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IoT, Big Data, and Cloud Platform for Rural African Needs

Corentin DUPONT[1], Mehdi SHEIKHALISHAHI[2], Abdur Rahim BISWAS[1], Tomas BURES[2]
[1]*Create-Net, via alla Cascata, 56/D, 38123 Trento, Italy*
Tel: +39 0461408400, Email: {cdupont, abdur.rahim}@create-net.org
[2]*Innotec 21, Gohliser Str. 13, 04105 Leipzig, Germany*
Tel: +49 3412368990, Email: {mehdi.sheikhalishahi,tomas.bures}@innotec21.de

Abstract: IoT has not fully diffused in Africa to address various challenges faced by African people. To address the emergence and pervasiveness of IoT in Africa, we present an open IoT, and big data platform as an innovation platform to accelerate innovations in rural Africa. However, the technology is not dedicated to the rural cases; it is designed for any IoT application. The platform will allow to develop IoT applications coupled with Big Data capacities. Moreover, the platform can be tailored to the specific requirements and constraints of African users. In this paper, we give an overview of the proposed IoT and Big Data platform, detail its technical aspects, and finally introduce three use case deployments to prove the validity of platform architecture.

Keywords: IoT, big data, cloud computing, sensors, agriculture, Africa.

1. Introduction

This paper is part of the Workshop session title *"Workshop on IoT and Big-data Technology and Applications for Africa"*. ICT developments in Africa has already enabled significant modernizations across traditional sectors. Notable examples are the micro-health insurance accessible through mobile devices, index-based crop insurance and crowd-sourced management of public services. These innovative applications recognize and leverage commonalities between sectors, blur traditional lines, and open up new field of opportunities.

The opportunity for ICT in Africa is huge, especially for IoT and big data: these technologies are promising a big wave of innovation for our daily lives. The new mantras for the IoT era is the collection, convergence and exploitation of data. The information is collected from sensors, devices, gateways, edge equipment and networks and stored in their respective IoT platforms.

This information is processed in order to increase business efficiency through automation, while reducing downtime and improving people productivity. While developed countries are discussing massive deployment of IoT, countries in Sub-Saharan Africa are still far from being ready to enjoy the full benefit of IoT. They face many challenges, such as the *lack of infrastructure* and the *high cost of platforms* and *complexity of deployments*. At the same time, it is urgent to promote IoT worldwide.

In this paper, we describe an open IoT and big data platform and its architecture for African needs; then, we validate this platform through several Sub-Saharan Africa real-life use cases.

The platform has support from multiple African stakeholders with the aim of defining new innovation space to advance the African Rural Economy. It will do so by putting end-users communities in the loop, namely rural African communities of selected pilots, and by involving relevant public bodies in the project development. About 64% of population is living outside cities in Africa. The region will be predominantly rural for at least another generation. The pace of urbanization is slower compared to other continents, and the rural population is expected to grow until 2045. The majority of rural residents live on less than few Euros per day. Rural development is particularly imperative in sub-Saharan Africa, where half of the rural people depend on the agriculture/micro and small farm businesses, other half faces rare formal employment and pervasive unemployment. For rural development, technologies have to support several key application sectors such as *living quality, health, agriculture and climate change*.

The open IoT platform exploits the potential of big-data applications in the specific rural context. Data is collected from the IoT sensors themselves, but also collects open data from other sources to build predictive models. In addition, the platform addresses privacy and security aspects, with special attention to the involved communities (farmers, developers). Applications will receive requirements from user needs in order to have a personalized and user-friendly interface.

The challenges outlined above will be tackled using an open IoT-Big Data Platform with affordable sensors connected. The technical functionalities encompassed by the platform will be a cloud-based real-time data collection combined with analytics and automation software, an intelligent analysis of sensor and device data, an integration with third parties platforms and a Platform-as-a-Service (PaaS) provider. The PaaS will provide to business clients an independently maintained platform upon which their web applications, services and mobile applications can be built. In sum, this paper makes the following contributions into African IoT technologies:

- Developing an open architecture and platform for IoT and big data to increase IoT adoption in Africa.
- Reducing costs of IoT applications development & deployment.
- Increasing accessibility of technology by leveraging traditional communication means like SMS, and voice messages in addition to smart phone technologies.
- Addressing intermittent Internet connections through local cloud and IoT services at the edge.

The paper's organization is as follows. Section 1 reviews the most relevant prior work. Section 2 presents an overview of the platform architecture. Section 3 explores implementation details of the platform. Section 4 describes pilot use cases of IoT applications: fish farming, cattle rustling, agriculture weather information. Finally, section 5 concludes the paper.

2. State of the Art

Kevin Ashton has coined the Internet of Things (IoT). He conceived a system of ubiquitous sensors connecting the physical world to the Internet. IoT is paving the way to connect the physical and digital world for a better connected world. IoT can give us enormous insight into our world through the collective knowledge about the physical world. For instance, wind turbine operations can be improved by measuring vibrations from blades and performing real-time analysis. A wind farm operator can determine maintenance needs before the blades fail.

A report from Cisco [1] provides insight on the current use and potential of IoT technologies in tackling global development challenges, highlighting a number of IoT innovations helping to solve some of the world's most pressing issues. IoT applications for agriculture have been presented in several papers [2] [3] [4] [5] [6] [7] [8] [9].

IoT adoption in Africa has been explored in [10] [11]. Studies in [11] [12] state low penetration of IoT in Africa. [12] provides analysis and proposals to increase IoT adoption.

From the technical point of view, an IoT system should be able to leverage big data technique for storing, processing, and analysing data. Such a technique is Hadoop MapReduce [13]. It is a scalable data analysis and processing tool. Apache Spark [14] is a different data analytics system. With in-memory capability, it claimed to be faster than MapReduce up to a hundred times.

Apache Flume [15] is a distributed, reliable service for collecting, aggregating and moving large amounts of streaming data. Apache Kafka [16] is a high-throughput, distributed, publish-subscribe messaging system. With Kafka, data can be consumed by multiple applications. Orion Context Broker [17] provides a publish-subscribe mechanism for registering context elements and managing them through updates and queries. To this end, Apache Flink [18] is a streaming data flow engine (realtime stream processing) that provides data distribution, communication and fault-tolerance.

3. IoT & Big Data Platform

Several new concepts are proposed to respond to the user needs: Platform as a Service (PaaS) approach to IoT, the data processing capacity inspired from Big Data techniques and finally the local and global Cloud. The idea of extending the PaaS approach to IoT is to propose a platform dedicated to IoT developers that can reduce the time-to-market for an application by cutting the development costs. The Big Data techniques enable the processing of huge amount of data produced by sensors. These techniques allow creating actionable information and knowledge out of raw data. To this end, the local and global Clouds address the intermittent connection challenge: when Internet is not available, the user can still access some IoT functionalities from the local Cloud.

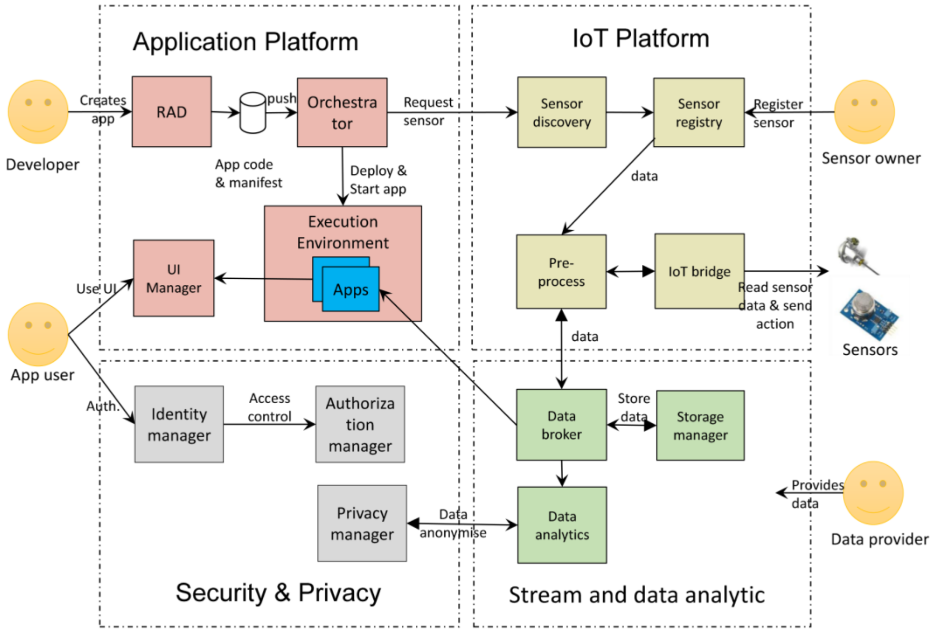

Figure 1: IoT and big data architecture

Figure 1 presents the complete architecture of the platform. It shows the four functional domains: Application Platform, IoT Platform, Security and Privacy, and Stream & Data Analytic. The Application Platform involves the development of the application itself and its deployment in the Cloud and in the Gateway. For this purpose, a rapid application development (RAD) tool can be used, such as Node-Red. A user provides the source code of the application, together with the manifest. The manifest is a file that describes the requirements of the application in terms of RAM, CPU, disk and also data sources (i.e. sensors, internet sources), big data processing engines (i.e Flink, Hadoop), and application deployment (in the Cloud and in the IoT Gateway).

The application source code, together with the manifest, is pushed to the Cloud platform by the user. The orchestrator component will read the manifest and trigger the compilation of the application. It will then deploy the application in the Cloud Execution Environment. It will also instantiate the services needed by the application, as described in the manifest. The last task of the orchestrator is to request the sensor and data sources connections from the IoT components. The sensor discovery module will be in charge of retrieving a list of sensors that matches the manifest description. On the left side of the diagram, sensor owners can register their sensors with the platform. External data sources such as Internet APIs can also be connected directly to data broker. The sensors selected for each application will deliver their data to data broker, through the IoT bridge and pre-processor. This last component is in charge of managing the connection and configuration of the sensors. In addition, it will contain the routines for pre-processing of data, such as cleaning, extrapolating, aggregating and averaging. Historical data can be stored using the Storage manager.

Security and Privacy domain contains three components: Identity Manager, Authorization Manager and Privacy Manager. The first one is in charge of providing the identification, the roles and the connections of the users. The Authorization Manager provides access policy for each of the platform resources. To this end, the Privacy Manager provides services for privacy of communication and anonymization of data.

4. Implementation

The platform (www.waziup.io) has been implemented with state of the art technology, and as an open source while taking into the account challenges at hand. The GitHub repository of platform is at https://github.com/Waziup/Platform. It is the main repository for platform developers as well as application developer, being open it is accessible to everybody.

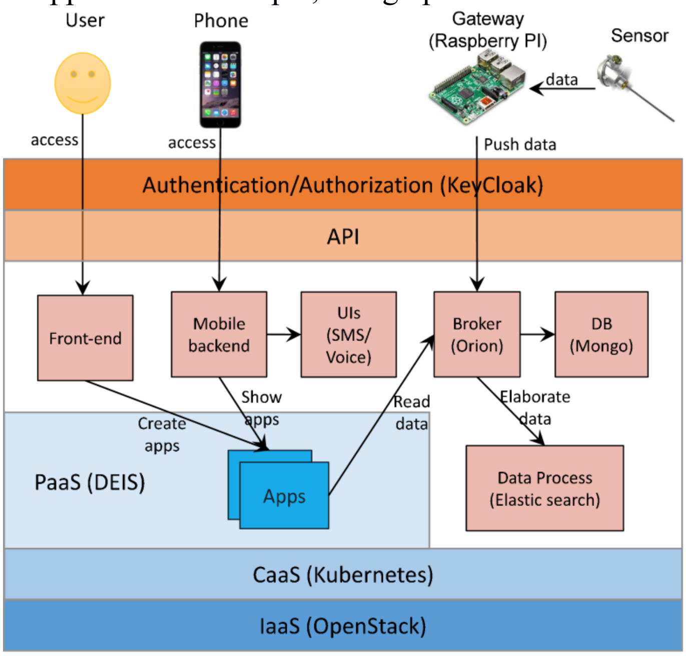

Figure 2: Platform implementation in a layered presentation

Figure 2 presents the implementation of the platform stack. The role of each component is presented, together with the technology selected in parenthesis. The platform uses three distinct Cloud layers (in blue in the picture):

- Infrastructure as a Service (IaaS),
- Container as a Service (CaaS),
- Platform as a Service (PaaS).

The first layer is provided by OpenStack [19]. Its main role is to provide Virtual Machines (VMs), in which we run the full platform. This layer is fundamental because most of Cloud vendors (Amazon, Rackspace) use VMs as basic selling units. The second layer is provided by Kubernetes [20]. The role of this layer is to provide containers, such as Docker containers. These containers provide light-weight and ultra-fast virtualization for applications and micro-services. The containers themselves are running inside the VMs.

The third and final Cloud layer is provided by Deis [21]. It provides services to developers, such as compiling and deploying and application. All the applications pushed by the users will be compiled with Deis and hosted in containers on Kubernetes.

To access the platform, the users and external components need to go through the Authentication and Authorization manager, which is managed by KeyCloak [22]. The external components also need to go through the API. Mobile phones can connect to the platform through the mobile back-end. The mobile back-end serves the data to mobile front-ends, and also interfaces with the SMS and voice commands components.

Finally, the Gateway pushes sensors' data to the data broker, which is FIWARE Orion . The data is distributed to the applications requesting it. Orion also interfaces with the database and the data processing (Elastic Search [23]), for historical data analysis.

5. Deployment for Pilot Use Cases

In this section, we present three IoT use cases based on the African farmer needs. This section meant to prove how our proposed platform fits well with various IoT applications in the field addressing African needs. The applications span over fish farming, cattle rustling, and agriculture.

5.1 Fish Farming

The use case's goal is to monitor the water quality in the fish ponds and to give information to fish farmers. Farmers are notified about the water temperature, dissolved oxygen, PH, alkalinity, ammonia, total dissolved solids, carbon dioxide in real-time. The solution is to deploy a buoy with sensors in fish ponds. The information gathered by the sensors are sent to a gateway and pushed to platform. All the data is stored in Cloud. Data visualisation is possible through the user interfaces. The platform sends alert notification to farmers either by SMS or voice calls when a measure falls below the acceptable threshold.

The notifications help the farmer to maintain his pond. It will help him to know when to treat the water, to change the water level or to feed the fish. The improvement of water quality will increase the productivity.

5.2 Cattle Rustling

The goal of this use case is to give critical information about cattle to the farmers in order to prevent the cattle theft.

The solution is to deploy LoRa [24] radio transmitters on the animals. The information gathered by LoRa end devices is sent to a gateway that will notify the farmer about critical situations. The position and the speed of the cattle group are provided to the farmer.

A LoRa gateway has been placed on the library building of the University Gaston Berger, Senegal, at the height of 90 meters. Some collars with LoRa end-devices need to be set around the neck of some identified animal. A collar will actively and periodically send "beacons" to the gateway.

Various LoRa parameters allow for range modulation. The absence of reception of a number of beacons for a given time period may mean that the animal becomes out-of-range (that mean it may be stolen). Advanced mechanisms can use collar-collar communication and rcv SNR and/or loss pattern to more accurately detect critical situations.

5.3 Agriculture Weather Information

The purpose of this use case is to obtain and produce weather related information which will be used to advise the farmers on how to proceed to increase the productivity or to prevent any disaster scenario.

This use case uses meteorological data which is obtained through the measurement of parameters such as: temperature, humidity, barometric pressure, wind speed, wind direction and rainfall. This data will be collected by the weather stations and will use LoRa to transmit the gathered data to the Gateways. The gateway and weather stations will be deployed in our pilot area in Kumassi, Ghana.

The data collected will be always accessible via the Platform in the Cloud. The platform will enable notifications to be sent to the farmers with detailed weather information about their farms.

Currently, for all the three pilots, sensors push the data to the platform, and farmers are able to check the status of their applications via the dashboard. Some components such as mobile application, social network and SMS notifications are under development.

6. Conclusions

With ICT technologies, Africa can dramatically improve its agricultural productivity by enabling the rapid and cost-effective deployment of advanced and real-time monitoring. However, deploying an IoT platform for Africa comes with many challenges. Among them, the most important are supporting *low cost*, *low power*, *low bandwidth*, and *intermittent Internet*. Moreover, widely accessible communication means such as SMS and voice calls need to be supported to reach the maximum users. In this paper, we proposed an architecture and implementation for the IoT Big Data platform. The concepts that underpin the platform are three: PaaS approach to IoT, data processing capacity inspired from Big Data techniques and, local and global Cloud. The idea of extending the PaaS approach to IoT is to propose a platform dedicated to IoT developers that can reduce the time-to-market for an application by cutting the development costs. The Big Data techniques enable the processing of the huge amount of data produced by sensors. Those techniques allow creating actionable information and knowledge out of the raw data. Finally, the local and global Clouds address the intermittent connection challenge: when Internet is not available, the user can still access some IoT functionalities from the local Cloud.

To that end, three use cases have used our open IoT platform, and were able to get all services needed for deployment, and implementation. Thus, this is a proof of concept for our proposed platform. IoT devices are able to push data to the platform, and platform provides a dashboard to present the latest information about the state of each pilots with graphs, etc.

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