An Hybrid Novel Layered Architecture and Case Study: IoT for Smart Agriculture and Smart LiveStock

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Abstract. The meteoric rise in the number of connected objects in our daily lives is proof that data transmission and improvement of services related to our activities are a permanent and urgent concern. Communicating objects transform our behaviors, our habits and our society in general. Despite the significant progress in the field of Internet of Things (IoT), much remains to be done especially in developing countries. In the field of e-agriculture, digital production techniques are not enough to guarantee a better yield and safeguard crops. Thus, in this work, we have focused on the resolution of the problems related to transhumance, given the expansion of the phenomenon in developing countries. Indeed, during transhumance, passages intended for animals, called corridors may not be followed by the breeders. This can lead to deadly clashes between herders and farmers. Our vision is to help through the implementation of a smart guidance system based on IoT Technologies, herders to better control their livestock following the predefined corridors from north to south of Benin and vice versa. In order to help farmers to save their crops in case of flood, our system will integrate a prediction module that will enable them to anticipate natural events such as flooding in the heavy rainy season. In this paper, our researches will therefore focus on the proposal of a multi-level architecture that can enable us to achieve the aforementioned objectives.

Keywords: IoT · Smart · Prototype · Sensors · E-agriculture · Smart-village · Livestock · Farmer · Big data

1 Introduction

One of the latest breakthroughs in the Internet world was the Internet of Things (IoT). The term IoT dates back to 1999 [1] and is a science that allows multiple objects to communicate with each other and/or with the cloud. This technology currently promises to positively and dramatically change human's life through

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these connected objects. Connected objects rely on embedded chips and sensors that connect them to the Internet and give them new features. Thanks to IoT, it is also possible to facilitate the convergence between several disciplines such as embedded systems, Artificial Intelligence, Big Data, Open Data, Cloud computing, Machine-to-Machine communication (M2M), etc. Once upon a time, isolated [2]. Gartner Institute predicts that nearly 21 billion connected devices could be in circulation by the end of 2020, two-thirds for private uses and the rest for the professional world. The Internet of Things has become today, a required tool for the rapid expansion of several sectors such as health, agriculture, transport, livestock, manufacturing, logistics, building, home automation, etc.

The fields of agriculture and livestock are of particular interest to us in this paper, as agriculture and livestock are the keys to economic development and poverty reduction in developing countries. For a long time and for a variety of reasons, including structural and technological constraints, misguided national policies and an unfavorable external economic environment, the potential of these two sectors has been ignored. The implementation of an intelligent farming system makes it possible to cope effectively with both productivity and low income issues and those related to climate change. The Food and Agriculture Organization (FAO), a specialized agency of United Nations, estimates that food production must increase by at least 60% to meet the demand of the 9 billion people expected to populate the world in 2050. It states that one people between eight is currently food insecure [3]. It is therefore urgent to find sustainable solutions to ensure global food security in the coming decades. As for the livestock sector, the use of technologies makes it possible, for example, to monitor animals, to know in real-time the state of their health and well-being, to acquire information on livestock, to improve the management of herds and to better guide them during transhumance through predefined corridors [4], etc.

The remaining of this paper is organized as follows. Section 2 presents the context and the motivation. Section 3 describes our multi-layered IoT architecture. Finally, Sect. 4 presents the related work and Sect. 5 concludes our work.

2 Context and Motivation

Transhumance is a phenomenon that involves migrating livestock from one place to another by traveling several kilometers and crossing fields of crops. The goal is to allow livestock to feed properly and reproduce. Generally, the non-respect of the passages planned for the animals called corridors can lead to a destruction of the harvests and lead to deadly clashes. This can have a negative impact on the development and economy of a country, especially in developing countries. In addition, it is noticed that the phenomenon of flood, can cause very serious damages and have significant impacts on the quality of life of the people living in rural areas. The damages can be both material and human. These two factors led us to think of the establishment in Benin, particularly in the Ouémé valley (second largest valley in the world) [5], of a project that we named THINGALIVE (**TH**e **I**nternet of thi**N**gs for intelli**G**ent **A**griculture and **L**ivestock

In the **V**alley of ou**E**me) that aims to introduce the Internet of Things [1] in agriculture and livestock, including the transhumance of animals.

This work will allow us, in addition to getting the usual information on a given crop field (soil condition, growth level, humidity, temperature), to provide reliable information about the imminent arrival of a flood so that the farmers can anticipate and save the harvest by sheltering more crops and also to reduce the risks of frequent drowning.

On the other hand, researches conducted in the course of this project will enable pastoralists in transhumance to effectively monitor livestock by following the corridor defined for their passage from the South of Benin and reduce clashes with farmers. Those clashes include the slaugther of cattle, the destruction of the harvest and the loss of human life. So, breeders will be able to have real-time information if they deviate from the corridors and have frequent information on the state of the grazing along the corridor.

THINGALIVE project will therefore lead to a more intelligent agriculture that will allow the farmer to be fulfilled and better enjoy the fruits of his toils. On the other hand, farmers will benefit from a transhumance that is both peaceful and intelligent in the predefined corridor by also providing useful information on the areas of the corridor where the pasture is well provided throughout the displacement or position of the water bodies.

Thus, THINGALIVE project will allow the use of technologies related to the IoT to achieve the following objectives:

- Better inform farmers and breeders to ensure peaceful relationships
- Make profitable the activities of farmers and breeders for a better development impact
- Reduce or eradicate the deadly clashes between farmers and breeders
- Create smart villages that are better organized to face the flood and avoid the destruction of the crops
- Preserve the security and privacy of the information.

The THINGALIVE project is still in its earlier stage and is divided into several phases, given its scale. Thus, this paper will only focus on the proposal of the architecture that will gradually lead to the achievement of the objectives mentioned above.

Thus, the proposed architecture is intended to allow:

- breeders to keep their herds as much as possible during transhumance in the corridors provided for this purpose.
- farmers to intervene in time to prevent the total destruction of their crops in case of negligence on the part of a breeder.
- the collection, storage and processing of data necessary for rapid decision-making.

3 High Level IoT Architecture for THINGALIVE

This section presents a short overview on IoT reference model, describes the architecture proposed for THINGALIVE project and compares the two architectures to show how our architecture fulfils the IoT basic requirements.

3.1 Reference IoT Model

Due to the rapid growth of the IoT, to cope with the lack of standardization of IoT model, it is important to have a reference architecture. This model needs to give a common view of the different levels of devices, tools, standards and protocols needed to make IoT running from the data generation by the devices, their processing and transmission, to their use by applications. Many models and architectures have been proposed such as Lamda Architecture [6,7], Kappa Architecture [7], IoT World Forum reference model [2] and many others, depending of the covered domains. The authors of [2] proposed a multilevel model to give clear definitions and descriptions applicable to elements and functions of IoT systems and applications. Then, the reference model has been proposed to bring simplification, clarification, identification, standardization and organization into IoT system setting up. The reference model has seven levels which are shown in Fig. 1:

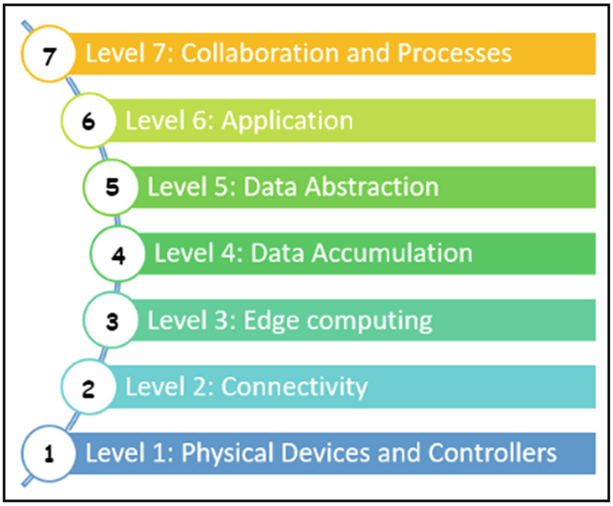

Fig. 1. IoT reference model

- Level 1: Physical Devices and Controllers. This level is composed by physical devices and controllers that might control many devices/endpoints which send and receive information and can give sometimes a first level of processing.

- Level 2: Connectivity. This level gives a reliable, timely information transmission between devices across networks on the one hand and between the network and the available functions at Level 3 on the other hand.
- Level 3: Edge Computing. This level ensures the conversion of the network data flows into information in order to serve the next level for storage and high level processing.
- Level 4: Data Accumulation. This level captures network data in movement from the previous levels and stores them, using different database technologies for non-real-time applications.
- Level 5: Data Abstraction. With IoT, data originate from many sources. This level aims at focusing on presenting data and its storage in such a way to enable easier implementation and provide powerful applications. This level processes the data to make them ready for the next level. Data protection with appropriate authentication and authorization is also provided.
- Level 6: Application. This level provides information interpretation. Different types of application can be developed depending of the nature of the data acquisition devices and business needs from data available at Level 5. This will allow getting better end-user experience for mobile users, business analysts and for monitoring purposes.
- Level 7: Collaboration and Processes. This level highlights the fact that many people need to collaborate to make working an overall IoT ecosystem through many processes that involve many data generated by IoT systems.

3.2 High Level Multi-layered Architecture for THINGALIVE

This section presents our proposed multi-layered architecture for smart agriculture and livestock based on IoT technologies.

We identified three main requirements for our architecture which are :

- Completeness: our architecture should meet the key properties of IoT reference model architecture.
- Flexibility: this gives our architecture the possibility to be independent from any technology and protocol constraints.
- Simplicity: this ensures our architecture to be clear and easy to understand.

Figure 2 shows the multi-layered architecture proposed for the THINGALIVE project. Our architecture is firstly composed of a stack of five main layers that highlight the required functionalities of an IoT-based architecture. Those layers are: Data Acquisition Layer, Connection Systems/Technologies Layer, Data Processing and Storage Layer, Service Layer and Notifications Layer.

Moreover, it integrates a lateral stack of two additional layers that show interaction with the other layers for monitoring and give access to the services provided to the different actors. Those are: Monitoring System and Stakeholders layers.

Following is the description of the proposed architecture.

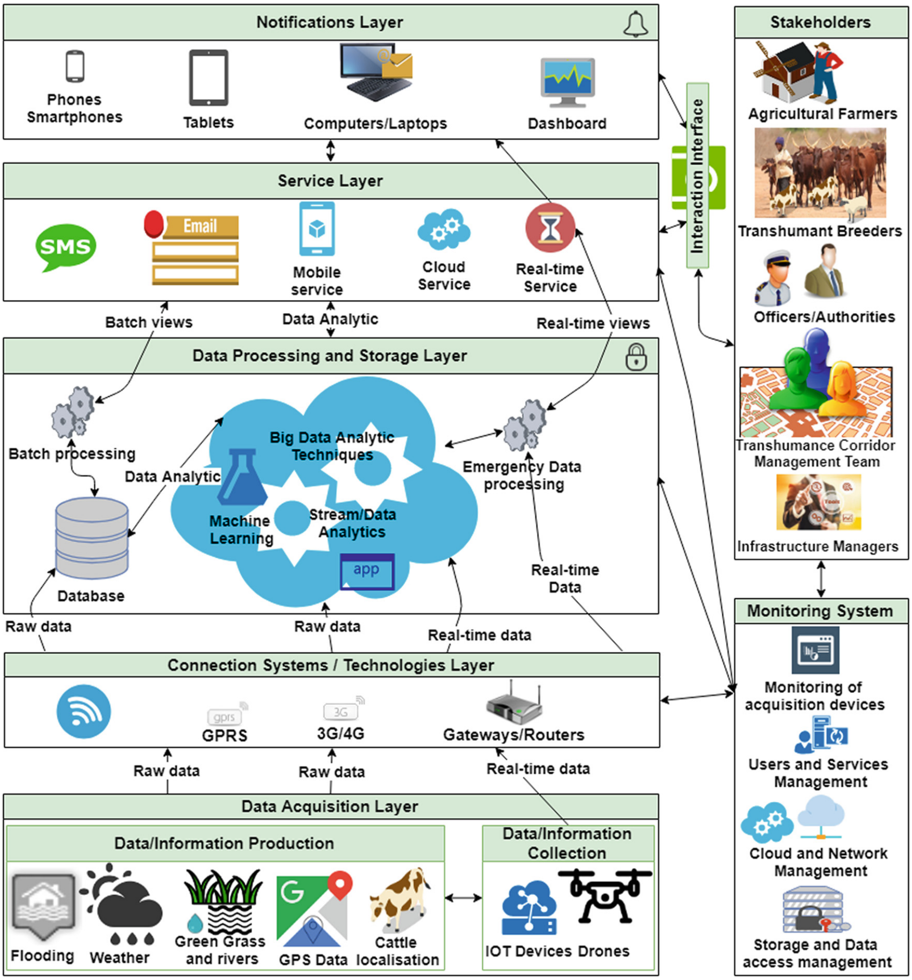

Fig. 2. THINGALIVE multi-layered IoT architecture

- **Data Acquisition Layer**
  This layer is composed of elements that produce information collected by IoT devices, sensors and actuators. The data can be produced by weather, flooding situation, the position of the green grass, rivers and cattle. Drones and IoT devices are used to collect data that are sent through the next layer using different communication technologies. The data transmitted can be processed in real-time or with delay depending of the usage.
- **Connection Systems/Technologies Layer**
  This layer provides communication functions for IoT devices. It allows the transmission of the data flows from the sensors to the next level for storage, processing and use. There are many proprietary technologies and protocols in

use, but the standardization increases quickly and allows more interoperability. IoT uses several well-known and emerging technologies, namely Wi-Fi, Bluetooth, ZigBee, Z-Wave, 6LowPAN, Tread, Neul, LoRaWAN, Near Field Communication (NFC), Sigfox, etc., in addition to 2G/3G/4G cellular technologies [2,8,9]. Depending of the purpose of the collected data, they could be sent either to the database for future use or directly to application for real-time exploitation. This layer is designed to be reliable and is able to deliver information in real-time between devices over the network by implementing various communication protocols. Both protocols in common use on the standard network and IoT-aware protocols will be used. For example, LoRaWAN or SigFox [8] technology can be used to transmit data from sensors to the place they will be analyzed in order to act and take decisions.
Among the common protocols available on TCP/IP stack, HTTP is used for some IoT devices. However, it does not support IoT devices environment constraints, such as low memory, low bandwidth, low power and others. Moreover, many web-derived protocols are also proposed but they have some limitations. In the literature, more suitable IoT protocols have been proposed to give better facilities for communication in IoT world. The most popular protocols are CoAP (Constrained Application Protocol) [10] and MQTT (Message Queuing Telemetry Transport) [11,12]. Depending of the IoT devices and the usage, our architecture will use one that suits a case.

- **Data Processing and Storage Layer**
  This layer is the most important of our architecture, since it provides data processing and storage. Data processing is performed according to the target of utilization by converting network data flows into information. This layer tackles high-volume data analysis and transformation since IoT devices may generate a lot of samples of data that need to be analyzed in order to take decision and to be stored. The analysis can be performed in real-time or delayed based on stored data. The existing analysis techniques and tools are based on common techniques such as machine learning, neural networks [13,14] and big data analytic techniques [15] used in cloud computing to process largest data. Emergency data are processed directly and sent to related service to serve for quick handling of events. Batch processing is based on stored raw data used to build analytic solution in order to act and perform prediction. This layer provides understandable information to the higher layer. Data are filtering, cleanup and aggregate for utilization by each service using data in motion and/or data at rest. For storage, streaming or continuous data may be stored on big data system such as Hadoop [16], MongoDB [17] and non-real-time data may be stored in relational database where data are always available. Real-time data is usually used to setup alert systems. This layer provides functionalities such as multiple data formats reconciliation, consistent semantics of data assurance across sources, transformation of data for higher level application, consolidation of data into one place using ETL (Extract, Transform and Load) or data replication, access to multiple data stored through data virtualization and data protection. Today, OLTP databases [18,19] and data

warehouses are used to carry and manage the amount of data generated by multiple IoT devices.

- **Service Layer**
  This layer is the one that helps to make use of the amount of data provided by the IoT systems. The interpretation of information is performed by this layer from real-time data and/or non-real-time data. The applications developed on the stack of this layer are based on different requirements, such as monitoring, prediction and control. The data transformed from the previous layer are used here to provide various functionalities. For example, alert system can be setup using real-time data to provide quick response time in case of disaster. Furthermore, analytic applications is setup to interpret data for business decisions. This layer is the one that provides interactions between the different actors and the IoT systems setup for smart Agriculture. The services developed by our architecture can be based on restful web service and many protocols designed for IoT.
- **Notifications Layer**
  This layer provides interaction with users through their devices. The services provided by the IoT systems are reachable from the common communication devices (laptops, phones, tablets, etc.). Web services using SOAP or REST and restful API are used to provide services to the end user. Taking into account user's position, the information received will provide him with the possibility to make a decision. This layer provides a dashboard to follow different events from the devices and to manage the different devices available in the IoT system.
- **Monitoring System**
  The first additional layer provides an interface to manage the devices, the tools, the services and our architecture end-users. This layer can take into account the monitoring of the IoT devices, the users and services management, the cloud infrastructure and services management, the communication network management and the databases administration.
- **Stakeholders**
  The use of the services developed around the data generated by the devices allows many interaction between the people involved and the processes that will run behind the real-time or non-real-time data that move through the network.
  The second additional layer is composed of the main actors of our architecture. Five of them are formally identified. They are:
  - The Agricultural farmers. This actor is the farmer that has the land and performs agricultural activities on it.
  - The Transhumant breeders. This actor is the breeder who travels along the corridors to have green grass and rivers for the cows and other animals.
  - The Officers and Authorities. The officer or the authority is the actor that can be called or can receive a message notifying that something wrong is happening so that the security company tries to solve the issue.
  - The Transhumance Corridor Management Team. This team is composed by many people, from the government, geographers to the representatives

of farmers and breeders. This committee defines each year the corridor that will be followed by the breeders.
- The infrastructure managers. The infrastructure will be managed by our team and may be used by some farmers that will be equipped with our IoT devices and materials. Some breeders also may have the devices placed on some cows to visualize in real-time their position along the corridor in order to send an alert when they didn't follow the corridor.

Our architecture provides six main functions that are spread over the seven layers namely: Collection, Storage, Analysis, Prediction, Adaptation and Output (Application).

3.3 THINGALIVE Architecture vs IoT World Forum Reference Model

This section compares the IoT World Forum reference model [2] with our proposed architecture in order to show how our architecture is complete by taking into account all of the functionalities delivered by the seven layers of the reference model. Our architecture has two layers less than the reference model and aggregates many functions on each layer to reduce the complexity. Figure 3 shows a comparison between our architecture and the IoT World Forum reference model. The links from the reference model to our architecture show the correspondence between the layers on the both sides.

Our Data Acquisition Layer provides the functionalities delivered by the first layer of the reference model, Physical Devices and Controllers.

Our Connection Systems/Technologies Layer plays the role of the second layer which is Connectivity.

Our third layer, Data Processing and Storage Layer is the most important and aggregates the functionalities of the third, fourth and fifth layers of the

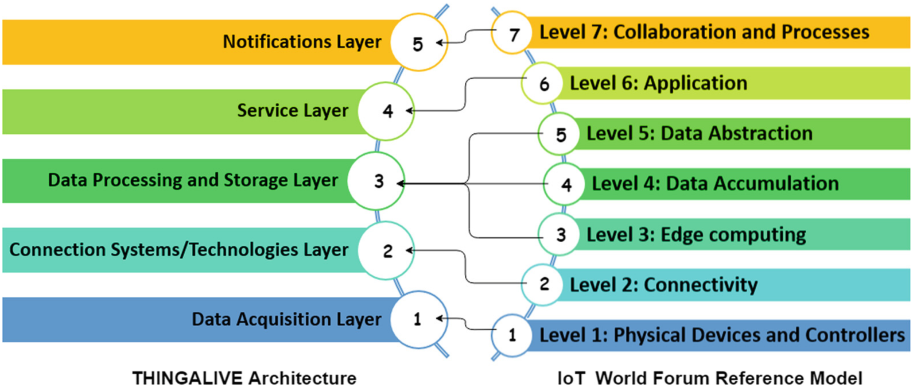

Fig. 3. Comparison between THINGALIVE architecture and IoT world reference model

reference model, Edge Computing, Data Accumulation and Data Abstraction. This layer is the core of our architecture.

The fourth proposed layer, named Service Layer tackles the functions given by the application layer of the reference model. The additional Monitoring System layer can also be associated for services delivery one.

The last layer named Notifications layer proposed the role played by the seventh layer of the reference model, Collaboration and Processes. The additional Stakeholders and Monitoring system layers can be associated to add more functionalities.

This comparison shows that our architecture fulfils the basic requirements of IoT systems.

4 Related Work

The Lambda Architecture presented in [6] is a robust system for massive amount of data collection and processing, but its core is centralized in the data centers or in the cloud. This architecture can limit the effectiveness of the analytics to quickly respond.

The authors of [2] proposed a layered IoT architectural reference model that provides a clean, simplified perspective on IoT and solutions that make easy the data collection, processing and service. This proposition splits the IoT problem into smaller parts and provides interoperability between devices in addition to security. This architecture needs to be adapted according to each application, in particular in african context where few communication technologies are available.

The authors of [20,21] show that the problem between breeders and farmers is real, but they didn't provide any concrete IT solutions to overcome the situation.

The work in [4], proposed a solution that addresses the mapping of the corridors without showing a full applicable IT solution to reduce clashes between breeders and farmers.

Many existing IoT-based solutions [22–24] are partial whereas the solution we proposed in this paper, aims to provide an integrated architecture that is useful for both breeders, farmers and authorities. This architecture tries to handle many aspects which are common for breeders and farmers.

5 Conclusion

The IoT agricultural applications are making it possible for ranchers and farmers to collect meaningful data. Large landowners and small farmers must understand the potential of IoT market for agriculture by installing smart technologies to increase competitiveness and sustainability in their productions. With the rapid growth of the population, the demand can be successfully met if the ranchers, as well as small farmers, use agricultural IoT-based solutions in a prosperous manner. This is the reason why we wanted to propose an architecture whose main objectives were to allow both farmers and breeders to be alerted in case of deviation of herds during transhumance. This is only possible through the data collection, storage and processing system that can assist in reliable decision-making inherent in good herd management. The architectural solution proposed in this paper represents an important step that should create the hope of definitively solving the conflicts related to the destruction of crops due to the transhumance of animals on the one hand and issues related to crops destruction due to flooding occurrence on the other hand. Indeed, the Data Acquisition Layer allows the collection of information that is subsequently sent to the Data Processing and Storage Layer through the Connection system layer for processing and storage. The processed data are used to send alerts to different stakeholders through the Notification Layer by using services offered by the Service Layer.

In future work, our architecture will be improved to take into account all of the IoT ecosystem and new technologies, protocols and devices. We will provide full details on the implementation of each stack of our architecture.

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