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***Abstract*—The advent of the 5G network is a key enabler to the growth of IoT, with the promise to innovate and revolutionize contemporary architectures by enabling new IoT-optimized services. Far from being just a bandwidth and latency improvement, the real potential of 5G lies in the intelligent management of network resources, and in the possibility of offering new services at the network level. Developers of IoT applications will no longer be forced to adopt a cloud-centric approach, where all storage and computation is centralized, but will be able to exploit network-provided resources, adopting Edge or Fog computing approaches, with numerous advantages such as higher locality, increased computation power and reliability, reduced latency and power consumption. Network operators, on the other hand, need to offer a compelling set of services while designing the intelligent components of their 5G networks, which would drive IoT developers to prefer their network-hosted services to cloud-based ones managed by over-the-top players. This paper aims at identifying which sets of services may be offered by a 5G network, by analyzing the computing, storage, and communication services that are currently offered by 11 major IoT platform providers, as well as those that are currently not being provided due to limitations of the cloud computing paradigm.**

***Index Terms*—Internet of Things, 5G, Cloud-based Services, Storage, Notification, Network-hosted Services**

I. Introduction

The Internet of Things (IoT) is a well-established paradigm for a network of devices and sensors that connect to the Internet. As the IoT takes root, the number of such "things" is predicted to increase dramatically over the next few years: according to Cisco's Internet Business Solutions Group [1], in fact, the IoT will steadily grow up to over 50 billion devices by 2020. As the number of available interconnected "things" grows, network-enabled objects should become adaptive to new circumstances, more resource efficient, and generally user optimized [2]. Expanding the IoT to the mentioned levels, requires data to be transmitted and processed with very high reliability and decisions taken almost in real-time.

The advent of the 5G network represents, therefore, a disruptive element in such a scenario. The increased data rate, reduced end-to-end latency, improved coverage, and the support for large amounts of devices hold the potential to satisfy the most demanding IoT applications in terms of *communication requirements* [3], [4]. However, most of the contemporary IoT applications employ several *advanced services*, typically cloud-based, that go beyond the communication requirements: e.g., different storage capabilities, or notification and alerting functionality. Nowadays, developers rely on such centralized cloud providers (over-the-top players) for their IoT applications, and experience several issues, such as a relatively high latency, unpredictable reliability, etc.

The 5G network could have a significant impact in this context. It may provide intelligent management of the connected resources and/or offer some of those advanced services directly at the network level. In this way, developers of IoT applications will be able to exploit network-provided resources, adopting Edge or Fog computing approaches [5], together with all the other advantages brought on by the 5G network. Telecommunications companies (Telcos), similarly, could exploit the 5G technology for different purposes: from being a traditional provider of basic communication infrastructure to being an end-to-end solution provider for the IoT [6]. Network operators may offer a compelling set of services in the 5G network, which would drive IoT developers to prefer their network-hosted services to cloud-based ones.

Before moving computing, storage, and notification services from the cloud to the 5G network, or before adapting those services to better cope with the opportunities brought on by the joint usage of IoT and 5G technologies, we should understand which common functionality and best practices are currently used by IoT application developers. The paper considers the 11 major IoT cloud platforms, and compares their computing, storage, and notification services according to a vendor-neutral set of 27 feature categories. Starting this analysis, we aim at identifying which set of services, suitable for IoT applications, a 5G network could and should offer. Moreover, the paper envisions novel services that are currently not being provided due to limitations of the cloud computing paradigm, but that could be easily supplied by network operators. Through a scenario, some of the selected services are exemplified and the benefits of hosting them in the 5G network are further highlighted.

II. Related Works

Several works in the literature explore the relationship between the IoT and 5G networks, mainly from the telcos' point of view and from the communication requirements.

Palatella et al. [3] recently analyzed the potential of 5G technologies for the IoT, by considering both technological and standardization aspects. In their paper, they reviewed the contemporary IoT connectivity landscape (e.g., Zigbee, Bluetooth Low Energy, LP-Wifi), as well as the main features that may enable a widespread and convenient usage of 5G systems for the IoT. In particular, they envisioned the need of decoupling down/uplinks and to provide both a License Assisted Access and Radio Access Network as a Service [7]. Furthermore, they identified Software Defined Networks (SDN) and Network Function Virtualization (NFV) as the main 5G network enablers. They also illustrated the expected business shifts that a link between IoT and 5G may cause in both the operator and vendor ecosystems.

Among the 5G enablers, the usage of SDN was deeply investigated by the research community for both 5G and IoT technologies. Granelli et al. [8] recognized that SDN, with their ability to intelligently route Internet traffic and efficiently use network resources, will allow the removal of bottlenecks and an efficient processing of the data generated by IoT applications, without placing a strain on the network. SDN capabilities of service changing, bandwidth calendaring, and dynamic load management, in particular, will be particularly useful for the IoT. On the 5G side, Cho et al. [9] further extended the SDN approach and proposed a cross-layer architecture combining Software Defined Radio and SDN characteristics for enhancing 5G network performance.

Finally, Cero et al. [6] presented a work that could be considered as complementary of our paper. They would like to accomplish the vision of a pervasive IoT, able to span a wide range of application domains and to address the enabling 5G technologies needed to meet the performance requirements of various IoT applications. To do so, they performed a literature review to propose a new classification of IoT applications. Their goal was to specify and prioritize performance requirements of such IoT application classes, and give an insight into state-of-the-art technologies used to meet these requirements, from a telco's perspective. They recognized most of the features identified in [3], but they also added energy-related technologies (e.g., energy harvesting) to the overall scenario. Moreover, they conclude their paper by recognizing current research gaps and directions towards 5G enabling technologies for IoT applications.

III. Analysis

The aim of the analysis, as said before, is to identify a set of computing, storage, and communication services that are currently offered by IoT cloud-based platforms, but that could (and should) be offered by the 5G network. To do so, we chose the most widespread IoT platforms, according to market and technology benchmarks. In particular, we selected the leader platforms indicated by the IDC MarketScape report [10] and by the CXP Group IoT Platforms vendor benchmark [11]; the 11 selected platforms are listed in Table I.

The first step of the analysis was to define a set of macro-categories (criteria) for services, to enable a fair and transparent comparison of the platforms. Then, for each platform, it was determined whether a given service is offered and which

TABLE I
Considered IoT Platforms

Arrayent	Arrayent IoT Cloud Services
Amazon	AWS IoT Core
Bosch	Bosch IoT Suite
General Electrics	General Electrics Predix
Google	Google Cloud IoT Platform
IBM	IBM Watson IoT Platform
Microsoft	Microsoft Azure IoT
Oracle	Oracle IoT Cloud Service
SAP	SAP IoT Platform
thinger.io	thinger.io
Xively	Xively

product of the platform provides it. Among the identified criteria, three of them (Data Storage, Push Notifications, and Virtual Devices) were decomposed into smaller features so that the analysis could be more specific and accurate. Hereinafter are described the details of the comparison criteria, and the results of the analysis are presented and discussed.

A. Comparison Criteria

We derive eight criteria for the IoT services that allowed us to perform a well balanced comparison between the considered IoT cloud platforms. They encompass a wide variety of domains, from data storage to notification systems and Software Development Kit (SDK). The criteria are:

1) **Data Storage**. Whether and how the platform provides storage capabilities. In IoT cloud platforms these services are managed differently depending on the source, the format, and mainly, the purpose of the data. Most analyzed platforms offer the following services: *Disk storage* for I/O-intensive applications with low latency and high throughput (e.g., Amazon Elastic Block Store); *NoSQL database* storage for semi-structured data (e.g., Google Cloud Datastore); *BLOB storage* that consists of massively-scalable object storage for unstructured data like images, videos, and audio (e.g., Azure Blob Storage); *File storage*, corresponding to cross-platform file system (e.g., Amazon Elastic File System); *Relational database* management (e.g., Google Cloud SQL).
2) **Devices SDK**. Whether the platform provides a SDK to connect and (remotely) manage IoT devices.
3) **Mobile SDK**. Whether the platform provides a SDK to enable the interaction of mobile apps with IoT devices.
4) **Push Notifications**. Whether the platform provides a push notification or real-time alert mechanism. Common features involve the management of topics, which are communication channels to send messages and subscribe to notifications. The features are: *Register a device as an endpoint*, meaning that it will be receiving notifications; *Creates a topic* to which notifications can be published; *Delete a topic* along with all the endpoints subscribed to that topic; *Subscribe an endpoint device to a topic* so that the concerned endpoint is enabled to receive

all the messages published to that topic; *Removing an endpoint device from a topic* to delete a subscription; *Send a notification to a single device* using some specific identifier; *Send a notification* to all the devices that have been subscribed to a given topic. Moreover, it is also possible to *Integrate with the custom notification service of various OS*, i.e., send push notification messages to mobile devices by using their supported push notification services (e.g., Apple Push Notification Service, or Google Cloud Messaging).

5) **REST APIs**. Whether the platform provides REST APIs to enable the integration with software applications.
6) **Supported protocols**. Which protocols can be used to communicate between the IoT devices and the platform.
7) **Virtual devices**. Whether and how the state of a IoT device is stored in the platform, so that the physical device can be remotely controlled. To this end, a virtual representation of the physical device (also called *device twin*) is registered and controlled through the platform. The set of features commonly provided by the IoT platforms are: *Create virtual devices*; *Retrieve virtual device by id*; *Update a virtual device*; *Replace the device properties*, which means to overwrite the properties of the device through its twin; *Define the structure of the device twins metadata* according to the physical device capabilities, and *Remotely assign jobs to the virtual device* executes the deployment of a given function.
8) **Analytics**. Whether the platform provides a graphical interface (e.g., a dashboard) through which users can visualize and manage the deployed IoT devices.

B. Results

Table II shows the selected platforms (first column), along with the comparison criteria (first row), where cells indicate whether the platform offers the given service (✘), or even the name of the platform's product providing it.

It can be noted that most cloud platforms overlap in the provided services. In particular, AWS IoT Core, Google Cloud IoT, IBM Watson IoT, Microsoft Azure IoT, Oracle IoT Cloud Service, and SAP IoT rely on a wide catalog of generic cloud services, not strictly related to the IoT ecosystem. They provide, broadly speaking, the same set of services. Push notifications are mostly managed through the MQTT publish-subscribe messaging protocol.

The Bosch IoT Suite and the Arrayent IoT Cloud Services, conversely, are the most "limited" platforms. They do not provide any data storage support, SDK for other applications, nor support for virtual devices.

A small separation in the supported functionality could be observed: while "traditional" ICT vendors (e.g., Google, Microsoft, Oracle) support different facets of the development and deployment of IoT applications, vendors that come from other domains (e.g., Bosch, General Electrics) expose a narrower and more focused set of functions.

Finally, most provided services are tuned for cloud-based applications, not specifically for the IoT: long term data storage or analytics are two important examples. However, as described in Section IV, a few services could be moved and/or adapted to the 5G network, to further benefit the development and the usage of novel IoT applications.

IV. Advanced Services for IoT In The 5G Network

Before presenting the services that could be exposed by 5G networks for the creation of more reliable IoT applications, we would like to exemplify and highlight a possible usage of those services with a brief scenario. The example scenario also aims at suggesting possible services not being currently provided due to limitations of the cloud computing paradigm.

A. Example Scenario

John loves to go rafting in the mountains. He uses a smart adventure camera for recording and sharing his sport activities with friends and family. The camera exploits advanced services offered by the novel 5G cellular network. For example, it can store video and photos, without long waiting, directly in the network. Moreover, it can enhance the photos' metadata thanks to the fine localization capabilities of the network.

John was particularly interested in both these aspects, since he would like to immediately store and share the photos and videos taken during rafting. After sport activity and once back in town, all his photos and videos will be available through a dedicated mobile app. Thanks to that app, he could then upload the media on the cloud, for permanent storage or for taking advantage of the machine learning capability of his photos/videos platform.

B. Identified Services

Taking into account the service comparison for IoT cloud platforms, two of these services were identified as suitable to be provided by a 5G network. A service that is likely to be one of the most useful to provide at a network level would be storage. In particular, *storage* for I/O-intensive applications with high throughput. This would prevent resources to be brought from the cloud every time a device requests them, favoring the low latency that IoT applications typically require. Moreover, a temporary object storage for unstructured data (e.g., images, videos, and audio) would be desirable. The second service that could be moved from the IoT cloud platforms to the 5G network is the virtual devices management. Through this service, virtual replicas of the devices can be stored in the edge of the network, and given the case that a physical device becomes disconnected, its last status or default configuration can be quickly recovered from the replica.

Furthermore, based on the example scenario, we identified two services that are not being provided by the IoT cloud platforms, and in our opinion, would be worthwhile to be offered by a 5G network. The first one concerns location-based services. Since the cellular network is capable of determining the position of a device with a sufficient level of accuracy (10 meters with no additional energy or computational cost [12]), the 5G network could take advantage of such precision and provide a set of *location-based services*. The second service

TABLE II
SERVICE COMPARISON FOR IOT PLATFORMS

Platform	Data storage	Devices SDK	Mobile SDK	Push notifications	REST APIs	Supported protocols	Virtual devices	Analytics
Arrayent			Android, iOS	Realtime Alerts	EcoAdaptor framework	HTTPS, WebSockets		✘
Amazon	S3	AWS Greengrass	Android, iOS	Amazon SNS	✘	HTTP, MQTT, WebSocket	✘	AWS Console
Bosch		IoT Remote Manager		Remote Event Push	Java client or HTTP API	HTTP, MQTT, LWM2M, mPRM	✘	IoT Developer Console
General Electrics	Blobstore (S3)	Predix Machine	Predix SDK for Hybrid		Asset Services	HTTPS, WebSockets	Mobile gateway	
Google	Cloud Storage	✘	✘	Cloud Pub/Sub	Google Cloud IoT API	MQTT, HTTP	Cloud Pub/Sub (7 days)	Google Data Studio
IBM	Bluemix Storage	Edge Analytics SDK	Android	Bluemix Push Notifications	✘	MQTT, HTTP	MQTT	Watson IoT dashboard
Microsoft	Azure Storage	Device Provisioning	Android, iOS	Notification Hubs	✘	MQTT, HTTPS, AMQP	IoT Edge	✘
Oracle	✘	Endpoint Management	Java, iOS	✘	✘	MQTT, HTTPs	✘	✘
SAP	✘	✘	Cloud Platform, iOS	Apple Push Notification Service	✘		Thing Registry	
thinger.io	Data Bucket	Arduino, Sigfox or Linux	Android application		Server API	HTTPs	✘	Cloud Console
Xively		✘	Template mobile apps	Alerting and monitoring	✘	MQTT, HTTP	MQTT	✘

Legend: empty = not supported; ✘ = supported; other = supported with product name

that we identified concerns data processing. The cellular network could preprocess the data coming from the devices before transmitting it. This approach helps devices to save battery by releasing them from some data processing computing tasks, and it guarantees that the data being transmitted through the network is consuming the lowest possible bandwidth.

V. CONCLUSIONS

This paper analyzed the computing, storage and communication services that are currently offered by 11 major IoT cloud platforms, seeking to identify which services could and should be offered by the 5G network to enable the development of new IoT solutions. Eight services were identified and discussed, by offering deeper insights on three of them: Data Storage, Push Notifications, and Virtual Devices. Some features of the Data Storage and Virtual Devices services can successfully be moved to the 5G network, to allow developers to create more reliable IoT applications. Finally, the paper proposes two other services (fine localization and network-based data processing) that are not currently being provided due to limitations of the cloud computing paradigm and the current capabilities of 3G/4G networks.

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