Rethinking the Design of Wearable Expert Systems: The Role of Network Infrastructures

Marco Savi, Fabio Sartori, Riccardo Melen
Department of Informatics, Systems and Communication, University of Milano-Bicocca, Milano, Italy
{marco.savi, fabio.sartori, riccardo.melen}@unimib.it

***Abstract*—The recent COVID-19 emergency has pointed out the importance of effective and efficient tools to support users in their day-by-day activities, ranging from health-related ones to studying, remote working and recreation. Indeed, wearables and modern network technologies, such as network slicing and SD-WAN, play a key role in this scenario, but existing applications should be rethought to be really useful in critical situations like the current pandemic. In this paper, we reflect about this topic, trying to design an innovative architectural framework where Wearable Expert Systems, IoT and network infrastructures are integrated to obtain the best level of performance.**

***Index Terms*—Wearable Expert Systems, Internet of Things, SD-WAN, Network Slicing.**

I. Introduction

In this short paper we present an ongoing research about the adoption of Wearable Expert Systems in the telehealth domain, inspired by the emergency due to COVID-19 pandemic. In order to understand the motivation of this paper, we will briefly summarize where we are nowadays.

First of all, Wearable Expert Systems (WES) [1] have been introduced as conceptual and computational tools for developing time-dependent decision support systems. The main rationale behind this proposal was the possibility for an expert system to dynamically exploit data detected locally by wearable devices, in order to update knowledge bases following the environment changes over time. In the WES paradigm the same set of data can be used to support different, possibly correlated decision making processes, according to different kinds of experts they are provided to.

Second, this approach has been adopted to implement innovative applications capable to support different roles involved in the treatment of chronic diseases, enabling the development of virtual communities, where people can share information and knowledge with peers based on their perceptions of data. The PERCIVAL platform [2] can provide recommendations to the user through the analysis of both quantitative and qualitative data about her/his physical and psychological conditions.

A third step of our research was the generalization of PERCIVAL principles to build up a framework for the design and implementation of general-purpose distributed applications interacting with wearable devices. To this aim, the Wearable Environment notion has been proposed [3], formalizing a set of Application Programming Interfaces (APIs), called *Wear-It*, that enable applications to interact with different kinds of Internet-of-Things (IoT) sensors hosted on different types of wearable devices.

Although the three steps above have been successfully accomplished, the COVID-19 pandemic has taught us that new efforts are necessary to improve usability, scalability and performance of our solutions. As highlighted in [4], *healthcare systems are making enormous efforts to adjust and mitigate the damage. These adaptation processes accelerate the use of health technologies that were on previously slow adoption paths, including telehealth. Disrupted healthcare systems and the need for physical distancing seem to open a window of opportunity for a broader exposure to telehealth solutions, many of which might have the potential to improve care long after the pandemic passes*. This means to rethink completely the way wearable technologies are employed in the design of such applications.

Here, we reflect on how the network infrastructure capabilities should be exploited to improve the performance of wearable environments in support of medical applications design, focusing on enhancements to the *network slicing* concept [5]. We choose as an example scenario *remote physiotherapy*, given that physiotherapy activities have been significantly compromised by social distance and lockdown measures, and could greatly benefit from an approach where WES make the best use of networking technologies.

The short paper is structured as follows: Section II introduces Wear-It and motivates the work, while Section III describes the proposed framework, components and workflow. Finally, Section IV concludes the work.

II. Motivation and Background

Fig. 1 shows the current status of wearable environment development [2][3], as introduced above. Sensors at the *data level* can be queried by Wear-It, exploiting a dedicated API. Such API is used by applications at the *WES level*, which can choose the most suitable sensors to execute their decision-making model while being sure that needed data will be available in the right format. In this way, accessing data is made transparent to applications by means of the Wear-It middleware, able to identify and query different kinds of wearable devices (in the figure, the heart-beat rate monitor PulseOn^{TM} is shown): currently, Android Wear and Bluetooth devices are supported.

The former implementation of Wear-It made very few assumptions about the network quality of service (QoS) capabilities, implicitly assuming a best-effort infrastructure providing "good enough" services. In the scenario we are

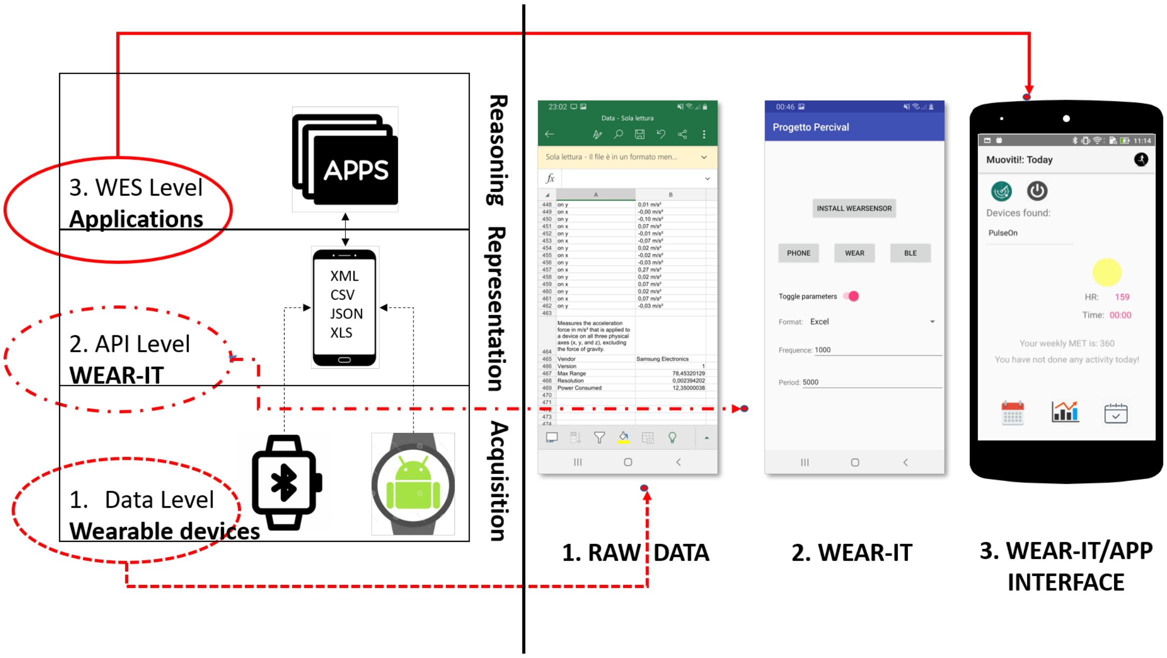

Fig. 1. On the left, a sketch of the current wearable environment architecture [3]; on the right, its implementation in the PERCIVAL [2] project.

considering at present, we depart from this simple-minded model of best-effort networking. We believe that network technologies should be considered by-design in order to improve the efficacy of information transfer. In particular, the employed network services shall be matched to the application requirements.

Network slicing [5] is an innovative networking concept, developed mainly under the 5G umbrella, for the automated creation of segregated virtual networks on a shared physical network infrastructure, by properly allocating its available resources. With network slicing, an infrastructure can be used to offer services with differentiated requirements (e.g. ultra-low latency and/or ultra-high availability services [6]) to a multitude of verticals. Nonetheless, such a concept is not confined to the domain of 5G networks; the creation of dynamic virtual networks/slices for guaranteed QoS tiers has also been investigated in IP/optical (multi-layer) networks [7][8] and in various Software-Defined Networking (SDN) approaches [9], including SD-WAN [10].

In our approach, network slicing is agnostic to the underlying network technology and thus suitable for heterogeneous networks[1]; in this way, a user can, in principle, negotiate with multiple wired, wireless and mobile providers the usage of services from one or more slices with the goal of gaining the most appropriate service guarantees for distributed applications such as telehealth. Looking at it differently, our model enriches current SD-WAN approaches providing a tighter relationship with application requirements.

[1]The terminology requires a bit of explanation. As a matter of fact, in our scenario we envision the existence of several (virtual and/or physical) networks accessible from the user premises (or mobile device); these are actually independent networks, possibly managed by different providers. However, as seen from the user perspective, they constitute a single, heterogeneous network.

III. Rethinking Wear-It: An Application-Network Holistic Approach

We illustrate our approach, based on the exploitation of networking technologies in the application design, by describing a *remote assistance framework*. In this framework, patients can be monitored through wearable sensors by healthcare professionals and remotely followed in real-time, being provided with useful feedback on their activity. As an example, as already anticipated, we consider the case of *remote physiotherapy*, where patients interact with their physiotherapist during their recovery sessions. We describe here the envisioned framework components and how the end-to-end service is created, with a tight interaction between the application domain (Wear-It, IoT Platform and Applications) and a network that provides slices with different QoS characteristics, possibly based on different technologies (e.g. FTTx, WiFi, 5G).

A. Framework components

The framework consists of a Distributed Application, the Patient's Wearable Environment and the Physiotherapist's Working Environment (Fig. 2).

1) Distributed Application: It is the front-end portion of the framework, enabling the interaction between patients and the physiotherapist. It is composed of two interacting components:

- **Patient's Application**: executed on the patient's Smartphone, it is used by the patient (i) to interact with the physiotherapist and (ii) to acquire data from sensors.
- **Physiotherapist's Application**: executed on the physiotherapist's Working Station, it is used by the physiotherapist (i) to monitor the patient's session and (ii) to interact with the IoT Platform for the remote management of the Patient's Wearable Environment.

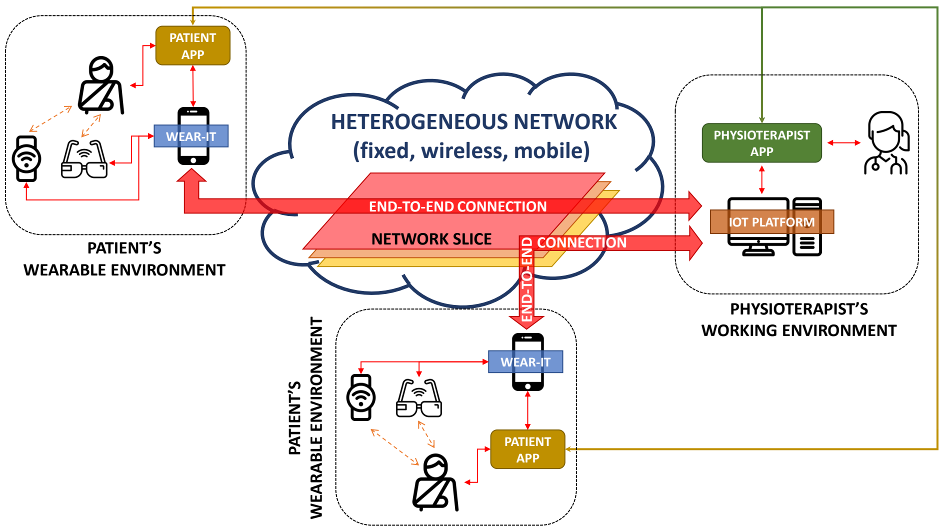

Fig. 2. High-Level view of the proposed remote assistance framework.

2) Patient's Wearable Environment: It is dynamically created when the physiotherapy session is about to start and hosts the Patient Application. It consists of:

- **Smartphone**: it is the data collection hub for the Wearable Devices and a data-generating device itself (through its built-in sensors, such as the accelerometer), being also equipped with heterogeneous connectivity capabilities.
- **Wearable Devices**: they connect to the Smartphone (potentially through different short-range communication technologies [3]) for the delivery of generated data.
- **Wear-It APIs**: they are implemented on the patient's Smartphone and are used by the Distributed Application in support of remote physiotherapy. They ease data acquisition from heterogeneous sensors, offering a middleware for a simple and intuitive creation and management of the Wearable Environment.

3) Physiotherapist's Working Environment: It is more static than the Patient's Wearable Environment, given the assumption that a physiotherapist follows many patients during each day. It is responsible for setting up the remote connectivity with patients and for interacting with their Wearable Environments. It consists of:

- **Working Station**: it is the computer used by the physiotherapist to carry on her/his work; it can collect remote data from Patient's Wearable Environments and is used to interact with them. It is also equipped with a *Network Module* with advanced *network connectivity* features, being able to autonomously negotiate with multiple fixed, wireless and mobile network providers the creation of *end-to-end (e2e) connections* with the patients' Smartphone, relying on the network slicing [5] concept.
- **IoT Platform**: it runs on the Working Station and supports Wear-It APIs, and is used by the Physiotherapist's Application for the remote management of the Wearable Environment (e.g. request for collection of specific data from the Wearable Devices, configuration of a Wearable Device, etc.). It also guarantees patients' data persistency.

B. Service management

To make remote assistance possible, an interaction between the Distributed Application and the heterogeneous network is needed in order to ensure an adequate QoS level in the communication between the involved components. Specifically, when a request for an e2e network connection is triggered by the Physiotherapist's Application, the usage of resources from one or more appropriate network slices must be automatically negotiated by the Working Station's Network Module and set up by the chosen network provider.

We report the high-level steps for enabling a QoS-guaranteed interaction between Patient's Wearable and Physiotherapist's Working Environments:

1) The physiotherapist executes and configures its Application to set up the Working Environment; she/he requests for an e2e connection towards the endpoint of the patient, requiring some guaranteed latency, availability and an appropriate level of security. This operation is carried out employing an extension of the present Wear-It APIs: our ongoing work deals with the enrichment of its primitives to embody vectors of QoS parameters.
2) The Working Station's Network Module autonomously requests the configuration of the end-to-end network resources that best match the requirements of the application, exploiting the services available from all the accessible fixed, wireless and mobile network slices. It then waits for a confirmation from the chosen provider(s).
3) Once an e2e connection has been established and both Patient and Physiotherapist's Applications have been notified, the network connection is used to make the patient's Smartphone and the physiotherapist's IoT Platform communicate in a reliable, secure and timely way. The exchanged data can then be used by the Distributed Application for remote physiotherapy purposes.
4) During the physiotherapy session, data acquisition and sensors' remote management can be easily controlled

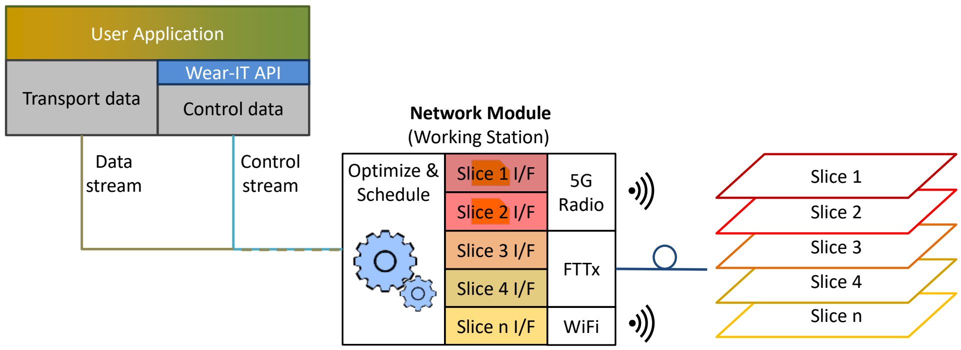

Fig. 3. End-to-end slice-based connectivity on heterogeneous networks.

through Wear-It APIs.

5) Once the session is over, the physiotherapist requires, through its Application, the e2e connection to be torn down. This request is passed to the network provider(s) by the Working Station's Network Module. The provider(s) deletes the connection(s), frees network slice(s) resources and notifies both Patient and Physiotherapist's Applications on the conclusion of the operation (possibly including billing information).

In the following, we provide more details on how the establishment of end-to-end connections is envisioned.

C. End-to-end connectivity setup

Fig. 3 shows how the Working Station's Network Module provisions the requested end-to-end connectivity (Step 3 above) using existing slices. Such module is equipped with a set of (pluggable) physical interfaces to different network types and/or providers offering slicing capabilities, and implements two different algorithms: an *Optimizer* and a *Scheduler*.

The Optimizer is in charge of choosing, among all the available mobile, fixed and wireless slices, the one(s) that can guarantee (alone or as a combination) the requirements of the end-to-end connection request that has to be set up, and for negotiating the access, also from a pricing perspective.

Instead, the Scheduler decides how to use the set of slices/services, whose access has been acquired by the Optimizer, for the transmission of each application-generated packet (related to both data, such as sensor measurements, and control) and for maintaining the desired level of quality of service. Such a Scheduler works in a very similar way to an SD-WAN scheduler [10], with the only difference that packets are conveyed on network slices that can provide various levels of service, and not just on best-effort connections.

It is clear that designing and implementing the Optimizer and Scheduler logic described above poses many different research and technological challenges that we have just started tackling. However, we believe that such a solution, where SD-WAN concepts are applied to network slicing, is promising, especially for the provisioning of end-to-end connectivity with strict QoS requirements (as it happens in the telehealth field).

IV. Conclusion and Future Work

This paper indicates how modern network technologies such as network slicing and SD-WAN can be exploited to improve the performance of wearable environments in collecting data to be elaborated for remote physiotherapy recommendations. This is especially important given the current COVID-19 outbreak, which has brought to the surface the fundamental importance of telehealth. Although the proposed scenario pertains to such domain, the approach can be generalized to several different application domains.

The proposed framework comes with many research challenges that need to be tackled and addressed. As starting point, our current and (short-term) future work is devoted to the extension of wearable environment APIs to include those QoS requirements (i.e., latency, reliability and security) that should be met by the network infrastructure.

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