# An Experimental Testbed for Managing BAN Services at the Network Edge

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*Abstract*—**In this article we investigate how to support Intra- or On-Body Area Network (BAN) applications with strict delay requirements using a network edge architecture. By using an SDN/NFV approach integrated with a mobile system it is possible to transmit a multimedia stream generated inside the human body to a mobile device, which then relays the information to the cloud for further processing. Therefore, we propose an edge approach to reduce overheads, thus making the support of time-constrained medical applications feasible. The proposed architecture has been implemented in a real testbed and the performance of the system were assessed to prove its feasibility.**

## I. INTRODUCTION

Recently there has been an increasing interest in advanced healthcare systems [1], [2] that allow to monitor patient conditions and promptly react to alarms. Important aspects of these systems regard the *collection, analysis* and *storage* of the data. In fact, the information obtained using sensors and Body Area Networks (BANs) should be promptly processed and delivered to a medical center with the possibility to process the data close to the users to take rapid actions.

For what concerns *collection* of data generated by BANs, the use of RF waves raises doubts in terms of performance and health risks [3]–[6]. To this purpose, ultrasonic waves have been proposed as a safe and efficient alternative to RF for transmission of data on or inside the body, across tissues and organs, especially in case of implanted BANs (IBANs) [3].

The problem of *analyzing* and *processing* the information to be forwarded to the data center relies on the use of softwarized communication systems that allows to virtualize relevant application and network functions and move them closer to the user. This can be done by providing network and application services as Virtual Network Functions (VNFs) and Virtual Application Functions (VAF). These functions can be located on the edge, closer to the users who need them, so as to take responsive actions and guarantee efficient management of services [7].

In this paper we investigate on the feasibility of supporting advanced healthcare services through the combination of a ultrasonic BAN, a mobile network, and a hierarchical cloud. Such system combines different technologies, and can work efficiently in case of multimedia traffic trasmission, such as for esophagogastroduodenoscopy (EGD) videos.

The rest of this paper is organized as follows. In Section II we describe the architecture of the system. In Section III we describe our testbed, while the numerical results are shown in Section IV. Finally, in Section V some conclusions are drawn.

## II. ARCHITECTURE

In this section we present an integrated architecture that supports delay-constrained BAN applications. The architecture consists of two parts: the BAN subsystem and the Hierarchical Cloud subsystem.

### A. BAN subsystem

The BAN subsystem consists of a set of devices, each of them equipped with several sensors and one ultrasonic transducer [8]. The sensed information is sent through multiple hops to a gateway node (e.g. a smart watch) that can work as a gateway between the ultrasonic network and a Bluetooth or WiFi network, and which can communicate with a mobile phone/handheld device to deliver the collected information to a remote collection point.

At the link layer, a reliable medium access protocol will be used to manage medium access in case of multiple devices that share the same medium; to guarantee simplicity in the approach the use of carrier sense is to be preferred [9].

Data collected by the gateway node can be discarded, stored, or processed. Therefore, the BAN can be regarded as a generator of different flows of information. For each of these flows, different processing and storage resources should be provided. However, not all the data generated are informative, so some local pre-processing can be implemented to avoid congestion. Moreover, in particular applications, like for example telesurgery, it is important to minimize the transmission delay, because data are elaborated and processed out of the BAN. To this purpose, the use of an intelligent hierarchical cloud subsystem could be of help. In fact, as discussed in the following, the cloud can provide elaboration and processing functions, by means of VNFs, so that data generated by sensor devices located inside the body, can be elaborated and filtered without traversing the entire network to reach the remote medical center.

### B. Hierarchical Cloud subsystem

In future 5G networks a distributed framework to provide computing, storage, and networking resources to support enhanced and heterogeneous applications to customers and third-party service providers will be granted. This framework is denoted as *cloud*. Accordingly, the architecture of a typical 5G system is characterized by a hierarchy of clouds, starting from the Remote Cloud, going down to the Cloudlets (or Nano Clouds), the closest to the users [10], [11]. In particular,

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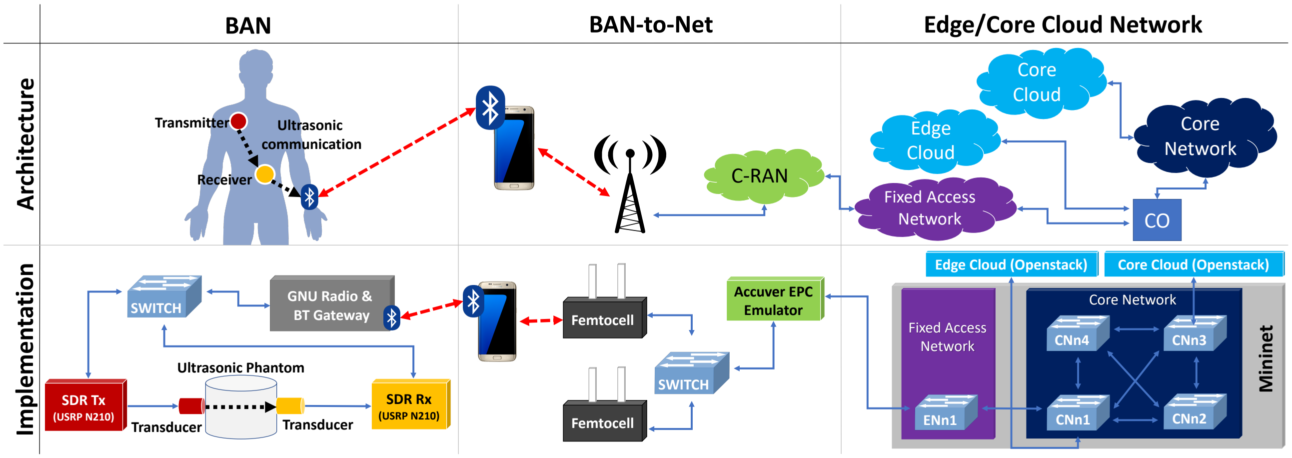

Fig. 1. System Architecture and Implementation.

the following levels can be distinguished: *a Remote Cloud*, which is a public cloud available on the Internet; *a Central Cloud*, which is deployed in a centrally located data center of the Telco Operator domain, hosting a large collection of processing, storage, networking, and other fundamental computing resources; *a Regional Cloud*, which is available in densely populated areas; *an Edge Cloud*, which is typically installed inside the Central Office (CO) serving for example a city area; *a Cloudlet or Nano Cloud*, which is a small-scale data center, aimed at supporting resource-intensive and interactive mobile applications very close to mobile users.

Depending on the type of processing to be performed, the data flow can travel from the BAN through the mobile network to be processed at different levels of the hierarchical cloud network in which virtual applications functions (VAFs), such as Image Filters, or VNFs, such as Firewalls, are running. Therefore, functions that need fast response times have to be stored and executed at the Edge Cloud.

In such a complex architecture, an *Orchestrator* is needed [12]. The Orchestrator is responsible for creating *network slices* [13] for the considered smart-health service, and controlling the available virtual resources and functions inside it. For this reason, the Orchestrator is connected to all the network and cloud components. The Core Cloud, the Edge Cloud and the C-RAN provide the network and computing resources, while the Core Network and the Fixed Access Network provide the SDN-based WAN transport network [14].

## III. TESTBED IMPLEMENTATION

The proposed testbed includes three different sub-parts: *BAN*, *BAN-to-Net*, and *Edge/Core Cloud Network*. These parts are shown in Fig. 1 and detailed below.

### A. BAN

The BAN part consists of two ultrasonic nodes that communicate across a phantom that emulates human tissues. The ultrasonic nodes are implemented using two Software Defined Radio (SDR) systems connected to two ultrasonic transducers. The ultrasonic transducers are capable of producing and receiving ultrasonic waves using a piezoelectric effect [8], [15]. The BAN part implementation is reported in Fig. 1.

The SDR system consists of a PC running a GNU Radio flow graph. The PC is connected to two ETTUS USRP N210 SDR devices [16] using Gigabit Ethernet and a switch. The flow graph follows a standard layered architecture. At the PHY layer we considered an OFDM modulation, as it guarantees good transmission performance thanks to the use of multiple carriers, as shown in [17]. At the MAC layer a CRC overhead of 4 bytes is added and node addressing is implemented. At the network layer, although both one hop or QoS-aware multihop communications can be supported [18], for worth of illustration, one hop communication has been considered. In order to increase the signal-to-noise ratio, the signals transmitted and received by the USRPs are sent to an amplification device.

Choosing the appropriate transducer for a BAN environment is the result of a tradeoff between size, operating frequency range, attenuation and directivity. This becomes relevant in particular in the scenario of implanted BANs. In fact, as shown in [19], an increase in the operating frequency range allows to decrease the size of the transducer and improve the directivity of the ultrasonic beam. However, increasing the operating frequency results in a higher signal attenuation. Moreover, the size of the transducers is also inversely proportional to the beam width. Based on the above considerations, a reasonable ultrasonic transmission range has been chosen around 5 MHz [17]. In our testbed, we used the Olympus V326-SU immersion transducers [20] which operate at 5 MHz.

To emulate human body features in a ultrasonic communication channel we used ultrasonic phantoms consisting of a cylinder of ballistic gel, 8 cm of height and 78,5 $cm^2$ of section. The ballistic gel is widely used to test the effects caused by the penetration of firearms bullets as it well emulates the human muscles for its viscosity and density [21].

### B. BAN-to-Net

In order to forward the collected data to the Internet we used the Bluetooth Adapter of our PC to transmit to an Android smartphone running a custom made application that works as gateway towards the Internet through a mobile network. The PC acts as Bluetooth PAN coordinator, advertising an RFCOMM service on port 22 and establishing a connection with the smartphone.

Finally, the application running on the smartphone based on the feedback coming from the Orchestrator will use the VNFs and/or VAFs available in the Hierarchical Cloud subsystem to perform the needed processing on data. In the proposed testbed, the mobile network includes two Qualcomm LTE Band3 femtocells, operating as eNodeB, and a PC running the Accuver XCore tool that emulates the Enhanced Packet Core (EPC) part of the LTE network. In this way, we can replicate an LTE network. Note that the use of an LTE network will be fundamental for next generation 5G systems, as provision of services to users will still mainly rely on LTE infrastructure.

The two femtocells are able to establish connections via the X2 interface. In this way handover can take place without the direct intervention of the network, and in particular the Mobility Management Entity (MME), which is only informed upon completion of the procedure. This allows us to have even greater reactivity and reduced handover time. Also the S1 type handover can be obtained, but only intra-MME. In this last case the serving femtocell, once received the data from the smartphone, will have to forward the handover request to the MME instead of the target femtocell.

### *C. Edge/Core Cloud Network*

In order to evaluate the impact of using a Hierarchical Cloud, we have chosen to use a simplified 2-level architecture consisting of an Edge Cloud and a Core Cloud. The Orchestrator is in charge of the placements of the VNF/VAF on these Clouds. When performing management tasks, the Orchestrator takes also into account the impact of having a core network between the two clouds. In our testbed, the Fixed Access Network and the Core Network are emulated by a PC running the Mininet network emulator, as detailed in Fig. 1. The switches emulated in this network make use of OpenVSwitch, a software compatible with the OpenFlow protocol, which allows to manage packet forwarding by inserting special rules in the switch forwarding tables.

The control part of the Mininet network uses OpenDayLight [22], which allows to realize an SDN Controller running on another PC. The core network implemented with Mininet is constituted by 4 virtual switches, connected according to a completely meshed network, using 10 Mbit/s links adding a random delay with an average value of about 15 ms and considering a background traffic to emulate the real traffic in a network. These switches represent the Central Office (CO) nodes of a TELCO network. The $ENn1$ node is an additional switch representing the node where the radio access network emulated with XCore is attached.

In our tests, a PC that implements the Edge Cloud is connected to the $CNn1$ Node, while the Core Cloud is implemented through a PC connected to the $CNn3$ Node. Both the above PCs have OPENSTACK installed.

TABLE I
INTRABODY COMMUNICATIONS PERFORMANCE WHEN USING OFDM

| Mod. | FEC | Subcar. No | Data Rate | Pkt Size | BER |
|---|---|---|---|---|---|
| BPSK | 1/2 | 52 | 1.04 kB/s | 104 B | 0.00057 |
| BPSK | 1/2 | 52 | 38.00 kB/s | 1024 B | 0.00273 |
| BPSK | 3/4 | 52 | 1.04 kB/s | 104 B | 0.04509 |
| BPSK | 3/4 | 52 | 38.00 kB/s | 1024 B | 0.04232 |
| QPSK | 1/2 | 52 | 1.04 kB/s | 104 B | 0.02005 |
| QPSK | 1/2 | 52 | 38.00 kB/s | 1024 B | 0.02373 |
| QPSK | 3/4 | 52 | 1.04 kB/s | 104 B | 0.13986 |
| QPSK | 3/4 | 52 | 38.00 kB/s | 1024 B | 0.14280 |
| 16QAM | 1/2 | 52 | 1.04 kB/s | 104 B | 0.45300 |
| 16QAM | 1/2 | 52 | 38.00 kB/s | 1024 B | 0.45427 |
| 16QAM | 3/4 | 52 | 1.04 kB/s | 104 B | 0.49884 |
| 16QAM | 3/4 | 52 | 38.00 kB/s | 1024 B | 0.49893 |

## IV. NUMERICAL RESULTS

In this section we report some numerical results obtained in our system implementation. In particular, we considered a medical application consisting of the transmission of an EGD video. The video (116 kbps, 30 fps, 720x480 pixels, H.264 High Profile) is transmitted in a single hop from the transmitter ultrasonic node, across a human body phantom, to the receiver ultrasonic node. Then this stream is forwarded using a Bluetooth connection, through the mobile network towards the fixed network. The Orchestrator decides the VNFs/VAFs placement and, through the OpenDayLight Controller, configures the SDN switches to steer the flow through the clouds where the required functions are running. VNFs/VAFs placement, either on the Edge or the Core Cloud, is decided by the Orchestrator by applying optimization policies that consider the network traffic/congestion conditions, as well as the application delay constraints.

As a preliminary step, we have estimated the maximum data rate achievable in the ultrasonic testbed. Due to the Ethernet connection between the USRP device and the PC running GNU Radio, the highest achievable sample rate without losing samples is 781 kSample/s; therefore, according to the Nyquist-Shannon sampling theorem, the maximum bandwidth for the system is 390 kHz. We then used a carrier at 5 MHz and employed OFDM technique with different modulations, data rates, and FEC rates, considering 52 subcarriers similarly to 802.11 OFDM PHY. As Table I shows, we can support a maximum data rate of 38 kB/s with a BER in the order of $10^{-3}$ by using BPSK modulation. BER performance can be improved by considering a lower data rate.

After that, we analyzed the contribution of the delay added at 3 different points in our testbed. In Fig. 2 we report the probability density function (pdf) of the transmission delay from the BAN to the gateway node. The average delay is around 24 ms but note that most of the delay introduced depends on the GNU Radio flow graph that implement the OFDM modulation and demodulation [23].

In Fig. 3 we report the pdf of delay to transmit data from the GNURadio/BT gateway to the mobile node. Observe that this delay is, with high probability, lower than 10 ms, thus contributing less than 50% to the overall delay experienced.

The second step of our analysis involves the BAN gateway

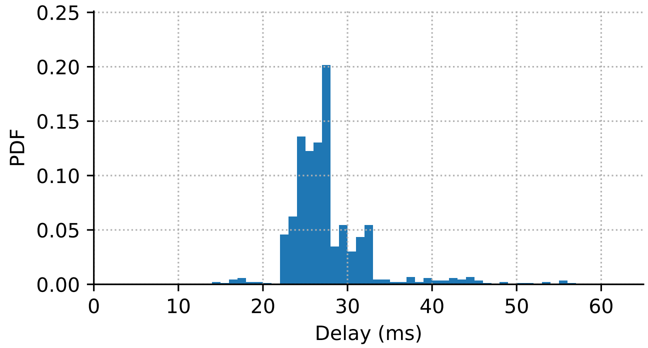

Fig. 2. Pdf of the transmission delay from the implanted sensor to the GNURadio/BT gateway node (BAN part of the testbed).

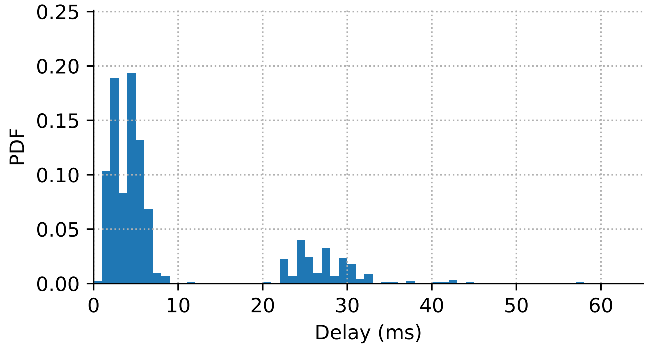

Fig. 3. Pdf of the transmission delay from the GNURadio/BT gateway to the mobile node (Ban-to-Net part of the testbed).

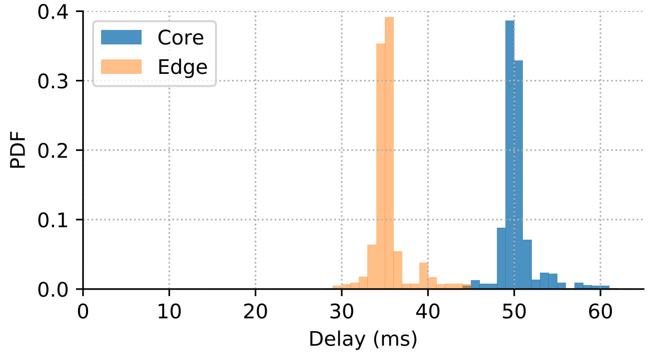

Fig. 4. Pdf of the transmission delay from the mobile node to the Edge Cloud and the Core Cloud (BAN-to-Net part of the testbed).

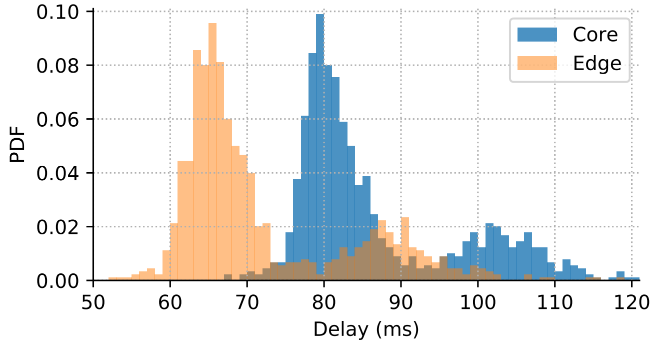

Fig. 5. Pdf of the overall transmission delay from the implanted sensor to the Edge Cloud and the Core Cloud.

communicating via Bluetooth with the smartphone. In this case the Bluetooth adapters of the PC where the gateway runs and the Bluetooth interface of the mobile phone allow a maximum data rate of 1 Mbit/s. In order to assess the performance on the system, we measured the transmission delay for sending the video stream. The measured delay are shown in Figure 3. In Fig. 5 we compare the transmission delay from the mobile node to the Edge Cloud when VNFs/VAFs are placed at the Edge with the case in which VNFs/VAFs are deployed in the Remote Cloud. We observe an increase in the delay of about 15 ms in the second case as a consequence of the network crossed. Note also that the ultrasonic technology contributes to about 50% of the end-to-end delay. Measures of the end-to-end delay have been collected using a simple TCP Server that collects the data sent by the BAN testbed and echoes them back to measure the round trip time.

In the above plots we are also taking into account the Bluetooth delay, partially originated by the design choices of commonly available Bluetooth devices that minimize energy consumption in spite of other metrics like jitter or delay [24].

Moreover, in the considered scenario, the use of an Android device introduces further delay related to the internal OS messaging system between the user interface and the threads.

Also spurious queues around 80-100 ms can appear, due to the significant multipath fading met upon using ultrasonic waves inside the body. The above pdf plots show that, in case of delay demanding applications, the impact of VAF/VNF positioning at the edge or in the core cloud is relevant as the delay linearly increases with the distance traveled in the edge/core cloud network. Accordingly, the Orchestrator should adopt appropriate techniques to tradeoff positioning of VAF/VNF functions, processing and/or computation requests, as well as balancing in network resource allocation.

## V. CONCLUSIONS

In this paper we have discussed an integrated system for advanced healthcare which relies on a combination of a ultrasonic BAN, a Bluetooth connection to a mobile network and a hierarchical cloud network for provision of medical services realized with virtual network and application functions. The system has been implemented in a testbed and used to preliminarily test the feasibility of the integrated approach to transmit multimedia data generated inside the human body to a remote medical center. Preprocessing and storage of these data are available by using an Orchestrator based on SDN/NFV approach.

Numerical results assess the feasibility of the approach while shading light on critical aspects of the system related, not only to Orchestrator choices, but also to the system generating data (high directivity of the transducers, latency due to software elaboration and network delay).

## ACKNOWLEDGMENTS

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