Special Purpose Networks in 5G and 6G Communications – an Outlook

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***Abstract*—There are ongoing research activities on 5th and 6th generation mobile networks. Emerging technologies, such as Software Defined Networks, Artificial Intelligence or Blockchain, and human-centric networking requirements are becoming essential for future developments. A relatively new term is the so-called Special Purpose Networks, which are considered very promising 5G/6G subnets for different use cases, for example, in Body Area Networks. This publication presents an overview of current research activities within the field of 5G/6G. It also highlights the need for specialized networks in the context of these mobile networks and outlines existing limitations. Furthermore, this publication introduces a novel conceptional outline of future Special Purpose Networks in the 5G/6G network with special consideration of Body Area Networks for eHealth applications. The proposed structure and considerations can also be transferred to other application areas. Overall, this publication serves as an outlook for future scenarios in 5G and 6G communications.**

Keywords—5G/6G, Body Area Networks, Special Purpose Networks, e-Health

I. Introduction

The use of mobile networks from 5G to the upcoming 6th generation will be an integral part of personal daily life and the business world. Different standardization efforts and working groups initiated from the ITU or other institutions are working on different aspects of the 5G and 6G evolution (such as [25-28]). The increasing number of intelligent devices and the development of new Internet of Things (IoT) applications combined with optimized communication possibilities also lead to specific use cases focusing on subnetworks connected to the 5G/6G network. These autonomously working subnetworks are called Special Purpose Networks (SPNs) [1, 28]. They benefit from the connection to the 5G/6G Wide Area Networks (WANs), are programmable, and ensure energy efficiency and sustainability.

Despite the benefits, these special networks are coming with different challenges in terms of scalability, availability, and resiliency. Another necessity is to support innovative technologies such as AR (augmented reality), VR (virtual reality), digital twins, or brain-computer interfaces. Furthermore, the operation of subnets and applications consisting of heterogeneous IoT devices is challenging and requires incorporating distributed orchestration, AI/ML (Artificial Intelligence/Machine Learning) algorithms, and edge or ubiquitous computing. Security, data protection, and trust are also open issues, where blockchain technology is also expected to play an important optimization role.

The aim of this paper is to touch on some points mentioned above and present an outlook on future trends beyond 5G. Furthermore, this paper introduces a concept of SPNs for 5G and 6G that focuses on human-centered mobile networking for eHealth. This paper is structured as follows: Section II explains various current developments in 5G/6G. It comprises ideas and recommendations conducted by different standardization and non-standardization working groups. Section III outlines the necessity of SPNs in 5G and 6G communications and depicts essential considerations to be included for such networks. Section IV presents the current state of the art of SPNs, focusing on Body Area Networks (BANs) and 5G/6G. It identifies essential use-cases in this area, highlights special requirements to be considered, and presents limitations of existing approaches. Section V summarizes the previous results and presents a novel concept and architecture of future SPNs in the 5G/6G network, especially for BANs for eHealth.

II. 5th and 6th Generation Mobile Networks

In September 2015, the ITU published its groundbreaking IMT (International Mobile Telecommunications) vision for 2020 and beyond: IMT-2020, describing a 5G target system [25]. Usage scenarios were developed and summarized in three main areas: Enhanced Mobile Broadband (eMBB), Ultra-Reliable and Low Latency Communications (URLLC), Massive Machine Type Communications (mMTC). eMBB addresses the human-centric use cases for access to multimedia content, services, and data. URLLC services have stringent requirements for capabilities such as throughput, latency, and availability. Examples include wireless control of industrial manufacturing or production processes, remote medical surgery, distribution automation in a smart grid, transportation safety, etc. mMTC is characterized by many connected devices, typically transmitting a relatively low volume of non-delay sensitive data. Devices are required to be low cost and provide a very long battery life. A 5G system that supports these three usage scenarios offers new application opportunities to vertical industry sectors like automotive, manufacturing, media, energy, eHealth, public safety, and smart cities.

Based on the IMT-2020 recommendations, the concrete standardization of the protocols, components, and systems of a 5G system took place at 3GPP in Releases 15 and 16, soon to be followed by Release 17 [26]. Release 15 already offers network slicing and SBA (Service Based Architecture) in the core network. Release 16 specifies 5G campus networks, non-public 5G networks (e.g., operated by a company) in a defined geographical area, standalone, hosted, or implemented as a network slice [27]. Release 17 extends network slicing to the RAN. Release 18, called 5G advanced, will add support for personal IoT networks [26]. These features picked out from the large set of 5G features have particular significance for edge subnets connected to a 5G system. This also applies to the QoS (Quality of Service) support, virtualization, edge computing, network automation, security, and privacy functions that are relevant for all releases [26, 27].

One of the first steps toward 6G was the establishment of the Focus Group Technologies for Network 2030 (FG NET-2030) by the ITU-T in July 2018. Its goal was to determine the fundamental properties of networks in 2030 and beyond. This was based on the assumption that new application scenarios must be supported, e.g., by holography, with extremely fast response in critical situations and with high-precision localization [23]. Network 2030 refers to an integrated, highly automated, intelligent infrastructure containing a number of operational domains in various types of network segments (e.g., wired/wireless access, core, edge, and space segments). This integration is based on a dynamic interaction between computing, storage, and network services/applications resources/devices in all network segments. The following architectural principles should apply to a Network 2030: simplicity, native programmability, backward compatibility, heterogeneity, native slicing, unambiguous naming, intrinsic anonymity and security, resilience, and network determinism [24]. According to the application scenarios considered for a Network 2030 (Figure 1), the concept of "ManyNets" as a seamless coexistence of heterogeneous network infrastructures including satellite networks, scalable private networks, special-purpose networks, dense networks, etc. was introduced [28].

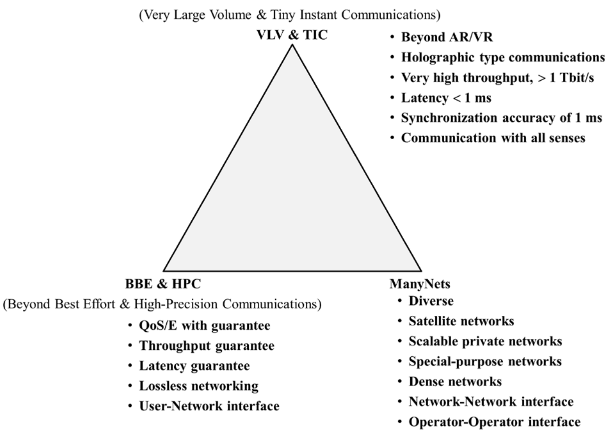

Fig. 1: Application scenarios for a Network 2030 [27]

An example of early bundled research on 6G is the 6G Flagship Project at the University of Oulo in Finland [20]. These 6G activities assume that the evolution beyond 5G will introduce a range of new services relying on higher capacity, with peak throughput reaching a 1 Tbit/s and low latency below 1 ms while leveraging the benefits of the Internet of things (IoT) and big data. New light-weight devices or wearables will emerge relying on distributed computing, intelligent computing surfaces and storage enabled via edge cloud. The goal is an evolution towards a true End-to-End Service Based Architecture with a new IP architecture for the support for ManyNets, networks of many large-scale private/public networks [21] (compare Network 2030 and Figure 1).

Hexa-X [18] is one of the 5G-PPP projects under the EU Horizon 2020 framework started in January 2021 with a duration of 30 months. It is a flagship project that develops a Beyond 5G (B5G)/6G vision and an intelligent fabric of technology enablers connecting human, physical and digital worlds. Key components for the 6G architecture are: enabling AI, programmability, architecture for a network of networks, new protocols for a new 6G spectrum, cloud softwarization, and service-based architecture incl. network slicing, continuum orchestration down to the extreme edge (Figure 2). This should include flexibility to different topologies, the ability of the network of networks to adapt to various scenarios such as new non-public networks, autonomous networks, mesh networks, new spectrum, etc., without loss of performance and easy deployment [19].

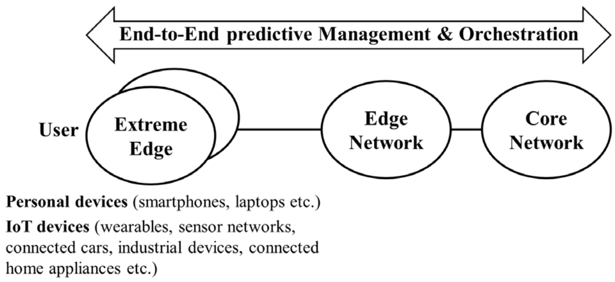

Fig. 2: 6G continuum orchestration [19]

In the Hexa-X project, the concept of network of networks is described as follows according to [19]: “defined as a network that can both incorporate different network solutions as well as a network that easily (flexibly) can adapt to new topologies”. Flexibility to different topologies means “the ability of the network to adapt to various scenarios such as new non-public networks, autonomous networks, mesh networks, new spectrum, etc., without loss of performance and easy deployment”.

The 6G Smart Networks and Services Industry Association (6G-IA) is the voice of European industry and research for next generation networks and services. Its primary objective is to contribute to Europe's leadership on 5G, beyond 5G and SNS/6G (Smart Networks and Services) research. The 6G-IA represents the private side, and the European Commission represents the public side [22]. In its 6G vision published in June 2021, the 5G-IA as the predecessor of the 6G-IA identifies SPNs as a key technology for 6G: "Driven by the capability to meet ultra-reliable and low latency requirements, we are beginning to see the use of 5G in vertical industries for industrial automation. The trend will likely further expand, resulting in increasing demand for 6G for verticals with application to SPN or even smaller range 'sub-networks' that can generally operate in a standalone fashion but may benefit from connectivity to the WAN. Examples of sub-networks that will benefit from 6G performance enhancement will range from in-body sub-network, in-robot to in-car and sub-network of swarm of drones." [1]

Last but not least, as already done for 5G with IMT-2020, the ITU-R Working Party 5D [28] has started to elaborate a target system for 6G under the topic "IMT towards 2030 and beyond" as a basis for concrete standardization by e.g., 3GPP.

III. Motivation for Special Purpose Networks

The mentioned standardization and research activities according to 5G and 6G as well as current trends [2] show that the demand for communication and IoT applications with extended requirements is increasing and will continue to increase, and thus also the demand for specialized networks and subnets in the context of 6G that meet the requirements of the applications. These 6G subnets, referred to as SPN in [1, 28], are characterized by limited ranges and are generally operated autonomously. Examples include Wireless Body Area Networks (WBANs) [3], Unmanned Aerial Vehicle

(UAV) Networks, and IoT Networks [1]. These special 6G subnets benefit from the connection to the 6G WAN and thus offer the possibility to provide the corresponding comprehensive applications. Such SPNs can operate autonomously and programmable, provide optimized architectures and interfaces, ensure the highest energy efficiency and sustainability in their context, and offer optimal security, strong data protection, and especially the highest trustworthiness for their application area. A very important application area for such future 6G SPNs are BANs, which, for example, offer the possibility of controlling and monitoring vital functions such as pacemakers or even assisted interventions on the body from a distance. One example is BANs specifically for eHealth or smart healthcare applications. The direct environment of the BAN and corresponding applications via 6G WAN can also be included in an end-to-end consideration.

This 6G SPN overall solution should, on the one side, take into account today's usual BAN requirements [3, 5] and, on the other side, new, highly demanding ones such as AR, VR, use of all senses [6], holography, digital twins, brain-computer interfaces [8] and currently unknown ones. Based on this, solutions for optimal architectures will be developed, taking into account scalability, availability, and resilience. Such a 6G subnet should support heterogeneous IoT devices, function as a multi-sensor, and be extremely energy-efficient. Distributed orchestration, AI/ML algorithms, and edge or ubiquitous computing are used to operate the highly virtualized and programmable subnet and the applications. Open interfaces to the WAN and for applications as well as the required QoS regarding throughput, latency, and deterministic end-to-end communication with an Enhanced IPv6 will also play an important role. Special attention should be paid to the topics of security, data protection, digital sovereignty, and trust, which are considered particularly important. Blockchain is also an interesting topic to increase the trustworthiness in such networks and ensure high data integrity.

IV. Use Cases, Requirements, and the State of the Art

As already mentioned, this paper aims to present a concept for an adaptable overall solution for SPNs for 6G. In particular, the focus is on human-centered mobile networking for eHealth. According to [1], SPNs are named as key technologies of future 6G network architectures that can work standalone and at the same time benefit from the connection to the "large" 6G network. Body area subnets for life-critical purposes are a very important application area [1, 9] or non-medical applications such as for military and defense or sports [4]. This already results in extreme requirements for availability, reliability, and energy efficiency [1, 3, 5] regardless of location [6]. According to [1], basic technologies are already known for this in 5G, but these must be further developed to meet future extreme requirements. With regard to the reliability of such body area subnets, QoS will also be a decisive factor [3], e.g., based on SDN (Software Defined Networking) [5].

Today's WBANs use well-known transmission technologies such as Bluetooth Low Energy, ZigBee, WiFi, Li-Fi (Light Fidelity), LoRa (Long Range), NB-IoT (Narrowband IoT), but in the future also 5G and 6G [3]. However, according to [8], the IEEE 802.15.4 and IEEE 802.15.6 standards currently used do not meet the requirements for future WBANs.

WBANs consist of sensors and actuators on-body, e.g., in wearables for the acquisition of bio parameters, or in-body, e.g., through implants such as pacemakers or nano-devices [3, 6], which are connected to the public network, e.g., for pre-processing of the data with a personal device (e.g., smartphone) as a gateway [3] acc. to Figure 3, where applications in the field of eHealth for monitoring, assessment and treatment of human health values are provided on servers [3, 6].

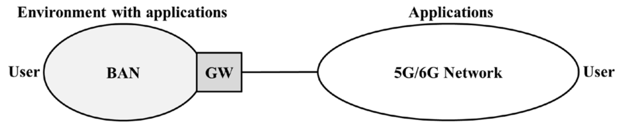

Fig. 3: Conventional BAN

Energy consumption in WBANs due to the required longevity and associated reliability of, e.g., implants such as pacemakers or insulin pumps is another huge challenge [4, 6, 8]. In addition, bio-compatibility or overheating of, e.g., sensors on and/or in the human body are important factors here [5]. But sustainability regarding WBANs will also be an important aspect, e.g., to further increase longevity by means of energy harvesting [5]. Questions regarding the radiation absorption of the human body [3, 6] and interference due to the densely communicating in- and on-body devices are also areas to be explored [3].

Today's WBANs are based on a star-structure subnet architecture or multi-hop communication with a central gateway at the transition to the public network and only relatively low bit rates in the subnet itself [3]. According to [3], this will not be sufficient for future e-health applications with AR, VR, holography, and digital twins. This gives rise to research questions regarding future optimized architectures of the subnetworks [3] as well as their flexibility, modularity and scalability [3, 5], but also regarding the interfaces to the 6G access network [3, 5, 9]. According to [8, 9], terahertz communication with very high transmission rates will be used in the BAN itself and its environment and will replace Bluetooth and WLAN in parts.

Furthermore, 6G subnets for special applications will be equipped with AI to detect unused frequency ranges in the terahertz band, for example, and to make them available to the services at any time of transmission so that, for example, sufficient bandwidth is available without affecting neighboring subnets [9].

For remote diagnosis and treatment, future applications, e.g., remote operations or holographic applications, require extremely high data rates of 1 TBit/s and extremely low latency of < 1ms [3, 7]. The delay is imperceptible to humans. Current 5G systems do not have the bandwidth to support, e.g., high-resolution holographic communication. New applications such as Brain-Computer Interface, Synesthesia Internet (linking of the senses), nanorobots, or even digital organs will present still unknown requirements and challenges, which are envisaged in [8] with the help of future 6G WBANs.

Currently, the dependencies on manufacturers and the associated static manufacturer-specific WBAN architectures, which do not allow cooperation between different manufacturers, are also a major problem [5]. The standardization of the interfaces, optimization and modularization of the architectures, and programmability of the network and virtualization, including orchestration of the services, offer solutions not only for this.

In particular, the integration of cloud applications and the lack of mobility support, e.g., for patients, are already a problem today [5]. Virtualization techniques and the use of edge and ubiquitous computing in connection with 6G WBANs can offer a solution here.

Furthermore, due to the use of very different IoT devices and services with very different processing and bit rate requirements with a few short data packets up to high bit rate real-time communication, the efficient use of resources will play a decisive role in such heterogeneous 6G WBANs, especially in terms of energy. In this context, the future use of IoT devices with energy harvesting should also be mentioned [5, 6].

In particular, for all the human-centric eHealth applications such as monitoring and control tasks for diabetes, body temperature, heart rate, asthma, Parkinson's disease, depression, electrocardiogram, oxygen saturation, Covid-19 [3] to AR, VR, holography, digital twins and brain-computer interface, issues of privacy, IT security, trust, reliability, availability and resilience play a very crucial role [3, 5]. Blockchain and smart contracts can be part of the solution [5].

Blockchain technology and its cryptographic elements ensure protection against unauthorized data access or data manipulation and protect the digital infrastructure. Currently, various blockchain-based solutions are predicted for use in 6G [10, 11]. These include spectrum, asset, infrastructure, computing power, or data storage management. Other blockchain perspectives [12] target secure access controls and data and identity protection. However, these conceptual ideas do not address the potential trust issues at different network layers in specialized 6G networks. A blockchain itself cannot solve these. An optimization approach could be the fusion of trust concepts in decentralized networks with the blockchain. Additionally, the technical design of the blockchain is crucial, considering security, transparency, scalability, and especially energy consumption.

In the following, various EU projects are examined to determine whether they focus on the topics of SPN or BAN in 6G.

The above-mentioned EU-funded Hexa-X project [13] aims to develop key technologies for 6G. The focus is on research into fundamental new radio access technologies for extremely high bit rates and high-resolution localization and sensing using sub-THz frequencies, the linking of intelligence through AI-controlled air interfaces, and network development and expansion to increase the flexibility and efficiency of networks, e.g., integrating further types of access such as non-terrestrial networks (NTN), device-to-device communication (D2D) or mesh networks. Requirements and research questions concerning SPNs, such as trust, availability, resilience and subnet architectures, are not the subject of this project. However, the Hexa-X project addresses the SPN issue with one of its key components, the continuum orchestration concept (see Figure 2). This implies the evolution of regular management and orchestration techniques towards the continuum consisting of the joint combination of different orchestration domains: core network, transport network, edge, extreme-edge, and other networks that can be external to the mobile network operator (e.g., fixed access networks, private networks or hyperscaler networks) [19].

The EU-funded RISE-6G [14] project builds on current advances in Reconfigurable Intelligent Surfaces (RIS) technologies to control the propagation of radio waves in order to realize intelligent, sustainable and dynamically programmable wireless environments. The RISE-6G project focuses exclusively on RIS and its associated requirements. SPNs and related aspects such as virtualization, orchestration, trustworthiness, and subnet architectures are not covered by the project.

The EU-funded DEDICAT 6G [15] project is investigating solutions for dynamic distribution of intelligence to improve task execution time, increase energy efficiency and ultimately reduce end-to-end latency. In addition, the project explores key elements for dynamically extending coverage using robots, drones, and connected vehicles. The scope includes techniques for ensuring security, privacy and trust, including key elements for novel interactions between humans and digital systems using innovative interfaces and devices such as smart glasses. The research project focuses on developing a smart connectivity platform that uses artificial intelligence and blockchain techniques to enable 6G networks to combine existing communication infrastructure with a novel distribution of intelligence (data, computation, and storage) at the edge. While the planned platform includes research issues such as blockchain technologies and edge computing, looking at SPNs and their specific requirements and research questions is outside the research interest of the project.

The EU-funded 6G BRAINS [16] project will develop an AI-driven self-learning platform to intelligently and dynamically allocate resources, increase capacity and reliability, and improve positional accuracy while reducing response latency for future industrial applications of large scale and diverse requirements. The focus of this project is to develop further 5G technologies such as network slicing and integration of AI specifically for industrial applications, but not based on SPNs.

The EU-funded ROVER [17] project is developing new solutions and processes to promote the commercialization of innovative, non-invasive wireless technologies applied on or in the body. A system architecture is being developed that draws on engineering, physics, medicine, computer science, and product development expertise. This new architecture will use non-ionizing diagnostics and monitoring, complemented by secure data transmission at all levels with medical involvement. The special interest of the project lies in the development and research of sensors and actuators in the eHealth environment, specifically on and in the human body, which is considered an independent network node. The linked technical and security-relevant aspects in this regard are to be researched. However, SPNs and their connectivity and architectures as well as end-to-end services and requirements such as QoS or even the access network, are not part of the ROVER project.

The overview of the state of the art described above and the new requirements that will arise in the future show the deficits of existing solutions for BANs today and in the future and identify corresponding research questions and approaches to solutions. These are summarized below in keywords and represent the rough concept for a future BAN for e-health applications or SPNs with similar requirements:

1. Optimized architectures according to the use cases, incl. the formation of autonomous subnetworks in the subnetworks
2. Flexible, modular, and scalable subnet architecture
3. Good scalability with suitable transmission technologies wireline (glass fibers, copper lines) or wireless (with conventional frequency ranges, mmW, sub-THz, THz, infrared, visible light) taking into account electromagnetic environmental compatibility
4. Availability and resilience
5. Interface(s) to the 5G/6G Access Network
6. Enhanced IPv6 for 6G SPNs
7. APIs (Application Programming Interfaces) for users of the subnets and third-party service providers
8. SDN with Enhanced IPv6 and QoS in 6G Special Purpose Networks
9. Deterministic end-to-end services for users
10. Programmability of subnets
11. Optimal use of virtualization with microservices and distributed predictive orchestration, incl. end-to-end SBA
12. AI/ML deployment in (autonomous) subnet operations and to support user services
13. The massive use of edge and ubiquitous computing
14. Best possible support for Digital Twins
15. Trust
16. Applications for blockchain
17. Data privacy
18. Security
19. Efficient integration of various IoT devices
20. Subnets as multi-sensors for users, network operators, and society
21. Highest possible energy efficiency for, among other things, extremely long battery runtimes
22. Careful consideration of sustainability aspects with regard to the subnets themselves and their related support of services and users.

V. Proposed Approach for Special Purpose Networks in 5G/6G

Based on the requirements for SPNs connected to 6G or even 5G networks elaborated in Chapter IV, this chapter provides an outlook on an implementation concept. For this purpose, Figure 4 shows a possible SPN architecture. Basically, this approach assumes an optimized architecture of an autonomously operating SPN with internal subnets, incl. network slicing (requirement 1. from Chap. IV). Such an SPN can consist of several sensor/actuator networks, which have different bit rates and availability/reliability requirements according to the services to be supported. For example, a relatively low bit rate is sufficient for a connected pacemaker, but the availability must be very high. A surveillance camera, on the other hand, would require a high bit rate and high availability. Depending on bit rates and availability requirements, the sensors and actuators can be grouped in clusters and meshed to a greater or lesser extent. Accordingly, the transmission technologies are also selected, e.g., low energy Bluetooth or WLAN or also 5G/6G interfaces (requirements 2, 3, 4, and 19).

The connection of the aforementioned sensor/actuator subnets to one or more 5G/6G networks is carried out according to Figure 4 by means of usually at least two gateways due to availability, which can provide highly redundant connections both internally and externally (requirements 4, 5, and 6). The aim is to provide deterministic services end-to-end via enhanced IPv6 interfaces compared to today, QoS support, the use of virtualization, SBA, and orchestration right down to SPN subnets with even simple sensors (extreme edge). To achieve this, the SPN in Figure 4 must support distributed network functions, distributed compute and storage, distributed orchestration, and internal network slicing (requirements 6, 8, 9, 11, 13).

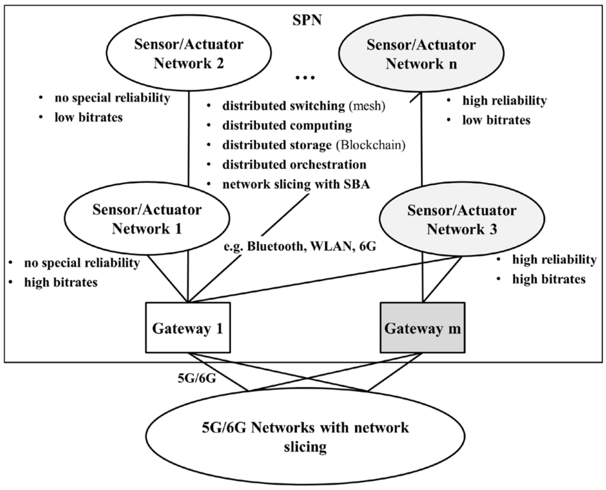

Fig. 4: Network architecture of an SPN in a 5G/6G environment

The SPN described in Figure 4 is further substantiated by the layer model for an SPN (or a special SPN in BAN form for eHealth) shown in Figure 5. This view includes the functions already mentioned and extends the range of functions regarding trust, data privacy, and security (requirements 15, 16, 17, and 18). In this context, or for distributed storage in general, the use of blockchain will also be advantageous (requirement 16). Moreover, Figure 5 also shows that such a flexibly manageable, modular, highly available, and resilient subnet is only possible by using distributed mechanisms for management and orchestration with the assistance of AI/ML algorithms (requirements 4, 10, 11, and 12). Via defined APIs, SPN users themselves or third-party providers can configure or offer applications (requirement 7).

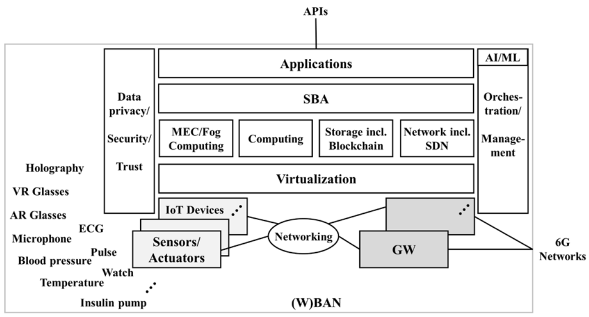

Fig. 5: Future BAN for eHealth as SPN in the 5G/6G network

Figure 5, with the exemplary sensors, actuators, or IoT devices in general, also makes it obvious that such an SPN can be used as a multi-sensor or to support digital twins (requirements 14 and 20). In the exemplary SPN here, the focus is on a WBAN for eHealth applications. This is clearly illustrated by the sensors used - VR glasses, AR glasses, microphone, watch, blood pressure monitor, temperature sensor, pulse monitor, and ECG monitor - as well as the insulin pump actuator.

If the functionalities shown in Figure 5 are integrated into the architecture according to Figure 4, it becomes clear that, depending on the requirements and use cases, even functionally simple sensors or actuators with little computing and storage power must be integrated into the distributed infrastructure, including network slicing. Depending on the type of sensor or actuator, extreme energy efficiency requirements must also be considered (requirement 21).

Sustainability aspects must be taken into account with regard to the production of the SPN components, the operation of the network, and the use of the services and applications provided (requirement 22).

VI. Conclusion

This publication presented an outlook for SPNs in 5G and 6G communications. First, it summarized current developments on 5G/6G and highlighted the demand for special subnetworks for future networks. Then, related work in the field of BANs and other emerging technologies within the context of 5G/6G were examined, and relevant requirements for a future BAN for e-health applications or, more generally, for SPNs were identified. The findings are used to present a novel implementation concept for SPNs connected to 5G and 6G. This concept includes an optimized architecture of an autonomously operating SPN with internal subnets, including network slicing. The SPN architecture consists of several sensor/actuator networks with heterogeneous transmission technologies, mesh networking as well as high availability and reliability. By incorporating blockchain technology and AI/ML algorithms, the proposed architecture supports distributed network functions, compute and storage, and distributed orchestration. The outcomes of this publication serve as a basis for further research activities. The expected exploitation results include a broad knowledge transfer on 6G, new concepts for 6G SPNs, open technological solutions, prototype implementations and testbeds as well as preliminary products for automated secure networking, BANs, and eHealth applications.

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