Secure 5G Network Slicing for Elderly Care

Boning Feng[1], Van Thuan Do[1,2], Niels Jacot[2], Bernardo Santos[1], Bruno Dzogovic[1], Ewout Brandsma[3], Thanh van Do[4,1]

[1] Oslo Metropolitan University, Pilestredet 35, 0167 Oslo, Norway
[2] Wolffia AS, Haugerudvn. 40, 0673 Oslo, Norway
[3] Philips Research, High Tech Campus 34, 5656 AE, Eindhoven, The Netherlands
[4] Telenor ASA. Snarøyveien 30 1331 Fornebu, Norway
vt.do@wolffia.no
{vt.do,n.jacot}@wolffia.net
{boning.feng, bersan, bruno.dzogovic}@oslomet.no
ewout.brandsma@philips.com
thanh-van.do@telenor.com

Abstract. In the time of an ageing world, aging at home is both an economically and socially viable and sustainable solution which may also improve the elderly's well-being. There are currently a few Home-based Elderly Care systems which although operational are not yet optimal in terms of efficiency and security. The paper propose a Home-based Elderly Care solution which makes use of the 5G mobile network slicing with two secure and isolated slices, namely the Health Care slice and the Smart Home slice to provide an inherent secure connection. Further, the solution includes an efficient and secure Emergency Call which ensures that the appropriate caregivers can dispatched and provide help in shorter times. A proof-of-concept implementation is described thoroughly.

Keywords: 5G mobile networks, 5G network slicing, assisted living, elderly care, Home based Elderly Care

1 Introduction

Europe and actually the whole world are facing an ageing population [1]. Although there are multiple advantages with an ageing population such as positive contributions to the community through their volunteer services, lower crime rate, familial assistance, etc. an ageing population brings significant challenges like decreased participation rates, increased dependency rates, overload of the healthcare systems, lack of elderly homes, etc. Probably, one of the best solutions to meet these problems is to enable elderly people to live at home as long as possible. Such a solution puts less pressure on the current healthcare systems and is by far more cost efficient than retirement homes while the well-being and happiness of seniors is better preserved. However, to enable aging at home it is essential that elderly people can have a safe,

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secure and comfortable life at home. For that, it is important to be able to monitor the senior citizen's well-being and to provide appropriate guidance and assistance.

There are currently a few total solutions which provide both monitoring and assistance by combining a variety of technologies like sensor technologies, smart home, eHealth, remote surveillance, etc. Unfortunately, they make use of wireless LAN as wireless technology and suffer of disadvantages like poor security, complex configuration, restricted portability, dependent on electricity, etc. To remedy these shortcomings, we propose a Home-based Elderly Care solution which makes use the 5G network slicing concept. More specifically, dedicated logical networks aka network slices will be allocated to the Home-based Elderly Care solution and connect in a secure way all the health sensors and devices, all the caregivers to the Health Care application running on the cloud. The proposed solution will ensure higher level of security and privacy while improving the caregiver's assistance. This paper starts with a brief summary of challenges in Home-based Elderly Care. Next, the state-of-the art and related works on Home-based Elderly Care are comprehensively reviewed. To ease the reading of the paper a brief introduction of the 5G mobile network slicing is included before the main part of the paper, which is the thorough explanation of the proposed solution. Last but not least is the description of the proof-of-concept implementation at the Oslo Metropolitan University's Secure 5G4IoT lab. The paper concludes with some suggestions for future works.

2 Challenges in Home-based Elderly Care

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 a Home-based Elderly Care solution needs to fulfil 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 State of the art of Home-based Elderly Care

With the advent of the Internet of Things (IoT) more and more IoT devices have been adopted and used by Home-based Elderly Care solutions [2], which become more and more efficient and trustable. As specified in [3], a Home-based Elderly Care consists of the following components:

- **Vital Signs Monitoring System:** allows the monitoring of vital signs such as heart rate (HR) [5], body temperature (BT), respiration rate (RR) and blood pressure (BP), etc. that are used by the medical professionals to get a good overview about the health of the elderly person.
- **Reminding System:** helps elderly citizens remembering to take their medicines as well as meals at correct time and dosage [5].
- **Automated Activity and Fall Detection System:** is able to distinguish between normal and abnormal activities and to detect a fall in order to trigger an alert, which can again result to an emergency with intervention of caregivers [7].
- **Automated Emergency Call System:** locates, contacts and directs the near-by appropriate caregiver who gives assistance to the elderly person in emergency cases [8].

Figure 1 depicts a typical Home-based Elderly Care solution. All sensors, actuators, devices used by the Home-based Elderly Care components are connected the Healthcare center and the caregivers through the Internet. The local connectivity to the Internet is done via a Home Gateway with wired connections or mostly wireless ones using the IEEE 802.1 Wireless Local Network Area (WLAN) family [9].

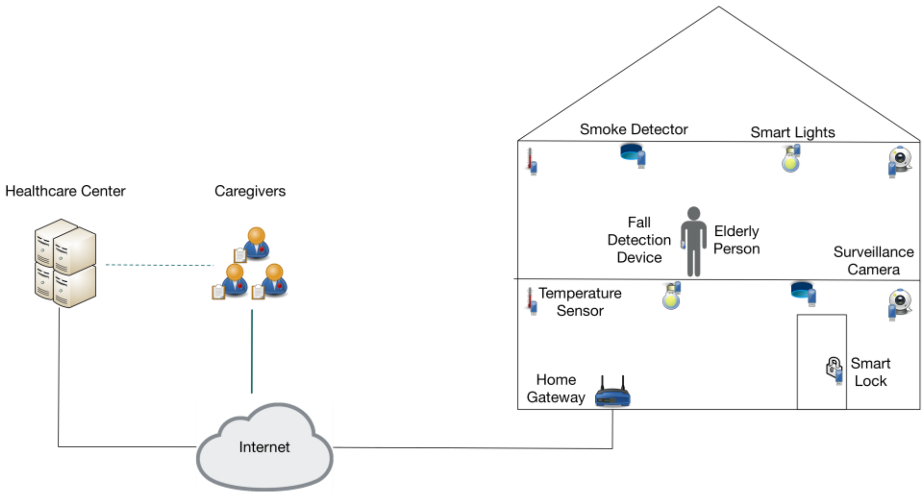

Figure 1 A typical Home-based Elderly Healthcare solution

Although operational and useful current Home-based Elderly Care systems are subject to severe limitations. First, the connection between the Healthcare Center, caregivers and the Home-based Elderly Care component traversing the open Internet pose serious privacy, security and safety problems that research scientists are struggling to find remedies for [10][11]. Next, the local connectivity realized by wireless LAN is by default open and hence exposed to malicious attacks. Additional security measures such as encryption and password-based authentication can, of course be used but they will add more complexity in the configuration and management, which is already challenging for non-technical people. Last but not least is the dependency on electricity of Home Gateway and long power outages will paralyze the Home-based Elderly Care system.

There are currently only a few activities aiming at entire Home-based Elderly Care systems [10][11] but they focus on interoperability, security and privacy and none according to our knowledge, looks for a more secure wireless network or more specifically to make use of 5G network slicing concept in a Home-based Elderly Care as our work described in this paper.

4 Brief introduction to 5G network slicing

The 5th generation mobile network or simply 5G [12] 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 [13].

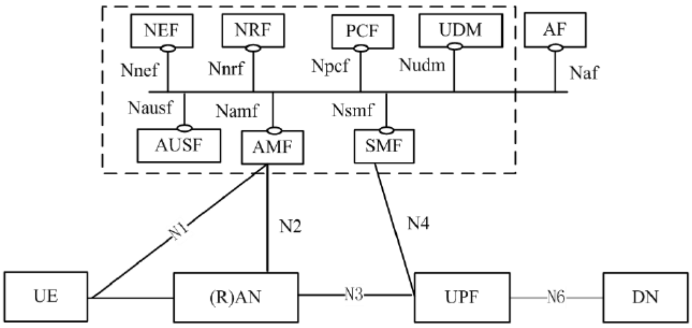

Figure 2 The 5G Reference Architecture (Courtesy of 3GPP)

As shown in Figure 2 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 brings with it both weaknesses and strengths. Indeed, the 5G mobile network has the same vulnerabilities as any other software at the same time as higher flexibility and dynamicity can be achieved through the logical network segments also known as Network slices.

Currently, there is no consensus on what a network slice is and how it can be realized [14]. In fact, while the 3rd Generation Partnership Project (3GPP) [15] provides a more network-focused definition stating that “network slices may differ for supported features and network functions optimizations” the 5G Infrastructure Public Private Partnership (5G PPP) adopts a business oriented view mandating that “network slice is a composition of adequately configured network functions, network 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” [16].

In this paper we use the 5G PPP's definition that allows the support of a variety of devices. To obtain a wireless Home Networking capable of supporting a broad range of devices the 5G network slicing concept is adopted to establish a secure 5G network for Elderly Care.

5 The proposed 5G Home-based Elderly Care

To improve the elderly people's security and privacy at the same time as to simplify the device management and to reduce the response time of the caregivers we propose to make use of the 5G network to tailor a logical wireless network which as shown in Figure 3 consists of two network slices:

- **A Healthcare Network slice:** is strictly reserved to the healthcare personnel and caregivers. This network slice is a typical enhanced mobile broadband (eMBB) with high data rates.
- **A SmartHome Network slice**: provides secure connectivity to the elderly home's sensors, actuators and medical devices. This network slice is both massive machine-type communications (mMTC) and ultra-reliable and low-latency communications (URLLC) network slice

Access to these two network slices is granted by the IMSIs (International Mobile Subscriber Identity) hosted in the SIM card carried by the devices. Outsiders are not allowed to access any of these two network slices. By using 5G as wireless technology instead of wireless LAN higher portability and ease of management are achieved since medical devices can be easily moved from one elderly home to the other without the need for re-configuration.

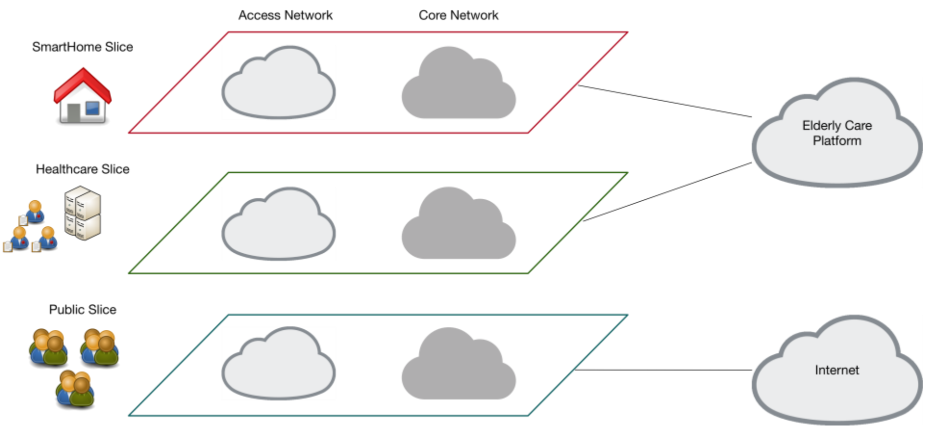

Figure 3 Network Slicing for Home-based Elderly Care

Another big advantage is the very efficient Emergency Call offered by the proposed solution. Indeed, by providing a dedicated network slice for the Healthcare center and caregivers, it is easier to reach all the actual caregivers in case of emergency by simply broadcasting the alert to the base stations nearby the home of the elderly person in distress.

To demonstrate the security and privacy improvements and the Emergency Call efficiency we propose a 5G Home-based Elderly Care as shown in Figure 4. All the home sensors, actuators and medical devices are connected to Health Care Center (HCC) through the Smart Home Network Slice while the caregivers communicate with the HCC using the Health Care Slice. It is worth noting that all the communications happen within dedicated networks without having to go through the open Internet.

The main scenario starts when an elderly person living at home falls. The fall detection will send an alarm to the Health Care which again dispatches appropriate caregivers to help the senior person. Since the focus is on demonstrating the strength of using 5G network slicing the fall detection is not implemented and the fall detection is simulated. To ensure a both flexible and secure physical access to the elderly's home smart locks are installed and connected on the Smart Home Slice to the Health Care Center which can grant access to eligible individuals, e.g. caregivers.

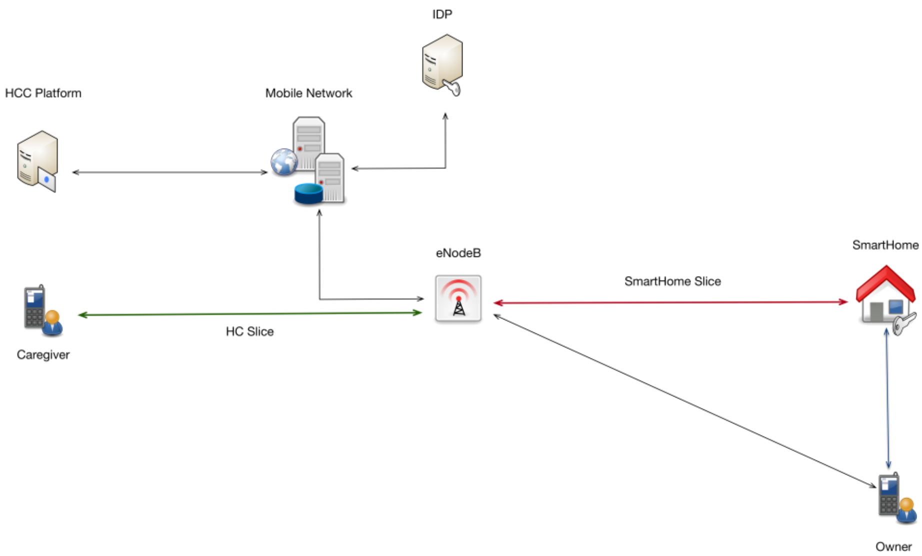

Figure 4 Overall architecture of the 5G Home-based Elderly Care

To minimize the response time, it is crucial to have a large and wide set of disponible caregivers consisting of different types of caregivers such as professional caregivers, informal caregivers like neighbours, relatives, volunteers, etc. and to locate the available caregivers who are in the vicinity of the elderly home. For that the 5G's ability to broadcast a message to a selected number of base stations gNBs (next Generation eNodeB) will be used. All the available caregivers nearby the elderly home will report themselves to the Health Care Center. The last one will select the most appropriate caregiver according to a variety of criteria such as arrival time, competence, equipment, etc. It will then send a response message to the selected caregiver with the accurate address of the elderly home and necessary instructions to help the senior in need. The caregiver can now proceed to the elderly home, unlock the door, enter and give necessary care to the senior.

It is worth noting that although there can be a large number of authorized caregivers there is only a few selected eligible ones who are granted access to the elderly home and can unlock the door. Security and privacy are ensured at 3 layers. First, only authorized caregiver's mobile phones are allowed to connect to the Health Care network slice and non-authorized persons may not even see the existence of the Health Care (HC) slice. Second, although the Health Care portal is only accessible on the HC slice proper authentication and authorization will still be performed before granting access. As shown in Figure 4 the authentication is delegated to the Identity Provider (IdP) which may carry out different authentication methods of different strengths such as password, SIM authentication, PKI, etc. Thirdly, only the selected caregivers dispatched for an elderly home can unlock the door.

The sequence of actions upon an elderly fall is as follows:

1. A fall is detected and reported to the Heath Care Center (HCC):
2. The HCC broadcasts an emergency response request to all the caregivers in the vicinity of the elderly home.
3. The available caregivers report themselves to the HCC
4. The HCC selects one or more appropriate caregiver and direct them to the elderly home with necessary instructions.
5. The selected caregivers proceed to the elderly home.
6. Upon arrival at the door the caregivers use their phone camera to take the picture of the QR code[1] and send it back the HCC with a `door_open` request.
7. The HCC checks the ID of the requesting caregiver and if it matches with the ID of one of the selected caregivers the HCC sends an `unlock` request to the door.
8. The door unlocks and the caregiver enters the house.

6 Proof-of-concept implementation

To provide a network slice for the Home-based Elderly Care, the users associated with the particular resources of the network they can access, have to be isolated from the outside world. Namely, other users from other network slices cannot and should not access the healthcare vertical. If otherwise, then any user in the mobile network can examine the private data of the patients in question.

To prevent illegal access to resources and elderly data the Home-based Elderly Care 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 Home-based Elderly Care slice and the resources and services associated to it.

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[1] QR code (abbreviated from Quick Response Code) is the trademark for a type of matrix barcode (or two-dimensional barcode) first designed in 1994 for the automotive industry in Japan

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.

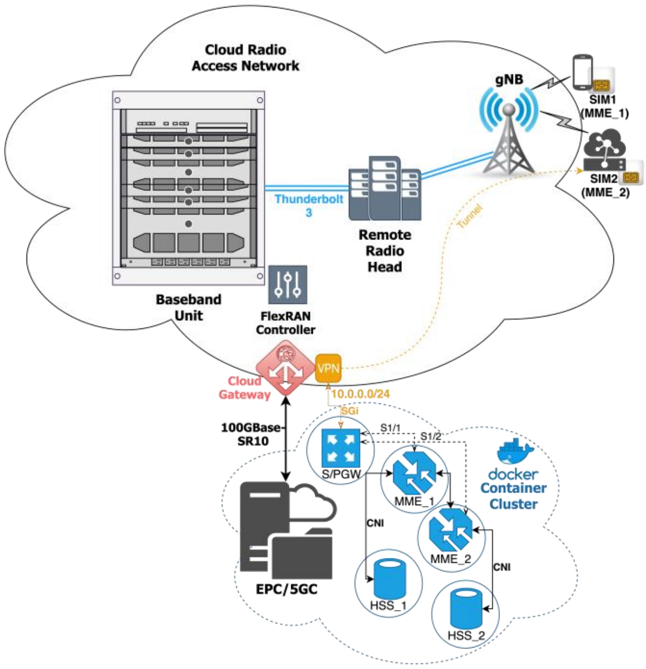

Figure 5 5G4IoT Lab Cloud Radio Access Network slicing concept

As shown in Figure 5, the 5G4IoT lab has established an early 5G network consisting of a Cloud Radio Access Network (C-RAN), connected to a cloudified OpenAirInterface[2] 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. The 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

[2] The OpenAirInterface Software Alliance (OSA) is a non-profit consortium fostering a community of industrial as well as research contributors for open source software and hardware development for the core network (EPC), access network and user equipment (EUTRAN) of 3GPP cellular networks. https://www.openairinterface.org/

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.

In order to associate an explicit user to the matching database, the FlexRAN controller conjoins the equivalent IMSI 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.

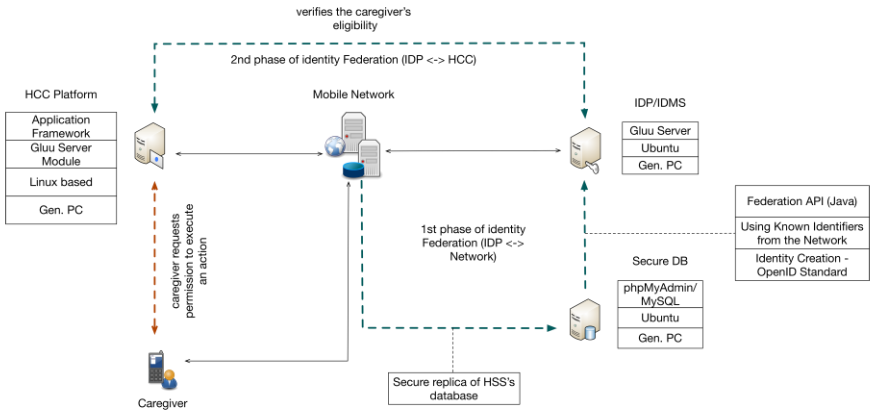

Figure 6 Implementation of the Identity Management system

Allied to the described network, an identity provisioning and management system (IDMS) [17] has been implemented as shown in Figure 6, 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 [18] 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 [19] that provides a combination of the provisioning and management tools, as well the option of deploying OpenID clients for integrations with third-party applications.

7 Conclusion

In this paper we have shown that 5G and its network slicing concept can provide more efficient and secure connectivity to IoT vertical applications such as Home-based Health Care. It is also demonstrated that in addition to the inherent security brought by the isolated nature of the 5G network slice security can be improved further by an Identity Management system, which provides stronger authentication of the caregivers and also paves the way for an efficient and flexible physical access control to the elderly home.

Although the proof-of-concept is working properly only positive testing with use cases as fall detection is carried out. Negative testing must be also performed to ensure that the proposed solution does not carry out actions that are not wanted. The ultimate validation will be a field trial with a limited set of elderly and a number of caregivers in a real 5G mobile network. This trial can be envisaged in the H2020 5G VINNI[3]'s facility pilot in Kongsberg, Norway when it is fully established by the beginning of 2020.

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[3] 5G-VINNI: 5G Verticals INNovation Infrastructure, an European H2020-ICT-2017 research project which aims at accelerating the uptake of 5G in Europe by providing an end-to-end (E2E) facility that validates the performance of new 5G technologies by operating trials of advanced vertical sector services

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