Requirements for 5G based telemetric cardiac monitoring

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***Abstract*—Several white papers have been published on general requirements for 5G in the health vertical. As 5G research and implementation continue more detailed real world information for application research are needed. This paper is focusing on the requirements for telemetric cardiac monitoring based on real world experiences from a joint project on early geriatric rehabilitation of elderly patients in a care of the elderly department after minimal invasive and conservative treatment in a highly specialized cardiology unit in Leipzig, Germany.**

***Keywords*—5G, cardiac monitoring, RRS, bandwidth, requirements, blockchain, cardiology, geriatric medicine, network slicing, SDN, NFV**

I. Introduction

Telemetric monitoring of patients with heart conditions has been a widely accepted concept for in-patient and outpatient use so far. However, there have always been some remaining challenges. The main challenges have been related to Quality of Service (QoS) issues as telemetry mainly operates on WLAN technology, which like 3G or 4G mobile technology is nowadays typically based on the „best effort“ paradigm and does not fulfil the requirements for „mission critical“ applications [1]. On the other hand there have been longstanding security concerns especially with regards to wifi connectivity via WLAN in public spaces. Standard 2.4 and 5 GHz access points, which are frequently used in hospitals, have never been considered a safe technology to start with. Moreover, there are so far no convincing lightweight concepts to secure smart medical devices with integrated connectivity, such as insulin pumps, pacemakers, smart asthma inhalers and – telemetric cardiac monitors. However, driven by tighter data protection laws, such as the European General Data Protection Regulation (GDPR) and the European Medical Device Regulation (MDR) there is now need for urgent action and rapid improvement of medical device connectivity, interoperability and security [2, 3]. A very important development in this context is the ongoing global development and implementation of 5G technology with the target of first large scale demonstrators in 2019. In Europe, there is ongoing work towards large scale 5G demonstrators supported by the European Commission under their 5G PPP program [4]. Initial general e-Health vertical requirements for 5G have been established as a white paper some time ago in a working group under the 5G PPP initiative [5]. Those early requirements have in the meantime been confirmed by white papers by other relevant groups [6]. A suitable 5G framework architecture has been published by the 5G PPP group in order to support an overarching, coherent industrial approach towards 5G mobile communications [7]. This paper needs to be read and understood in context with a recent 5G PPP Software Network paper [8].

All in all the scene seems to be set for attempts to establish European eHealth testbeds based on 4G LTE / 5G technology. This paper formulate a proposal for a real world implementation of a 4G LTE /5G - private / public hybrid network in the health domain based on our requirements in the Geronto-Cardiology section at Helios Park-Klinikum Leipzig, Leipzig Germany and assess the relevant requirements. Different from the currently existing white papers this paper will highlight specific real world requirements related to a single use case very precisely rather than to scratch the surface of a variety of exemplary applications.

After having provided an introduction to the topic I.) the paper will II.) explain the current, state of the art settings, III.) highlight the medical, technical, ethical / legal requirements and relevant standards, IV.) describe our intended test-bed specifications and V.) summarize the key points highlighted in this production.

II. Description of Current Setup in the Department

A. Network setup

Our hospital is running a standard intranet service. Different from many other health care providers, Helios is running their own regional data centres. This allows for large scale testing with roaming across several domains.

B. Telemetric cardiac monitoring

The current setting for telemetric cardiac monitoring in the geronto-cardiology department are based on Dräger telemetric equipment and the hospital WLAN network. The access points operate on 2.4 GHz and 5GHz, whereby continuous monitoring across the ward is only possible on 2.4 GHz. The ecg signal is not specifically encrypted but is protected through a propriety protected protocol. Details of the interface adapter between Dräger backend solution and user interface are therefore unknown.

C. Limitations

Continuous monitoring across the ward is only possible on 2.4 GHz. Roaming between different nodes across the entire hospital is in principle possible but is not implemented as a default option. Triangulation is not possible. There is no integrated GPS service, meaning that patients need to report to the nurse when they leave the ward. Incoming alarms from telemetric units do not carry any information where the patient is actually located. To be fair, most patients would normally not leave the ward due to reduced mobility and other conditions. However, if they do so and if they forget to inform staff where they will be going, currently there is no way to locate the patient. This is a big concern as in case of a cardiac arrest or severe, life threatening arrhythmia the patient cannot receive immediate emergency treatment and might face life threatening consequences. Another point of criticism by clinicians is that the ecg signal cannot be projected in real time to mobile end-devices, such as mobile phones or tablets. This prevents doctors from analysis and assessment of arrhythmic episodes on the fly.

III. Requirements

A continuous repetitive topic throughout 5G conferences is the issue of use-case specific requirements. Although well meant, in general, white papers are typically not detailed enough to start the process of project planning or implementation. Requirements are diverse and the relevance of requirements engineering in the health vertical must not be underestimated [9].

A. Medical Requirements

Typically our patients are referred to us from the nearby Heart Centre, Herzzentrum Leipzig, which is one of the major German heart centres, for early geriatric rehabilitation after minimal invasive procedures, such as valvoplasty, valve replacement (TAVI = Transcatheter aortic valve implantation), Mitral clipping, pacemaker revisions, implantation of Ventricle Assist Devices (LVAD, RVAD), heart infections or other severe heart conditions. These severe conditions frequently require the permanent monitoring of our patients to prevent deterioration and potential death. As geriatricians with a focus on severe cardiac conditions our task is typically to mobilise patients despite of their severe heart conditions, as immobility might lead to severe comorbidity such as pneumonia, cardiac insufficiency, pulmonary embolism, progressive weakness, sarcopenia, etc. In order to strengthen patients independence patients are allowed free movement on the ward with a telemetry unit.

B. Technical Requirements

- Functional requirements

The systems need to be able to transmit ecg signals in a single or multi-channel mode in next to real time. Latency should be kept to a minimum to enable potentially time critical study of the heart activity over different channels (< 1ms). There should also be a function enabling the continuous monitoring of the functional status of the device with regards to battery status, malfunctions and service requirements.

- Signal transmission and bandwidth

Standard clinical ecg applications have typical signal-bandwidths of 0.05 – 100 Hz. For a monitoring facility on intensive care units a signal bandwidth of up to 1 kHz for late potential measurements may be required [10]. However, these signal bandwidth requirements need to be translated into network bandwidth specifications where several factors play a significant role. Network bandwidth requirements are not only dependant on the original signal size, but also on potential security features, such as encryption, meta data and most famously on the noise level of the communication channel [11]. This typically translates into uplink baud rates of around 3.6 - 20 kbps per patient [12, 13].

- Privacy and security

Due to enhanced privacy and data protection legislation ideally patients should be able to monitor the use of their data. This could be achieved through the use of blockchain technology in the future [14]. Currently there is only limited experience with parallel systems, meaning systems, which allow upload and download for example for remote device management. There can be no doubt that accessibility of devices via external parties enhances the vulnerability of systems. However, security systems will eventually improve and solutions will be found to allow for safe remote access, at least for certain products and devices. 5G might significantly boost this development by providing specific network slices, which will allow for enhanced security features. However, for the health domain more than for any other industrial vertical a security by design approach will be required.

- Virtualization, orchestration, aggregation

5G specific features such as Software Defined Networks (SDN) and Network Function Virtualization (NFV) will allow for safe and secure enhanced seamless roaming across several networks and domains. Also these technologies will allow for orchestration and aggregation and enable the integration of generic services into individualised services [15]. This will help cardiologists to individualise diagnostics.

- Cloud based network structures

In principle three possible variations for e-Health networks may be applied for cardiac monitoring. Typically networks are based on cloud infrastructures, namely public clouds, private clouds and hybrid clouds. Hybrid networks are a merger of private and public cloud components whereby network traffic is typically monitored through single point of contact interfaces, governed by previously defined rules. While in the early days of cloud computing it was expected that data would have to be sent to the software in order to be processed this paradigm has changed. Edge cloud technology is expected to transport services to the data [16]. This is on the one hand supporting privacy and security and on the other hand allows for service orchestration and aggregation. Modern 5G services are expected to support the software to the data paradigm.

- Positioning

5G based Telemetric ecg monitoring should allow for geo-fencing features and 3D GPS technology to quickly localise a patient with arrhythmia or in a cardiac arrest. Ideally, 5G should allow for services to instantly find the nearest suitable medical professional to the patient and guide the professional to the whereabouts of the patient in distress.

- Quality of Service (QoS)

Currently, cardiac monitoring frequently takes place on a best effort level via WLAN. QoS is limited with loss of service if patient willingly or unwillingly move out of the range of the access points. Future 5G strategies should allow for permanent QoS monitoring. Service provision should be approach from a mission critical angle and service should be available at least at 99.999% of the time with an ultra-low error rate. In many cases QoS correlates significantly with Quality of Experience (QoE) which is extremely relevant for new business models.

C. *Ethical / Legal Requirements*

The devices and the 5G networks need to be in line with the EC Medical Device Regulation and the General Data Protection Regulation when operated within the EU. In general all relevant international standards should be adhered to. This also includes for example in the US HIPAA and all other relevant FDA regulations [17]. Relevant standards have been summarised in several publications but are certainly far from being final and completed [18, 19]. Some first agreements on standardization with regards to medical devices have also been agreed with China [20].

IV. Intended Test Bed Setup and Specifications for 5G Based Cardiac Telemetry

Future proof test bed - and use-case specifications will be based on private 5G networks. This is due to parallel developments in all industry 4.0 coined verticals, such as automotive (smart factory), fintech, retail and health (Health 4.0 [21]). Currently we are working towards a mobile test bed as a parallel structure to our existing WLAN system. We are aiming at the implementation of a small cell network with several light-weight base stations (EnodeBs) within the hospital or preferably covering a cluster of 2 hospitals within a 300 meter radius. The test bed could be used for several use cases scenarios, one being cardiac monitoring of our patients in the geronto-cardiology department. We are aiming to extend the amount of monitoring devices successively from currently 3 via WLAN to 10-15 via 4G LTE/ 5G technology. We are currently discussing the provision of test frequencies with the German regulator, the Bundesnetzagentur. Lower frequencies clearly provide a better penetration and further range especially in steel frame constructions, which are typical for modern hospital buildings. Collaborations with network operators are intended and several business models should be trialled to find a viable model for the future.

A. *Data Management and Service Orchestration*

Current cardiac telemetry infrastructures are typically based on a classical client-server model, with data being shipped to and processed in a central unit (data to the software). Under 5G mobile technology the envisaged service – and business models would fundamentally change. Ultimately services would be offered by different providers embedded in various network slices. Data processing would be subsidiary rather than hierarchical. Software would be transported to the data rather the other way round wherever more effective and efficient. This is well in line with the predicted evolution of cloud computing [22]. Software would be distributed via hybrid edge cloud infrastructures. Data processing may take place on the patient device, on a doctor's phone, on a work station depending on the concrete needs and the local capabilities. Services in network slices would be delivered via cloud infrastructures in software defined networks, orchestrated by SDN technologies thus creating individualised service infrastructures for patients and physicians. This would also allow for more sophisticated alarm strategies in case of predefined events. Instead of simple acoustic and optical signals for the uncritical alert of everybody the alarm could be routed through the appropriate team members and in a private mobile network setting the ecg could be displayed in real time on the mobile phone of the physicians in charge.

B. *Allocation of Frequencies For Telemetric Cardiac Monitoring*

Currently, test frequencies for short to mid-term application research in Germany may be allocated by the relevant regulator, the Bundesnetzagentur on application. However, in order to develop 5G based telemetric cardiac monitoring further suitable radio frequencies, ideally in the 2.3-2.4 GHz band would have to be made available. In this context Reconfigurable Radio Systems (RRS) could provide a solution for temporary spectrum access for local high quality wireless networks [23].

V. Summary

Telemetric cardiac monitoring is an established technology with certain, well known limitations owed to the fact that currently it is mostly used WLAN based. WLAN technology is a best effort technology with limited reliability. Deployment of access points can be challenging due to structural and architectural problems. Mobile technology might be a viable alternative as it offers more flexibility to the user and potentially higher reliability. Also, mobile technology is not based on hard-wiring, which is a problem especially when hospitals are re-organised and facilities have to move. 5G technology supports features such as low latency, the possibility to connect more devices, SDN/NFV, roaming and enhanced privacy and security. Moreover, bandwidth might be dynamically adjusted. Also, there might be better facilities for patients to monitor the use of their data, thus enhancing privacy and security.5G will be clearly capable of supporting individualised medicine or Precision Medicine which has been identified as strong growth markets. Ultimately, 5G technology holds the potential to enhance effectiveness and efficiency of care in hospitals and is very suited for a huge variety of real-time monitoring possibilities, among them cardiac monitoring. We are proposing the implementation of an application research facility in Leipzig Germany to study the diverse technical proprieties of 5G technology and their applicability and potential for the health domain and in particular digital health.

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