Fog-to-cloud Computing (F2C): the key technology enabler for dependable e-health services deployment

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***Abstract* — Fog Computing recently came up as an extension of cloud computing to facilitate the development of IoT services with strong requirements in latency, security while minimizing the traffic load in the network. The stack of resources set by putting together fog and cloud premises has been recently coined as Fog-to-Cloud (F2C) computing, and has been positioned as an innovative computing paradigm best matching current and foreseen IoT services demands. This paper emphasizes the benefits F2C may bring to a particular health area, namely COPD, whose patients' quality of life intensely depends on the patients mobility. We argue that by enriching current breath assistance systems for COPD patients with F2C capacities, the patients may comfortably afford physical activities, therefore impacting on reducing not only patients deterioration but also the re-admission incidence rate IRR) with a clear impact on the health costs as well.**

Keywords—eHealth, cloud computing, Fog-to-cloud computing

I. Introduction

Nowadays, the whole society is continuously looking at science innovations as the door to new services and apps, with a strong impact on daily activities. Several technological advances can be blamed to be the seed for these services to arise. In particular we can mention cloud computing, in its different forms –IaaS, PaaS, SaaS– as one of the most disruptive innovations in the last decade. The main contribution brought by cloud computing refers to the capability to decouple some computing and storage capacities far from the device requiring these capacities. To that end, centralized systems, known as data centers are built, offering the requiring capacities to run the users' services demands.

Certainly, managing the infrastructure building the datacenters is not trivial, and many substantial issues remain yet unsolved, such as those referring to virtualization, virtual machines migration or security. Intimately associated to the cloud resources is the need for handling an enormous amount of data. In fact, this is one of the key drives for cloud computing to come up. Otherwise, why would we need large but far computing and storage capacities?. But why do we have this big data processing need?. We can easily answer this question looking at bot. First, there are several strategies fostering the need to release data for free utilization. This policy strongly affects some services since more data must be "consumed", hence requiring higher computing capacities. The second aspect comes from the "smartness" concept. Indeed, networks but also technology have sufficiently evolved to ease the deployment of end devices (located at the edge of the network) with capacities enough to both collecting data and usually processing the collected data thus becoming information ready for feeding services to be executed. This scenario adopts smart capacities as a commodity and empowers the development of new scenarios such as smart cities, smart transportation systems, smart homes, all as a whole setting the well-known Internet of Things (IoT). Indeed, IoT leverages the capacity devices at the edge have to collect data along with the wide and powerful cloud capacities to foster a new smart scenario for novel services to pop up, with particular focus on areas with strong societal impact, such as health or generating strong industrial interest such as manufacturing processes monitoring or systems tracking.

However, the proposed smart scenario is growing with no limit. What does this mean?, is this good or bad?. Surely, technology evolution is a non-stop area, so new devices are continuously generated with wider and more powerful capacities, hence collecting more and more data, what undoubtedly drives the need for raising up the required devices at cloud premises. On the other hand, new services are unstoppably proposed, more exigent on the required needs, for example in terms of network capacity, quality delivery, security or end-user latency. In other words, technology evolution and services generation are feeding each other in a growing spiral with no end. And, let's not forget the network. Nowadays, cloud and service providers consider the network as a commodity what, with no doubt, is stressing the traditional telecom companies, not used to stress their networks for a flat rate at the client side, hence with no direct return in their revenue account. Although the aim of this paper is not on the network side, it is worth noticing that processing at cloud premises when all data is collected at the edge will undoubtedly require strong conditions on the network.

Hence for many years, cloud computing has been the centralized capacity to support IoT services. However, linked to the services evolution, new requirements popped up, strongly stressing the cloud computing paradigm. Before going deep to this set of requirements we must keep an eye to the challenges yet open for cloud computing. Beyond security and network load aspects, a critical issue refers to the distance from the edge device requiring the service up to the cloud premises providing the required resources to run the service. This distance is strongly impacting on the end-user delay what unquestionably limits the perceived quality a user has when running interactive or real-time services with hard constraints in latency. With the aim of providing a solution for reducing the large delays brought by cloud computing, the fog computing paradigm has been recently proposed [1]. From a conceptual perspective the idea is very simple. Which is the problem to be solved?, high delays; why is this latency there?, long distance from the cloud to the edge; easy then, let's move the computing capacities close to the edge. Surely, this is technologically possible because of the high and rich capacities edge devices are endowed with. These capacities allow these devices to provide some of the resources required by some services very close to thee edge, hence reducing the observed latency. In short, fog computing is a good strategy to run interactive or dependable services, or any service requiring low Service Response Time (SRT).

Thus, the envisioned IoT scenario is built by a set of highly demanding services to be executed on a set of resources distributed either at cloud or fog premises. But, the technology evolution is never stopping and the presented scenario is apparently with no limit still enriched, as it was for fog computing to come up. More demanding services are being developed and even more significant new resources management policies are been sought. The current stage is similar to the one we all lived many decades ago in the computing arena, which turned into the current multicore processor development strategy. Indeed, the main innovative concept refers to a scenario where end users may offer their resources for others to be used, hence setting a resource scenario collecting many and many resources with many different characteristics (from a simple sensor collecting data to a "aggregation" point storing and processing this data). This new collaborative scenario based on resource sharing policies is defined in [2] as the next evolution in cloud, referred to as Fog-to-cloud computing (F2C). The main concept for F2C is the capacity to utilize the most suitable set of resources (infrastructure but also data) to run a service, be it at cloud or fog premises or even a combination of them (see Figure 1). This collaborative model, unlike fog and cloud, allows parallel services execution at different premises (as done in High Performance Computing in the past), hence optimizing the user experience. Although this is a very incipient technology, and surely there are many challenges yet to be solved, its benefits in service execution have been already shown [2].

In this paper we argue that the inherent computing and storage capacities provided by F2C computing may be critical for guaranteeing an optimized execution of health services in particular, those referred to as dependable services. Indeed, we argue that the dynamicity in the resources handling provided by F2C computing, positions F2C as a key enabler for dependable ehealth services deployment. To that end, we propose to analyze the effects F2C computing may have on a specific health service with high impact on the society. The proposed health service refers to breath assistance systems for Chronic Obstructive Pulmonary Disease (COPD). Apart from limiting the capacity of patients to perform daily life activities, lack of oxygen supply can potentially damage the heart and / or the brain. Oxygen concentrator machines, cylinders and their portable versions are the devices use to provide oxygen at home to those patients requiring it. However, in all cases, specialists have to prescribe the amount of oxygen that each patient needs, to ensure that no harm will result. When assessing the patient, specialists assume the stability of the underlying condition and that patient is at rest or under minimal exertion. While this is true in a hospital scenario considering the patient lying down in the bed, it is less so when the patient is walking and , hence requiring different levels of oxygen.

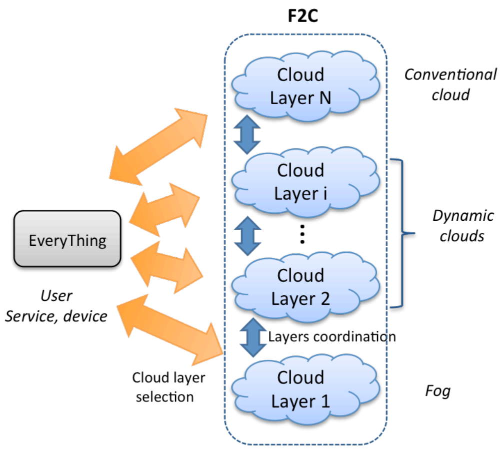

Fig. 1. F2C architectural model

This paper is structured as follows. In Section 2, we introduce the health scenario, the problem to be solved as well as current practices in handling the analyzed health service. In Section 3, we show the proposed solution adopting F2C computing, that is preliminary evaluated in Section 4. Finally section 5 concludes the paper.

II. Research Scenario and Current Practices

The proposed scenario considers a patient requiring oxygen at home as part of the treatment for his / her condition. To that end we assume two different scenarios. In the first scenario (static) the patient is quiet, hence carrying out no activity requiring a modification in the oxygen doses provided by the breath system. In the second scenario (dynamic) we consider the patient is on the move, hence realizing some physical effort requiring fine-tuning of the level of oxygen to be administrated by the system

Oxygen concentrators are preferred in those patients that stay at home most of their time, i.e., static scenario. A concentrator filters the oxygen from the air in the room and, then, delivers it to the patient by a nasal cannula or a mask. Usually patients also have cylinders of compressed oxygen as a backup in case of an electrical failure. These cylinders can also be used when the patient needs to go out of the house.

The indication of oxygen therapy regime depends on the underlying condition of the patient. In the case of Chronic Obstructive Pulmonary Disease (COPD), one of the commonest situations for considering oxygen therapy, the prescription of oxygen depends on the values of arterial blood gas measurements. In particular, patients with arterial oxygen partial pressure (P_aO_2) below 55 mmHg should receive oxygen therapy.

Patients with higher values of P_aO_2 (55-59 mmHg) will also get an indication of oxygen therapy if other clinical situations are present (such as tissue hypoxia, pulmonary hypertension, or impaired mental status). In other patients, the problem is not a persistent one but desaturation (decrease in oxygen concentration in the blood) occurs during the exercise or during sleep. In these cases, treatment should be adjusted accordingly in these situations. In any case, the importance of adequate prescription is paramount, in particular in those cases where there is uncertainty about whether the level of oxygen being supplied matches the needs of the patient. This is particularly the case of physical exercise in these patients, i.e. dynamic scenario.

From a technology perspective, authors in [3] have recently introduced the benefits of fog computing for monitoring COPD patients in static and controlled scenarios. Indeed the paper addresses a scenario where the patient is at home (hence guaranteeing connectivity and a very controlled context) and without considering any kind of physical exercise. In this scenario, the authors propose to include a fog node handling both data storage (data collected from distributed home sensors) and real-time data processing. Based on the collected information and on a smart processing, the fog node will issue a set of well-defined warnings regarding the oxygen doses and the patient behavior. Although this work is promising since it introduces for the first time the utilization of fog computing for COPD patients, the proposed scenario is too narrow, thus not considering physical activity what undoubtedly is highly recommended to these patients.

In fact, physical exercise (pulmonary rehabilitation) is always included in these patients as part of their treatment strategy. A Cochrane review on pulmonary rehabilitation for COPD published a year ago concludes that pulmonary rehabilitation improves health related quality of life for COPD patients [4]. In particular, the review highlights statistical significant changes in scores for dyspnoea, fatigue, emotional function and mastery. The review adds that changes were also statistically significant in all domains of the St. George's Respiratory Questionnaire (SGRQ). The patients in rehabilitation programmes also showed an increase in maximal exercise capacity. Another Cochrane review looked at the effects that pulmonary rehabilitation might have in people who had been in hospital with an exacerbation of chronic obstructive pulmonary disease [5]). In this review, authors found pulmonary rehabilitation to be a "highly effective and safe intervention to reduce hospital admissions and mortality and to improve health-related quality of life in COPD patients who have recently suffered an exacerbation of COPD."

However, indication of a pulmonary rehabilitation programme requires proper assessment of the physical capacity of each individual. It is important to explore the causes of exercise limitation in that patient and use this information to design a specific rehabilitation programme for that patient. Usually, cycle ergometry or treadmills are used to test the tolerance to exercise of an individual. During these tests physiological variables are recorded (peak oxygen uptake, peak heart rate and peak work load). Other less accurate tests include the 6-minute walking test (6MWT) and shuttle walking tests.

Pulmonary rehabilitation programmes are usually delivered as endurance training or as strength training. Endurance training focuses on improving exercise capacity for daily life activities (aerobic activities) and interval training seems to work better than constant load exercise, notably in the more severe patients. Target training intensity is usually derived from a percentage of the peak work (quite often 70%) and combined with a Borg scale of 4 to 6 (patient perception of the level of exertion between somewhat severe and severe)

Walking is one an important daily life activity for patients with COPD and there is evidence about the efficacy of walking-based training programmes in improving exercise capacity and quality of life in people with COPD [6], [7]. The advantage of walking is that it is an easy and cheap option for most of the patients. Also, the fact that it is an activity needed for daily life makes it a more interesting option to be trained and that quite often walking is impaired in these patients further supports the option for this training modality.

Several studies have evaluated the use of oxygen therapy with regard to the benefits in the exercise-training component of pulmonary rehabilitation. The argument is that it should allow patients with severe hypoxemia to train at higher intensities. However, results are inconsistent at this point. Moreover, in patients with a less severe status (not meeting the criteria for prescription of oxygen therapy) an improvement in the performance of exercise has been seen [8]

Thus, we may conclude that physical exercise is pretty effective for COPD patients in terms of reducing hospital

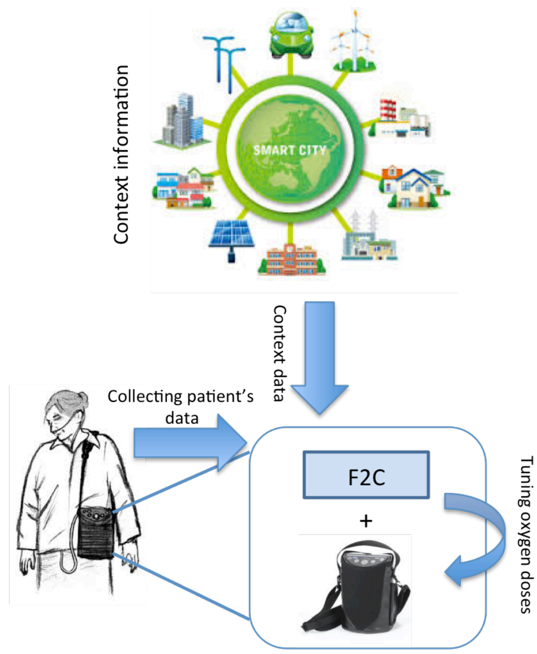

Fig. 2. COPD scenario

admissions, reducing patients' pharmacology and reducing exacerbations, i.e., the re-admission incidence rate and the patients deterioration, all in whole improving overall patients' quality of life.

III. PROPOSED STRATEGY

This paper deals with the dynamic scenario defined in previous section for COPD patients. Thus, recognized the fact that physical exercise is categorically beneficial for COPD patients, we propose a technology solution facilitating COPD patients to properly handle some daily physical activity. The envisioned scenario is shown in Figure 2, considering a smart scenario (i.e. smart city) where the context information is gathered from. The posed scenario shows a COPD patient on the move carrying a portable oxygen concentrator (POC). Unfortunately, the oxygen doses will strongly depend on the intensity of the physical activity but also on other parameters, such as the overall patient state, the air pollution, or even the air quality in closed spots, where, we illustrate how the oxygen doses is directly related to the intensity of the physical activity as well as to the air quality. Hence a smart mechanism must be designed to adjust and tailor the oxygen doses to the patients' real-time context and needs. To that end we propose to embed a so-called F2C box, enriching the POC with F2C capacities, hence embedding innovative functionalities including the capacity to: i) monitor the patient's oxygen doses; ii) process the context collected data; iii) monitor the physical effort estimated on the patient; iv) geographically position the patient, and; v) fine tuning the patient oxygen does. More specifically, the proposed F2C system must provide:

- Real-time monitoring of the patient's oxygen doses
- Real-time estimation of the patient's effort
- Patients' therapy tuned to patients' activity
- Context information collection and processing
- Patients' therapy tuned to context information

From a deployment perspective the proposed added capacities are deployed though an innovative F2C node that is embedded in the POC, whose functional architecture is shown in Figure 3, including all components to enable the above capabilities.

The Context data processing block is responsible for processing all data that is gathered from the context. This information is obtained through the appropriate platforms or systems (there are many IoT platforms in development) and in this block is suitably processed to meet the needs required by the F2C system. The system also embeds monitoring functionalities, split into two blocks. The first, the physical activity monitoring detects the intensity of the physical activity, in form of the effort required by the patient, be it in heartbeat frequency or in oxygen volume. The second monitoring activity collects all information regarding the patient state, including not only general health parameters, but also tracking the geographical position. The Predictive Models block handles all smartness introduced to tailor the system react to adaptive strategies, based for example on past activities, performance patrons, etc. Finally, the Smart Data Processing block is

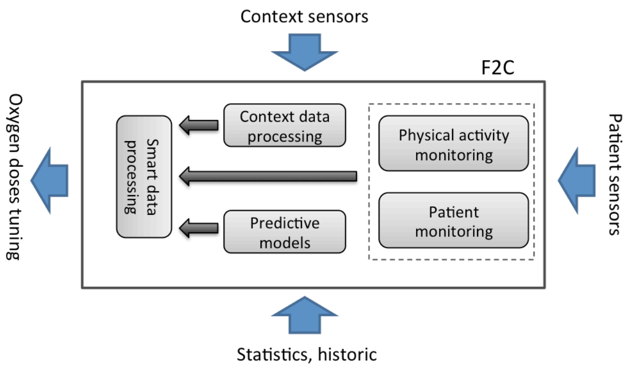

Fig. 3. F2C functional architecture

responsible for issuing the final decision about the oxygen doses, tailored to all data collected for the system.

All this set of functionalities may be supported by external devices through distributed computing and storage, whose coordination would be handled by F2C computing.

IV. F2C BENEFITS FOR COPD PATIENTS

In this section we present some analytical studies showing the impact our proposed F2C-based solution may have on facilitating the physical exercise benefits for COPD patients. In particular we show the effects in two well-assessed factors.

First, Figure 4 shows the impact physical activity has on the oxygen volume and in the heartbeat rate both measured in peak rates. The presented results have been obtained by considering the scenario described in [9]. We see how, as expected, both parameters grow with the activity intensity. In order to illustrate the presented magnitudes the figure also plots flat lines showing thresholds for the disease gravity for COPD affected people. These thresholds have been obtained after a thorough review of the literature and even there is no a final conclusion formally setting these values we argue the presented ones are suitable for a merely illustrative objective –we must also consider that gender is also affecting on this values. Oxygen volume below 15mL/min/kg will go for serious ill patients, not even demanding physical activity. Values upper than 20mL/min/kg may be considered as low serious thus requiring physical activity, and finally moderate gravity go for patients in between. This classification is good to understand

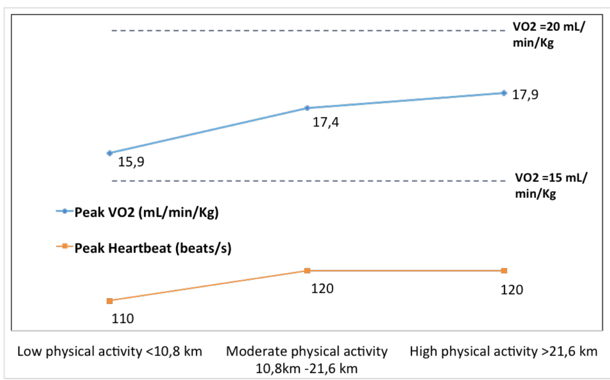

Fig. 4. Heartbeat and oxygen volume corves vs mobility

the need for physical activity and for the overall oxygen volume demand.

Second, Figure 5 depicts the Incidence Rate Ratio (IRR) of the Re-admission Rate and the Respiratory Mortality, both in terms of the physical activity per week carried out by a COPD patient measured in distance. The presented results have been obtained by considering the scenario described in [10]. We normalize all values to the one obtained when no physical activity is done. Analyzing the IRR of re-admission we observe that a reduction of a 28% is obtained when low physical activity is managed by the patient, going down directly proportional to the effort up to a breaking point when the effort done represents too much and does not help to reduce IRR but it does increase it. On the other hand, the IRR of Respiratory Mortality curve represents the decease for COPD patients in the first year. Again, normalized to the scenario where no physical activity is done, we observe that a substantial reduction of 11% is achieved by adding low physical activity to the patients daily routine, that is much better when this activity is moderate reaching up to a 32% reduction. As noticed for the IRR higher values of physical activity intensity does not report on a clear benefit compared to a moderate effort.

V. Conclusions

This paper introduces in an illustrative way the benefits F2C computing brings to COPD patients. The main concept boils down to embedding the currently deployed POC systems with smart processing capacities, that allow COPD patients to carry out physical activity. It has been demonstrated that physical activity is extremely beneficial to reduce patients deterioration and so improve their quality of life. Thus, the real-time processing brought by F2C computing enables a context-tailored and patient-tailored tuning of the oxygen volume a COPD needs to comfortably support the oxygen demands required by the physical activity to be done.

F2C may even allow most serious patients to carry out some light activity through a very deep and tailored oxygen therapy support. The effects of such improvement turn into a strong societal impact with effects going beyond patients quality of life and also moving towards family happiness and economic costs reduction

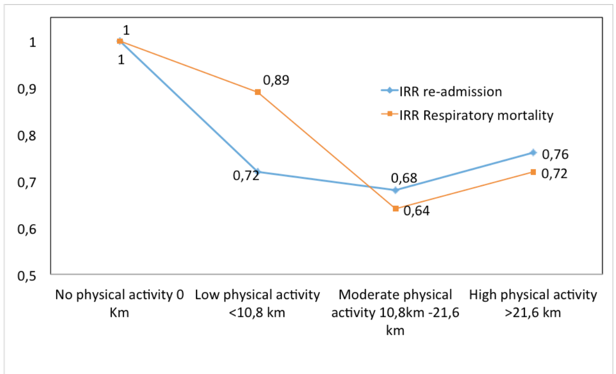

Fig. 5. IIR for Re-admission rate and Respiratory Mortality

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