

# Harnessing 5G Network Slicing for Advanced eHealth Systems

**Georgios Karampelas, Maria Tsoumani, Aikaterini Petridou, Andreas Gkatzofilas, Efthymia Kotsia, Konstantinos Vlachos, Dimitrios Papadopoulos**

*Department of Informatics, University of the Aegean, Samos, Greece; Department of Electrical and Computer Engineering, Aristotle University of Thessaloniki, Thessaloniki, Greece*

**Abstract**— In recent years, there has been a lot of focus on how medical and health monitoring devices, clinical wearables, and remote sensors can contribute to better health for patients and more efficient healthcare systems. The fifth generation of mobile, cellular technologies, networks and solutions, promises high bandwidth, low latency and reliability are highly demanded in order to support the needs of healthcare, it is undeniable that what is needed is the transformation of the healthcare providers-patients relationship by integrating richmedia communications into medical care. A key challenge refers to the amount of this information and the way it is transmitted and processed. The different formats, rates and size of datasets (continuously increasing) raise the need for environments able to manage these datasets in an efficient way, while also incorporating and facilitating the requirements of approaches that aim at analyzing them (e.g. through machine learning and artificial intelligence mechanisms) towards efficient healthcare. To this end, network slicing has been envisioned as the promising solution on the heterogeneous medical data requirements and diverse constraints. In this paper we propose an innovative eHealth system powered by 5G network slicing, in order to meet the requirements for establishing an efficient network with high capacity. In this context, healthcare data collection and management inside isolated slices are considered, for creating holistic views of patients, increasing the awareness concerning patients' health condition that leads to the personalization of treatments and enhances health outcomes.

**Keywords**— 5G networks, network slicing, heterogeneous requirements, healthcare, Internet of Things, data collection, data visualization, data analysis

## I. INTRODUCTION

The rapid development of communication and sensing technologies introduces the way to the Internet of Things (IoT), and its capabilities. The IoT area is the connectivity of numerous physical objects, such as sensors, mobile phones, wearables, health monitoring devices, and network connectivity that allows these objects to communicate and exchange data. Due to the dissemination of IoT devices, their potency as “things” for health monitoring and users' personal activity tracking, has become tremendous. Therefore, the strongest argument for the use of smartphones and IoT devices for data collection

in the healthcare domain, is the ease of acquisition of participants and scalability through simple software distribution [1]. According to the World Health Organization (WHO), leaders from United Nations agencies and global health partnerships, state that the need for more and better health data has become increasingly crucial [2]. Therefore, it is doubtless that the valid processing and of the data is based mainly on their accuracy, completeness, as well as reliability transfer through the network in combination with the performance of their analysis inside it. Although the amount of the available healthcare data will rise to approximately 25,000 petabytes by the year 2020 [3], there is an immediate need for the IoT industry to adopt to the next generation 5G networks potentials [4]. Thus, to satisfy the requirements of the new emerging IoT services, 5G aims to achieve more enhanced circulation of the exchanged data than the 4G LTE standard, in terms of speed and quantity, whilst escalating the support of connected devices up to 10-100 times, reducing their latency by 5 times at the same time [56]. However, looking forward to 2020, based on [7], there is no way that electronic medical records are not running primarily in the cloud and all medical information have to be instantly accessible. Henceforth, moving from cloud computing to the fully virtualized world, 5G represents a completely new way for accomplishing digital networking and upgrading the healthcare experiences, by delivering a holistic personalized view of the patients anytime and anywhere. 5G networks offer three types of services from enhanced mobile broadband (eMBB) with bandwidth-consuming and throughput-driving requirements to new services such as ultra-reliable low latency service (URLLC) and massive machine-type communications (mMTC) [8]. Thus, 5G networks aim to meet various Quality of Service (QoS) requirements, in different application scenarios (e.g. in terms of data transmission rate and latency), by offering full connection to all “things” [9]. At the same time, the everincreasing traffic demand is pushing network operators to detect new cost-efficient solutions toward the deployment of future 5G mobile networks. In this context, network slicing is a promising paradigm, yet realizing it is not without challenges. However, apart from this challenge additional problems remain, concerning the transmission of health data, as healthcare organizations or individual doctors are inundated with existing sets of data and information. On top of this, clean and engaging visualization is of high importance as it can make it much easier for a clinician to absorb information and use it appropriately. Healthcare organizations face unique challenges when implementing virtualization as part of their health Information Technology (IT) infrastructure. Consequently, healthcare data transmission, and data management are very challenging research topics in the field of healthcare.

To address the aforementioned challenges, an end-to-end eHealth system powered by 5G network slices is presented. Dynamic 5G network slice allocation is considered for enhancing the quality of the processes, analysis and visualization of the health data, taking into consideration possible conflicting requirements. The approach is evaluated through the development of an innovative mobile health application that dynamically collects indoor and outdoor

location healthcare data directly from patients who are registered and associated with specific health conditions. Furthermore, a website is also created that offers immediate access to the patients' health records, thus enabling an easy and fast extraction of the corresponding conclusions, while the creation of medical patterns occurs, based on the visualization of the analyzed data. The proposed 5G oriented eHealth System, will be a "substantial enabler" of a new era of personalized healthcare by providing organizations with the ability to leverage large amounts of patient-specific data they can use to develop predictive analytics.

The rest of this paper is organized as follows. Section II presents the state of the art regarding data transmission and 5G network slicing. Also, it introduces how this concept can benefit devices and data heterogeneity in the healthcare domain. Section III describes the proposed system of the health data collection, analysis and visualization, through an innovative 5G network architecture, while Section IV

presents a use case in which we evaluated our proposed approach. Finally, Section V analyzes our conclusions and future goals.

## II. MOTIVATION AND RELATED WORK

While many things on the road to 5G are uncertain, it is easy to envision the emergence of new and innovative use cases. This new technology allows a significantly higher data capacity and extremely fast response times, opening up completely new potential applications for a fully connected society. Especially in the healthcare domain, this constitutes a prerequisite, as faster and more accurate results are needed. Consequently, the industry is facing a new wave of digitalization, referred as Healthcare 4.0 [10]. Healthcare 4.0 is a vision of care delivery that is distributed and patientcentered, and there is already evidence of a shift towards virtualization and individualization of care. Virtualization in the healthcare domain comes with the emergence of next generation mobile network strategies (5G) as foundation, in order to complete the transition to personalized care [11]. The delivery of such virtualized care needs to be executed in real time and based on streaming data, which can be delivered anywhere, anyhow and at any time. Thus, 5G will be a catalyst to trigger innovation of new products and services in the healthcare domain, by integrating networking, computing and storage resources into one unified infrastructure.

As the 5G-PPP emphasized in [12], the new 5G network should facilitate the integration with the service layer and enable an effective network resource negotiation (i.e. QoS, latency, speed, reliability). Especially in the healthcare domain, various researches have been conducted trying to cover the different aspects of 5G. The authors in [13], built the case that 5G wireless technology, along with concomitant emerging technologies (such as IoT, big data, artificial intelligence and machine learning), will transform global healthcare systems in the near future. They also stated that these technologies together can finally crack a dysfunctional healthcare system that has largely been impervious to technological innovations. Furthermore, the authors in [14] presented recent research linking the growing mobile health (mHealth) field with the need for 5G and

machine-to-machine technologies. They explored the multiple benefits that these emerging technologies could offer to broadly expand mHealth solutions. Worth mentioned is the work in [15], where the authors introduced a novel 5G system architecture for healthcare system. The proposed system exploited the Transparent Interconnection of Lots of Links (TRILL) protocol for mobility management and data packet delivery. Additional research included in [16], where the authors introduced systems of wearable or implantable medical devices, and sensor systems for monitoring and transmitting physiological recorded signals, within a 5G infrastructure. Moreover, in [17] a potential 5G network and machine-to-machine communication was presented for developing and evolving mobile health applications. It is also worth mentioning that an initial research of this paper is also made in [18], where the authors proposed an IoT-Oriented architecture that enables the facilitation of concurrent IoT applications and services with diverse requirements based on dynamic 5G slices allocation. In detail, it introduces a dynamic slice manager that allows an automatic selection of customized network slices while providing optimized solutions for different IoT applications.

Software Defined and 5G Networks - a combination of Software Defined Networking (SDN) and Network Function Virtualization (NFV), is a significant area that tends to make IoT services and applications more flexible. 5G will allow upcoming devices to be smarter, with more bandwidth and real time data transfer. NFV decouples network functions from the underlying hardware and centralizes them at network servers, making the network architecture highly flexible from quick and adaptive reconfiguration [19]. Such network functions could be virtualized IoT services for any kind of diverse areas, especially for healthcare. The diversity and the advanced needs of those services could be easily managed through the transformation to NFVs and the deployment in a Software Defined environment. What is more, 5G networks are expected to be able to satisfy users' different QoS requirements. For that reason, network slicing is a promising technology for 5G networks to provide services tailored for users' specific QoS demands. Due to the diversity of 5G application scenarios, new mobility management schemes are greatly needed to guarantee seamless handover in networkslicing-based 5G systems. For that purpose, the authors in [20] introduced a logical architecture for network-slicingbased 5G systems and presented a scheme for managing mobility between different access networks, as well as a joint power and subchannel allocation scheme in spectrum-sharing two-tier systems based on network slicing, where both the cotier interference and the cross-tier interference were considered. Furthermore, while 5G network is considered as a key enabler in meeting continuously increasing demands for the future IoT services, the authors in [21] proposed an efficient and secure service-oriented authentication framework supporting network slicing and fog computing for 5G-enabled IoT services. What is more, a work worth mentioned is the one presented in [22]. In this paper, the recent standards effort on network slicing for IoT in various standards bodies such as 3GPP, NGMN, IETF, ETSI, and M2M, were presented. At the same time, they proposed a novel Edge Computing architecture customizing required network resources at the edge cloud, as close to users as

possible, to minimize network signaling overhead in providing optimal IoT services.

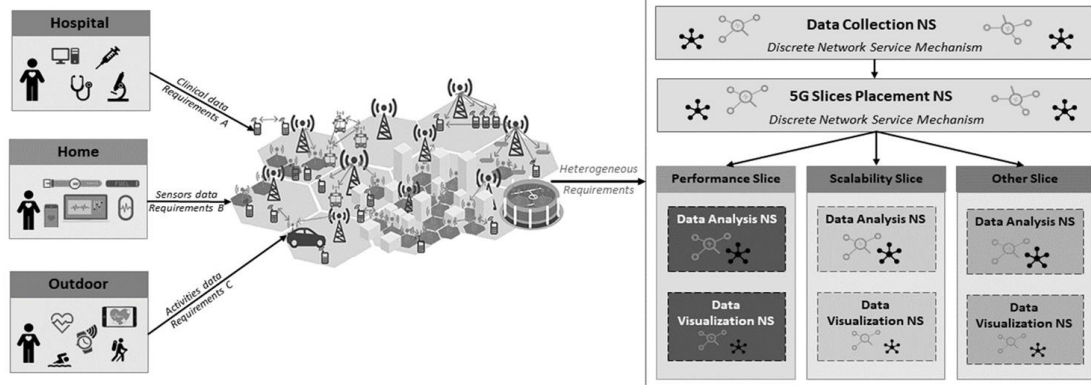


Fig. 1. Architecture of the proposed eHealth system powered by 5G slices

### III. PROPOSED APPROACH

In this paper, an innovative eHealth system is proposed for collecting heterogeneous medical data from a variety of medical devices (with diverse requirements) that are connected through a 5G network, as initially introduced in [23]. In essence, this mechanism follows an IoT-oriented architecture that aims to dynamically provision 5G slices, with respect to concurrent medical devices, with diverse requirements. Taking this into consideration, the proposed mechanism introduces various sub-mechanisms that aim to collect, analyze, as well as visualize all the devices' gathered data, following five different stages, as depicted in Figure 1. In more details, initially the IoT devices are discovered and connected to the mechanism through the provided 5G Radio Access Network (RAN) [24], followed by the collection of their data, in combination with the diverse requirements that all these devices may have. To this end, it should be mentioned that each one of these actions, is undertaken by a separate Network Services (NS) [25]. Sequentially, based upon both the data and the requirements that were captured, different 5G network slices are created for serving their management needs. As soon as these slices are successfully placed and deployed in the infrastructure, the analysis of those data takes place, implementing some specific machine learning techniques upon them, followed by the visualization of the results, which becomes in a very ultra-reliable way, due to the fact that it makes use of the 5G network slices.

#### A. 5G Connectivity

The architecture of the used 5G Network consists of two major steps related to the 5G communication and integration. Initially, the collection of the data takes place at high reliable edge-nodes, in order to allow the connection of the physical world (i.e. biological system) and the virtual world (i.e. 5G infrastructure). In order to achieve this, the deployment of an edge node in each medical device is being connected through a 5G RAN, enabling finally the analysis of the information inside the 5G Platform through the appropriate integration of different Virtual Network Functions (VNFs) [26]. In more details, identification of the available heterogeneous IoT medical devices takes place, through the established 5G RAN communication network. Due to the diverse and extreme requirements of the healthcare data, as well as the eHealth services, the 5G RAN is designed to operate in a

wide range of spectrum bands, with diverse characteristics, such as channel bandwidth and propagation conditions. The

challenge in 5G RANs is how to dynamically assign the foreseen wide range of services with diverse requirements to the many spectrum bands, usage types, and radio resources. Therefore, the proposed approach comes to resolve this challenge by using the Radio Access Network as a Service (RANaaS) [27], by partially centralizing the functionalities of the RAN depending on the actual needs, as well as the network characteristics, being able to handle huge amounts of data, in high-speed with low-cost, providing on-demand resource provisioning delay-aware storage, and high network capacity wherever and whenever needed. At this point it should be mentioned that we assume that all the data management mechanisms that are provided (i.e. data collection, slicing placement, data analysis, etc.) are constructed in the form of VNFs and NSs. This transformation is a prerequisite for the efficient operation of the platform, providing it with quite flexibility, cost-efficiency, and scalability, being able to be virtualized in different eHealth systems, running in different entities (i.e. hospitals, health clinics, etc.).

#### B. Data Collection

In the second stage, as soon as all the devices have been successfully connected to the system, the collection of the IoT devices' data and diverse requirements occurs. In more details, the Data Collection mechanism is responsible for collecting all the requirements by the different connected medical devices, as well as their heterogeneous health data. A device can be characterized by its functionalities or by its features. Thus, as an IoT device may be connected to the network (using wireless communications directly or indirectly through a smart phone) or not, we assume that all of our medical devices and smartphones are connected to the internet, through the 5G RAN. However, this information is not sufficient enough for our mechanism, as especially being in the healthcare industry means that even after collecting the enormous amounts of data, their aggregation is still needed. In addition to capturing so much healthcare data, health systems also need to analyze the healthcare data for many different needs, such as quality improvement, operations, research, and financial analytics. Thus, the Data Collection mechanism is also responsible for a) identifying possible conflicting requirements, and b) resolving those conflicts, by providing an optimal-aggregated result.

Therefore, this mechanism intends to resolve conflicts for heterogeneous requirements of different medical devices and parallel health data, taking into consideration the multi-objective optimization techniques and requirements engineering. For that purpose, the mechanism provides a 5G specific language, in order to gather the necessary requirements aligned with the International Telecommunication Union (ITU) requirements and 5G PPP KPIs [28], which can easily identify conflicts and inconsistencies. In that way, all the diverse IoT/health needs will be expressed in a common way – in terms of recourse requirements at least. To this end, it should be mentioned that all the actions of the Data Collection mechanism are undertaken by a discrete NS. Moreover, it should be noted that the gathered data come from different entities and systems, referring that are coming either from a) medical devices that are used by the patients for their in-home monitoring, or b) medical devices, EHRs, PHRs that are used by the patients and the healthcare professionals in medical laboratories for keeping patients' measurements, or c) medical devices, EHRs, PHRs that are used by the patients and the healthcare professionals in hospitals for recording and keeping patients' measurements, or finally d) medical devices that are used by the patients for their outdoor activities.

### C. Network Slices Placement

In the third stage, the 5G Network Slices Placement mechanism takes place, whose starting point for its proposed feasibility analysis is the output of the Data Collection mechanism. In more details, during the 5G Network Slices Placement mechanism, an end-to-end optimal deployment planning starts. Taking into consideration the available infrastructure recourses and the current situation of the network (i.e. active users, connected IoT devices, etc.), the implemented feasibility analysis decides whether the requested resource demands are achievable or not. In other words, through feasibility analysis it is automatically decided if the heterogeneous requirements are feasible, in order to deploy the necessary NS into a network slice. Thus, this part of the 5G Network Slices Placement mechanism ensures that the provision of the resources, their management and their orchestration are feasible for their concurrent use in the corresponding 5G slices. Once it is ensured that it is feasible for the infrastructure to support the defined requirements, the dynamic slice enabling part takes place, in order to achieve optimal recourse placement. The main concern of this part is to support the dynamic provisioning of 5G network slices using the aggregated and feasible requirements coming from the concurrent medical devices, EHRs, PHRs, etc. For that reason, in this part, the mechanism automatically analyzes the requirements as well as the available infrastructure resources, and then decides upon the most appropriate ones. The most appropriate deployment should achieve the best balance between system performance, QoS, and cost. Furthermore, unlike fixed network slices that can be scaled up by adding more hardware resources, radio access network slicing can quickly run into a physical constraint of the limited availability of spectrum. For this reason, the dynamic slice enabling part of the 5G Network Slices Placement mechanism, also applies network slicing from the mobile network operator's

(MNO's) perspective. Therefore, the compensation between flexible and static resource assignments is properly managed, considering the heterogeneous requirements coming from a diversity of IoT devices and health data.

### D. Data Analysis

In the fourth stage, the Data Analysis mechanism takes place, which is responsible for performing the required data analysis upon the gathered data. For this reason, this mechanism takes as an input all the devices' gathered data and analyzes them, using the K-means clustering algorithm [29]. In more details, the algorithm takes as an input health data from the acquired datasets, which involve different patients' health condition, the treatment that they follow, as well as their activity status. The algorithm compares these data with equivalent data from other patients who had similar health disorders. Sequentially, based on the health improvement or deterioration of previous users, it estimates the possibility of similar lifestyle and treatment. It is important to be pointed that we have set a confidence rate concerning user activity at 75%. As a result, the activity data of the patients are stored and analyzed only if it is ensured that user actually do this kind of activity with confidence rate 75% or higher. Afterwards, a machine learning classifier is trained based upon the patients' activities, using the periodic unlabeled accelerometer data that are gathered from the patients' IoT devices. More specifically, each device records accelerometer data for a time period (e.g. 24 hours) for each specific patient, computing different features (e.g. statistics) of these data, while afterwards it uses these features that are given as input parameters to the classifier model. Thus, the latter splits up the corresponding classes (e.g. walking, running classes) based on the input, in order to finally predict possible treatments of the patients. As a result, we consider two different perspectives of clinical decision support: a) evidence-based medicine and b) diagnosis support. Evidencebased medicine is driven by insights extracted from health data (mostly diagnosis, procedure and treatment) combined with a knowledge base with similar cases and used to find the most fitting treatment for each patient as well as to predict and avoid possible exacerbation, complication and readmission risks. Diagnosis support, in turn, processes symptoms and patient history details to suggest possible conditions and procedures to confirm the disease, which assists in achieving timely treatment, balanced length of stay and positive health outcomes.

### E. Data Visualization

Finally, in the fifth stage, the Data Visualization mechanism occurs, which makes it much easier for the clinicians to absorb their patients' information and use it appropriately. For that reason, the collected data should be transformed into a comprehensible form in order to offer to the clinicians the ability to gain insights concerning their patients' health patterns. Therefore, various useful data presentation and visual analytics techniques are considered, such as the charts that use proper proportions to illustrate contrasting figures, and correct labeling of information to reduce potential confusion. Examples of data visualizations include heat maps, bar charts, pie charts, scatterplots, and histograms, all of which have their own specific uses to illustrate concepts and information. Convolved flowcharts

cramped or overlapping text, and low-quality graphics may frustrate and annoy recipients, leading them to ignore or misinterpret data. Henceforth, it becomes clear that high-quality visual analytics techniques are essential to handle complex information in a complex world, as they deal with the datasets that are growing rapidly in capacity and complexity. The Data Visualization mechanism considers Apache Zeppelin as a key tool [30]. More specifically, Zeppelin is a Web-based notebook that enables data-driven, interactive data analytics, and collaborative documents. Moreover, it supports various languages via Zeppelin language interpreters, as for example Python, Scala, Hive, SparkSQL, while it provides built-in Apache Spark integration. Therefore, through the provided health data visualization, doctors gain access to their patients' data through charts, which associate each patient's location, activity status, and health condition during the desired time period. More precisely, the main information is concerned around a) indoor/outdoor location tracking, b) outdoor activity tracking, and c) health statistics based on measurements. Henceforth, the provided graphs aim to show how outdoor activities can affect positively or negatively the patients' health progress and which outdoor activity program should each patient to follow in order to improve her health condition. Moreover, in the Data Visualization mechanism are provided additional goal fulfillment charts, which depict in a colored ring to which degree the personal goal of a user is achieved, by combining time series data and the appraisal of these data in one chart.

#### IV. CASE STUDY

In our approach, "Dr. Pocket", an innovative mobile application for collection of health-related data from hospital, homes and outdoor medical devices, is introduced, based upon the proposed eHealth system. To begin with, the collection of both health and location data takes place, through a mobile application, currently developed for Android devices, where patients are registered using their unique credentials. Once a patient is logged in, the application starts tracking patient's indoor or outdoor location and collects medical and activity data, taking into consideration the personalized lifestyle. Indoor location is tracked by iBeacons [31], small Bluetooth devices, where the application can recognize whether a patient is in or out of the house using the device's GPS. In our scenario, three iBeacon Bluetooth Low Energy BLE 4.0 Proximity Devices were used. Furthermore, during the whole process, the medical devices transmit healthcare data, for example blood pressure and oxygen level. Moreover, it is important to be pointed that the application supports patients that belong to "Special Categories" and need medical attention for specific periods of their lives. For example, Dr. Pocket gives the opportunity to women to keep record of their health patterns during their pregnancy, and at the same time to their doctors to keep up constantly with their health condition. Every woman has the opportunity to be absolutely informed about the progress of her pregnancy and doctors have the ability to gain insights into the exact health patterns of the expectant mother. The interface of the application is depicted in Figure 2.

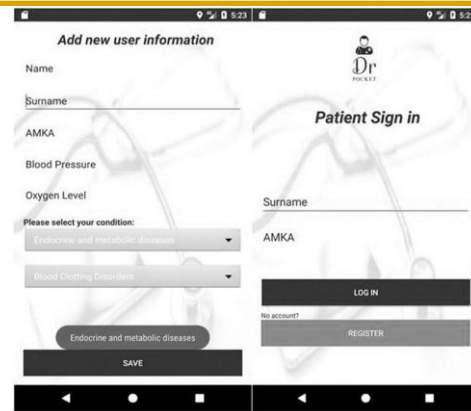


Fig. 2. Mobile application for data collection

It should be pointed out that, all the data are transmitted through a high reliable 5G tested infrastructure. As soon as the data are collected from the application, the feasibility analysis is taking place in order to define the appropriate network slices for the concurrent diverse requirements, coming from heterogeneous sources. Once the slices have been placed and all the network resources have been appropriately separated, it is time to analyze the healthcare data and visualize them through a web application. The latter (i.e. data analysis and data visualization) is taking place in form of NSs into the corresponding network slices. Finally, once the data have been analyzed, doctors can acquire online access to them through a "Doctor Web Application" in form of graphs and/or pies, as presented in Figure 3 and Figure 4.

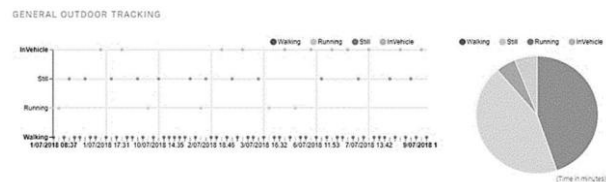


Fig.3 General outdoor tracking graph

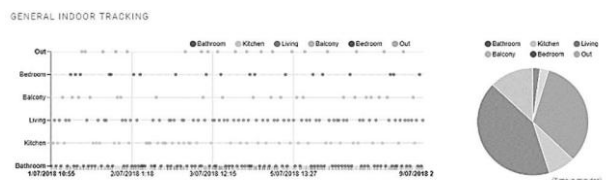


Fig.4 General indoor tracking graph

The proposed system was evaluated using existing data that were collected through the implemented mobile application. The application was tested to 20 users for 10 days, in order to produce a sufficient number of results, and conclude to some health patterns. The data that were concentrated in the end of the 10 days period were subjected to further analysis and visualized with diagrams. The graphs illustrate indicative results which were produced using our proposed approach and associate three recorded values: a) patients' location, b) activity and health status and c) time.

#### V. CONCLUSIONS

In this paper, we have studied the challenging topic of health data collection and analysis from heterogeneous IoT medical devices of different types through 5G networks. The

proposed approach enables the facilitation of concurrent IoT medical devices and smartphones with diverse requirements based on dynamic 5G slices allocation. The data are becoming immediately available in an ultra-reliable 5G network infrastructure, based on runtime recourse allocation through network slicing. Therefore, the proposed approach combine core, innovative technologies that are crucial in the healthcare domain, for delivering results of high-reliability and efficiency. In order to evaluate the proposed eHealth system, a mobile application among with a management web application were developed. The considered health data are coming from a variety of resources, such as iBeacons, are transmitted from the mobile application through 5G network and transform them into a common format, in order to be comprehensible by doctors while they are analyzed and visualized in a web application.

For the future, we envision a holistic architecture which allows the cleaning and interoperability of the health data prior to the analysis and visualization. In addition, there is a need for deeper investigation in real-time slicing adoption based on Quality of Experience (QoE) parameters extracted from the users, enabling runtime adaptation across all levels of the architecture. Finally, the enrichment of the mobile application it is also anticipated, considering the ability to interact with the patients in more ways, examining the seminal work on the Internet of Nano Things [32].

#### ACKNOWLEDGMENT

This work has been partially supported by the 5GTANGO project, funded by the European Commission under Grant number H2020ICT-2016-2 761493 through the Horizon 2020 and 5G-PPP programs (<http://5gtango.eu>). Moreover, A. Mavrogiorgou and A. Kiourtis would like to acknowledge the financial support from the “Hellenic Foundation for Research & Innovations (HFRI)”.

#### REFERENCES

- [1] “Using GPS Technology for Demand Data Collection”, Available at: [https://www.sutp.org/files/contents/documents/resources/B\\_Technical-Documents/GIZ\\_SUTP\\_TD17\\_GPS\\_Tracking\\_EN.pdf](https://www.sutp.org/files/contents/documents/resources/B_Technical-Documents/GIZ_SUTP_TD17_GPS_Tracking_EN.pdf)
- [2] “WHO|A global commitment to improve health data.”, Available at: <http://www.who.int/mediacentre/commentaries/improving-healthdata/en/>
- [3] J. Sun, C.K. Reddy, “Big Data Analytics for Healthcare,” 19th International Conference on Knowledge Discovery and Data Mining, pp. 1525-1525, 2013.
- [4] C. Vallati, A. Viridis, E. Mingozzi and G. Stea, “Mobile-Edge Computing Come Home Connecting things in future smart homes using LTE device-to-device communications”, IEEE Consumer Electronics Magazine, vol. 5, no. 4, pp. 77-83, 2016.
- [5] J. Ni, X. Lin and X. S. Shen, “Efficient and secure service-oriented authentication supporting network slicing for 5G-enabled IoT”, IEEE Journal on Selected Areas in Communications, vol. 36, no. 3, pp. 644657, 2018.
- [6] X. Shen, “Device-to-device communication in 5G cellular networks”, IEEE Network, vol. 29, no. 2, pp. 2–3, 2015.
- [7] “Gadgets Like Fitbit Are Remaking How Doctors Treat You”, Available at: <https://www.wired.com/2014/03/internet-things-health/>
- [8] R. Li et al., “Intelligent 5G: when cellular networks meet artificial intelligence”, IEEE Wireless Communications, vol. 24, no. 5, pp. 175183, 2017.
- [9] M. R. Palattella et al., “Internet of Things in the 5G Era: Enablers, Architecture, and Business Models”, IEEE Journal on Selected Areas in Communications, vol. 34, no. 3, pp. 510-527, 2016.
- [10] “Healthcare 4.0: A New Way Of Life?”, Available at: <http://www.vph-institute.org/news/healthcare-4-0-a-new-way-of-life.html>
- [11] “A new Generation of eHealth Systems Powered by 5G”, Available at: <http://www.wwrff.ch/files/wwrff/content/files/publications/outlook/Outlook17.pdf>
- [12] “5G on eHealth”, Available at: <https://5g-ppp.eu/wpcontent/uploads/2016/02/5G-PPP-White-Paper-on-eHealth-VerticalSector.pdf>
- [13] S. Latif, J.Qadir, S. Farooq, and M.A. Imran, “How 5G wireless (and concomitant technologies) will revolutionize healthcare?”, Future Internet, vol. 9, no. 4, pp. 93, 2017.
- [14] W. D. de Mattos and P. R. L. Gondim, “M-Health Solutions Using 5G Networks and M2M Communications”, IT Professional, vol. 18, no. 3, pp. 24-29, 2016.
- [15] S. Din, A. Paul, A. Ahmad, and S. Rho, “Emerging mobile communication technologies for healthcare system in 5G network.”, 14th International Conference on Pervasive Intelligence and Computing, pp. 47-54, 2016.
- [16] Oleshchuk, V., and Fensli, R., “Remote Patient Monitoring Within a Future 5G Infrastructure”, in Wireless Personal Communications Journal, vol. 57, no. 3, pp. 431-439, 2011
- [17] W. Mattos, and P. Gondim, “M-Health Solutions Using 5G Networks and M2M Communications”, in IT Professional, vol.18, no.3 pp. 24-29, 2016
- [18] E. Kapassa, M. Touloupou, P. Stavrianos, D. Kyriazis, “Dynamic 5G Slices for IoT applications with diverse requirements”, IEEE Fifth International Conference on Internet of Things: Systems, Management and Security, pp. 195-199, 2018.
- [19] F. Akyildiz, SC Lin, P. Wang, “Wireless software-defined networks (W-SDNs) and network function virtualization (NFV) for 5G cellular systems: An overview and qualitative evaluation”, Computer Networks, vol. 93, p. 66-79, 2015.
- [20] H. Zhang, N. Liu, X. Chu, K. Long, A. H. Aghvami, and V.C. Leung, “Network slicing based 5G and future mobile networks: mobility, resource management, and challenges.” IEEE Communications Magazine, vol. 55, no.8, pp.138-145, 2017.
- [21] J. Ni, X. Lin, and X. Shen, “Efficient and Secure Service-Oriented Authentication Supporting Network Slicing for 5G-Enabled IoT.” IEEE Journal on Selected Areas in Communications, vol. 36, no. 3, pp. 644-657, 2018.
- [22] S. Husain, A. Kunz, A. Prasad, K. Samdanis, and J. Song, “Mobile edge computing with network resource slicing for Internet-of-Things.”IEEE 4th World Forum on Internet of Things, pp. 1-6, 2018.
- [23] A. Mavrogiorgou et al., “The Road to the Future of Healthcare: Transmitting Interoperable Healthcare Data Through a 5G Based Communication Platform”, European, Mediterranean, and Middle Eastern Conference on Information Systems. Springer, Cham, pp. 383401, 2018.
- [24] M. Dighriri, G.M. Lee, T. Baker, “Big Data Environment for Smart Healthcare Applications Over 5G Mobile Network”, Applications of Big Data Analytics. Springer, Cham, pp. 1-29, 2018.
- [25] S. Van Rossem, W. Tavernier, D. Colle, M. Pickavet and P. Demeester, “Introducing Development Features for Virtualized Network Services”, IEEE Communications Magazine, vol. 56, no. 8, pp. 184-192, 2018.
- [26] Virtual Network Functions (VNF), Available at: <https://searchsdn.techtarget.com/definition/virtual-network-functions>
- [27] L. Ferreira, et al., “An architecture to offer cloud-based radio access network as a service.”, IEEE European Conference on Networks and Communications, pp. 1-5, 2014.
- [28] “D2.6Final report on programme progress and KPIs”, Available at: [https://5g-ppp.eu/wp-content/uploads/2017/10/Euro-5G-D2.6\\_Finalreport-on-programme-progress-and-KPIs.pdf](https://5g-ppp.eu/wp-content/uploads/2017/10/Euro-5G-D2.6_Finalreport-on-programme-progress-and-KPIs.pdf)

- [29] M. Vidal et al, "Implementation of the K-means algorithm on heterogeneous devices: a use case based on an industrial dataset", *Parallel Computing is Everywhere, serie: Advances in Parallel Computing*, vol. 32, pp. 642-651, 2018.
- [30] "Apache Zeppelin", Available at: <https://zeppelin.apache.org/>
- [31] "What is ibeacon? A guide to beacons", Available at: <http://www.ibeacon.com/what-is-ibeacon-a-guide-to-beacons/>
- [32] I. F. Akyildiz and J. M. Jomet, "The Internet of nano-things," in *IEEE Wireless Communications*, vol. 17, no. 6, pp. 58-63, December 2010 .