessary to detect accidents in the bathroom quickly but without invading privacy by using video camera. Again, mmWave sensors with high resolution range and humid resistance have proposed to monitor and collect data in the bathroom which are sent to the AI/ML platform for the estimation of various dangerous state or behavior using multiple ML algorithms.

6 Ageing@home 5G network slicing

6.1 Brief introduction to 5G network slicing

The 5th generation mobile network or simply 5G [10] is well known for its superiority compared to 4G in terms of performance, coverage and quality of service and the promise of enhanced mobile broadband (eMBB) with higher data speed and the support of a wide range of services and application ranging from massive machine-type communications (mMTC) to ultra-reliable and low-latency communications (URLLC). Less known but not less important is the fact that 5G is a softwarized and virtualized network. Indeed, a 5G network is not made up of physical network elements as traditional mobile network but of software virtual Network Functions [11].

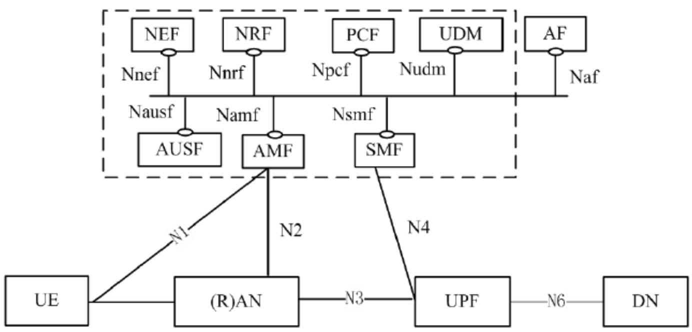

Figure 3 The 5G Reference Architecture (Courtesy of 3GPP)

As shown in Figure 3 the 5G Reference Architecture is composed of the following Network Functions:

On the User plane:

- **UE** (User Equipment): is the user's mobile phone.

- **(R)AN** (Radio Access Network): is the Access Network Function which provides connectivity to the mobile phone.
- **UPF** (User Plane Function): handles the user plane traffic, e.g., traffic routing & forwarding, traffic inspection and usage reporting. It can be deployed in various configurations and locations depending on the service type.
- **DN** (Data Network): represents operator services, Internet access or 3rd party services.

On the Control plane:

- **AMF** (Access and Mobility Management Function): performs access control, mobility control and transparent proxy for routing SMS (Short Message Service) messages.
- **AUSF** (Authentication Server Function): provides authentication functions.
- **UDM** (Unified Data Management): stores subscriber data and profiles. It has an equivalent role as HSS in 4G but will be used for both fixed and mobile access in 5G core.
- **SMF** (Session Management Function): sets up and manages the PDU session according to network policy.
- **NSSF** (Network Slice Selection Function): selects the *Network Slice Instance* (NSI), determines the allowed *network slice selection assistance information* (NSSAI) and AMF set to serve the UE.
- **NEF** (Network Exposure Function): exposes the services and capabilities provided by the 3GPP network functions.
- **NRF** (NF Repository Function): maintains NF profiles and supports service discovery.
- **PCF** (Policy Control function): provides a policy framework incorporating network slicing, roaming and mobility management and has an equivalent role as PCRF in 4G.
- **AF** (Application Function): interacts with the 3GPP Core Network (CN) to provide services

The software nature of the 5G network enables the realisation of the network slicing concept which can be defined as by the 5G Infrastructure Public Private Partnership (5G PPP) as *"network slice is a composition of adequately configured network functions,* net-*work applications, and the underlying cloud infrastructure (physical, virtual or even emulated resources, RAN resources etc.), that are bundled together to meet the requirements of a specific use case, e.g., bandwidth, latency, processing, and resiliency, coupled with a business purpose"* [12].

6.2 The Ageing@home network slicing

In order to provide a connection which provides adequate protection of security and privacy at an acceptable level of reliability a dedicated and isolated end-to-end network slice will be established. This healthcare network slice is a logical network realised by dedicated vNFs (Virtual Network Functions) [13] for both access network and core network as shown by Figure 4. Only devices equipped with SIM cards own by the hospital can be authorised to connect to this healthcare network slice. While IoT devices are in general not allowed to some smartphones may be permitted to have simultaneous connection to the public network slice depending on the security policy of the hospital.

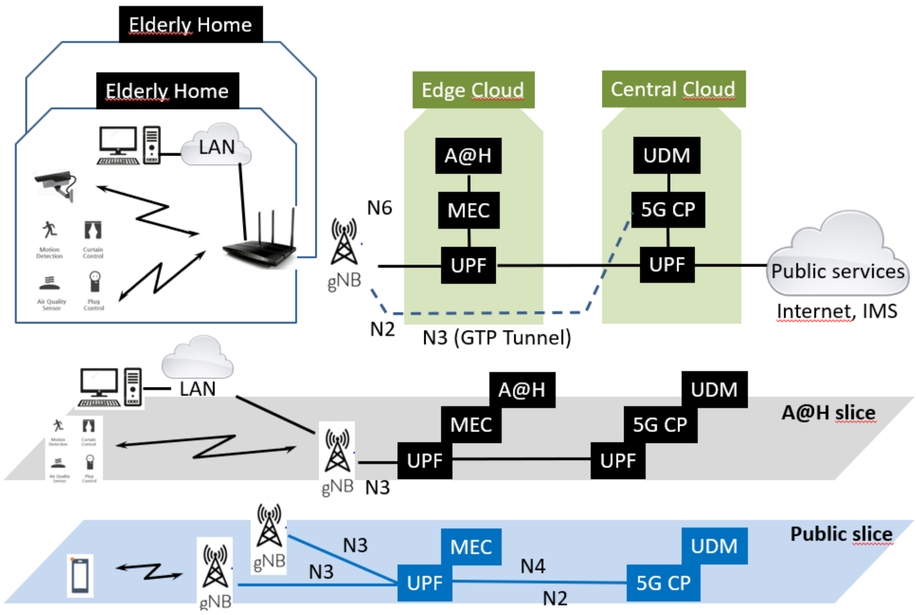

Figure 4 Network Slicing for Ageing@home

As shown in Figure 3, the Ageing@Home solution consisting of OUIP (open unifying IoT platform), AI/ML platform and a variety of Ageing@Home applications are hosted on a MEC (Multi-access Edge Computing) host, which is located on Edge Cloud. Since the Edge Cloud is in the same area as the elderly home, very low latency can be achieved making this deployment option quite suitable for Welfare technologies, such as Broadcasting of physical exercises and mobility sessions technology. Further, both the security and privacy are considerably enhanced because communications between sensors and the Ageing@home do not have to traverse the entire mobile network, but only a short path between the gNBs and the Edge Cloud.

7 An open unifying cloud IoT gateway

Current IoT applications such as eHealth, Smart Home, Smart Living, security, etc. are mostly vertical applications that are not able to communicate with each other. The Ageing@home solution shall include an open unifying cloud based IoT platform capable of incorporating heterogeneous devices and sensors from different manufacturers and also capable of interacting with other IoT platforms. The interoperability between IoT platforms is achieved by developing a data integration framework, focusing on the implementation of a data exchange architecture, application interfaces and identity management that enable data to be accessed and shared appropriately and securely across the complete spectrum of care, within all applicable settings and with relevant stakeholders, including by the individual senior citizen. Last but not least, the Ageing@home open IoT platform is able to interact with existing IoT systems at the elderly home such as security system, consumer electronics, energy, etc. which enable re-use and integration of existing infrastructure.

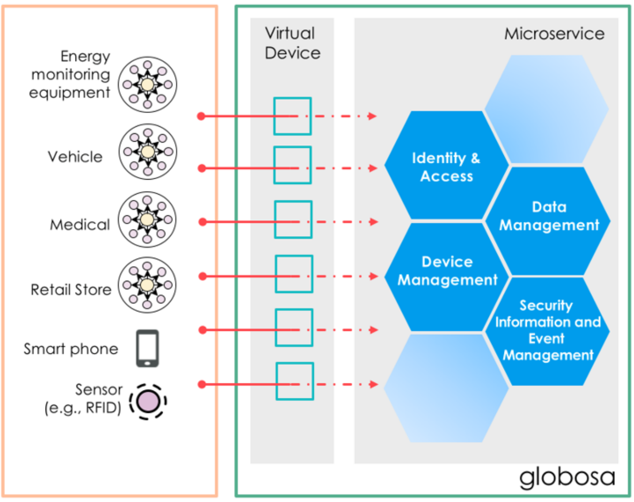

Figure 5 The Ageing@home open unifying cloud IoT platform

To address those challenges, we propose a user-centric privacy-aware framework that handles data of different devices and components from various vendors to efficiently integrate smart objects into IoT solutions. The framework will ensure that consumers' personal data will only be shared with consumers' consent, unless required and limited for the use of product features.

A further development has been the disassociation of data from the architectures. In IoT architectures, data continues to be managed and processed for primary applications (the applications for which the architectures were originally designed). However, enterprises have recognized that data sets from one IoT architecture may in fact add value to other IoT architectures and applications. By disassociating data from IoT architectures, or making it accessible for other applications, a range of opportunities has opened to design and develop new services based on aggregation of data sets and federation of information from different sources, potentially delivering unparalleled insights.

Given the dynamism of deployment and scalability expectations which comes with IoT, microservice-based architecture is an important part of the overall IoT strategy. Microservice-based architecture offers a way of scaling the infrastructure both horizontally and vertically giving long term benefits to the IoT application systems. Each of the services as shown in Figure can scale based on the needs.

In IoT, the role of Identity Management is expanding [14]. It is no longer just about identifying people and managing their access to various online services and to different types of data (i.e. sensitive data, non-sensitive data, personal data, device data, etc.). Identity Management must now be able to identify devices, sensors, monitors, and manage their access to sensitive and non-sensitive data. Our open user-centric privacy-aware framework must include methods for managing device identity and be able to do some of the following:

- Establish a naming system for IoT devices.
- Determine an identity lifecycle for IoT devices, making sure it can be modified to meet the projected lifetime of these devices.
- Create a well-defined process for registering the IoT devices; the type of data that the device will be transmitting and receiving should shape the registration process.
- Define security safeguards for data streams from IoT devices.

8 Proof-of-concept implementation

To prevent illegal access to resources and elderly data the Healthcare slice has to be completely isolated from the other slices, especially the public enhanced Mobile Broadband slice for regular smartphones. This means that regular mobile subscribers will be prevented to access the Healthcare slice and the resources and services associated to it.

To fulfil the requirement, a specific restricted network policy has to be established in the Cloud Radio Access network aiming at constraining access to specific network resources and allowing only authorised traffic.

As shown in Figure 6, the 5G4IoT lab has established an early 5G network consisting of a Cloud Radio Access Network (C-RAN), connected to a cloudified OpenAirInterface [15] EPC (Evolved Core Network). The infrastructure is deployed using functional split between a Baseband Unit and the Remote Radio Head, with the NGFI (Next Generation Fronthaul Interface). In order to achieve network slicing, the User Equipment with SIM_1 is associated with the Mobility Management Entity MME_1 instance running in the core network, as well as the IoT device with SIM_2 correlated with the MME_2. Both MME instances are virtualized into container environment using the Docker technology. The same applies to the other constituents of the core network, including two instances of HSS (Home Subscriber Server) databases, specifically HSS_1 and HSS_2 related to MME_1 and MME_2 instances correspondingly. The Docker container networking interface (CNI) should thus disallow the two databases to communicate with each other and allow only their corresponding MME instances to perform DIAMETER authentication in their own network domain. By establishing tunnel within a VPN network, the IoT devices with SIM_2 can also securely access their own slice to the SGW (Serving Gateway) and PGW (Packet data network Gateway), initiating a route to the corresponding MME_2 with a private network broadcast domain. For the purpose of establishing appropriate routes, the S/PGW are set to create virtual GTP-U (GPRS Tunneling Protocol User data tunneling) tunnels between the virtual interface of the instance to the corresponding virtual interface of the MME_1 and MME_2 subsequently, with different IP domains.

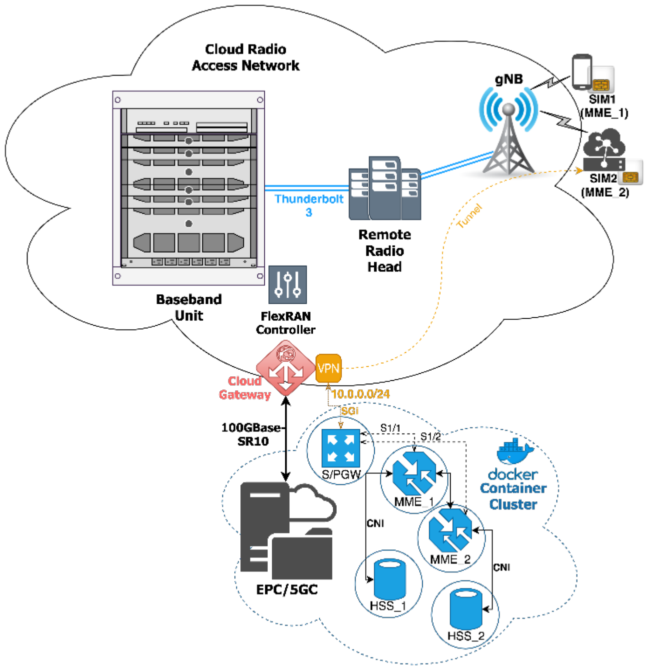

Figure 6 5G4IoT Lab Cloud Radio Access Network slicing concept

In order to associate an explicit user to the matching database, the FlexRAN controller conjoins the equivalent IMSI (International Mobile Subscriber Identity) values of the device to the ones in the conforming HSS_2 database. This way, the User Equipment (mobile phones) are incapable of reaching the registered devices in the HSS_2 database, since their IMSI values are meticulously canalised into the HSS_1 and their traffic routed explicitly within that route.

Allied to the described network, an identity provisioning and management system (IDMS) [14] has been implemented as shown in Figure 7, as a way to strengthen as well as simplify the authentication process for users (e.g. caregivers) and devices using the network by offering a single sign-on mechanism across the network and the application layers. More precisely, we inherit existing components from the network that can provide a secure way to identify a device and used it a unified way between layers.

To achieve a consensus on which parameters can be used as identifiers, i.e. identity federation, an API was also developed [16] to bridge between the IDMS and the network. After issuing the identities for the desired caregivers/devices, a module is created and given to the healthcare center, so that when a verification request has to occur, the healthcare center will confirm with the system as if one is eligible to provide support to an elderly person.

This identity management system is created by using an instance of the Gluu Server [17] that provides a combination of the provisioning and management tools, as well the option of deploying OpenID clients for integrations with third-party applications.

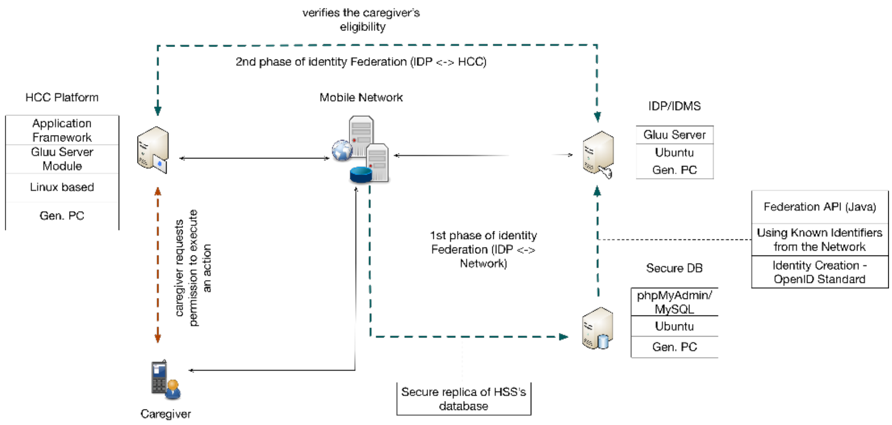

Figure 7 Implementation of the Identity Management system

9 Conclusion

In this paper we have presented Ageing@home, a welfare solution which enables elderly to age comfortable, safely and securely at their home by making use of three major technologies namely mmWave sensors, 5G network slicing and open unifying IoT platform. Although these technologies have been tested and successfully validated separately at the Secure 5G4IoT lab and the Kajiwara lab, a fully integrated prototype has not been done. Further, it is necessary to carry out proper validation with real users [18,19]. For that it is required to run a field trial at with a limited number of elderlies living in a municipality in Norway or Japan. Findings from the field trial will be used to improve and optimize the sensors, the 5G network slice, the IoT platform and also the AI/ML algorithms used in the detection and prediction of anomalies. As longer-term continuation works, innovative welfare technologies and services are envisaged to be included and deployed in Ageing@home. The ultimate goal is naturally the successful commercial deployment and the wide adoption of Ageing@home in Norway, Japan and all over the world.

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