Proc. of the Eighth International Conference On Advances in Computing, Electronics and Electrical Technology - CEET 2018

ISBN: 978-1-63248-144-3 doi: 10.15224/ 978-1-63248-144-3-37

Blockchain-based Distributed Cloud/Fog Platform for IoT Supply Chain Management

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***Abstract*— This paper is inspired by the project proposal ID 7807232014 submitted for the EU Horizon 2020 topic ICT-11-2017 in April 25, 2017. It aims at applying state-of-the-art ICT technologies, systems and functions such as Cloud/Fog and IoT to enable food supply chain. A new approach will lead to trusted cooperative applications and services within the agro-food chains. Blockchain technologies will enhance the transparency, information flow and management capacity allowing better interactions of farmers with other part of supply chain, especially the consumer. Our research will provide better performing value chains by proposing new food-on-demand business model, based on new Quality of Experience (QoE) food metrics, bridging the gap between subjective experience and objective matrics based on quality standards. Finally, we provided an awareness qustionaire for fresh food products (FFP) and survay for a group of 30 students from the University of Skopje. This study showed that the majority of students are aware and focused just on few common FFP aspects without deeper knowledge of FFP quality.**

Keywords—Cloud, IoT supply chain; food on-demand business model; customer behaviour; Quality of Experience (QoE);

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I. INTRODUCTION

The concept of circular economy [25] (introduced in the 60's) is rapidly gaining attention as a way of decoupling growth from resource constraints.The proposed supply chain platform in this research will accelerate product development, expand into new markets, leverage partnerships, and mitigate unbalanced distribution of available resources. In particular the platform will allow us to promote and support innovation across the components of the supply chains to enable faster new product development, more effective market expansion, better understand of customer needs and building a human-centred supply chain giving values to waste achieving sustainable development as the greatest challenges of the 21st century.

Supply chains are becoming more and more complex due to growing number of firms, more complex transportation and distribution as well as personalized consumers' demands and satisfaction. These challenges are particularly evident in food supply chains, which have socio-economic, organisational, sanitary and environmental aspects, which require the implementation of specific cognitive –based measures. One of this is trust which provides the products' quality and the reliable products delivery, which leads to win-win situations across the socioeconomic and environmental domains.

Recent developments in areas such as Open Data, Cooperative Smart Infrastructures, Social Networks, Cloud (Mobile) Computing, the Internet of Things (IoT), Big Data technologies, RFID and NFC tags, Blockchain and various innovative applications on top of them may all be used as instruments for building trust among the stakeholders.

The key goal of the research study is therefore to make use of advanced, state-of-the-art ICT technologies, holistically use them to foster high quality of products and processes and thus contribute to provide supply chains management beyond the current standard-based certification schemes.

The research focuses at few essential steps of the food chain, and addresses the emergent needs of core stakeholders, encompassing farm production, packaging, transport, and warehousing (food storage) companies. The project focuses on one typical food product – grapes (as a case study), the quality of which is specifically difficult to observe – from farm production, through the packaging and transport, up to its adequate storage by various companies in the supply chain. The results of the research are applicable for any food product, so this study will provide quite generic solutions.

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The paper is organized as follows. Section II presents the concept and methodology in this research study. The related work is given in Section III. Section IV gives the modeling and implementation issues, while in Section V we give some details about our preliminary case study. Section VI gives the awareness study while Section VII concludes the paper.

II. ARCHITECTURE OF COGNITIVE SUPPLY CHAINS MANAGEMENT

Fig. 1 presents the supply chains management architecture.

Data processing occurs in part at the network edge along the cloud-to-endpoint continuum. Fog and Mobile Edge Computing (FMEC) will address latency , limited device processing and storage, battery life, bandwidth constraints and costs. FMEC will also address security and privacy problems (via blockchain technology) that arise from the emerging IoT and energy efficient processing.

Producers, packiging, transport and distribution, as part of Food Supply Chain (FSC), communicate with consumers via IoT/Fog/Edge/Cloud. Pilot module contains tools for customer social behaviour and satisfaction from the products. All modules have quality control indicators. The most important is QoE metrics based on customers' quality perception.

A. *Concept*

The Supply chain platform has a modular structure suitable for cirrcular economy model. Although the circular economy usually is focused on recycling, this should not be the top priority in our case because it is considered as high value reducer. Reuse, redistribute, remanufacture have similar importance. The objective of a circular economy is to keep products at their highest utility and value at all times and to provide sustainable food supply chain. This is the reason why we provide feedback from consumer to producer (farms), transformer (firms), packaging, transport and distribution (from warehouses) modules. The idea is to support modular design (mix & match modularity) as a design approach of the circular economy[25].

Modularity of the supply chain fits and allow excellent usage of the block-chain technology [26] which could be considered as decentralized, distributed database where all transactions from all modules are recorded, replicated and available for all modules and consumers. This is the way how we keep our Collective Awareness Platform (CAP) leading to trusted supply chain.

The consumers may order and monitor the customized food products specifying the source, quality, quantity, speed, time and place of delivery and other specific requirements. Innovative trusted tools for analysis of customer behaviour as well as direct feedback from the customers must be analysed. Trusted digital food services will be needed as support to increase the performance, competitiveness, reliability and sustainability of the production, while decreasing as much as possible the negative impacts on the environment, climate and health. By using the new QoE food metrics, the producers will have to take into account not only the quality measures according to regulations and standards, but also the estimation of consumer's satisfaction.

The farm management module will conduct both precision agriculture and macro agriculture. It will provide integration with sensors, weather forecast systems, and *in situ* webcam in order to provide adequate information for the farmers. Different webcams installed directly in the crops or inside the greenhouses can guarantee a continuous control also by remote of the situation and share some images with experts (agronomists) and authorities. This is very useful in ordinary activities but also when extraordinary events can occur (flood, earthquake). The farm management module will provide web interfaces. It will be accessible by laptop or mobile devices both by the farmers and possible consumers. The qualitative benefits for farmers are multiple, including savings of not only time and money, but also savings related to the environment.

In the second step, an efficient and trusted packaging must be provided. Again the data from RFID identifying the product is of big importance to ascertain quality. Moreover, other methods for providing quality measures will also be considered. Next, the data from optimal trusted food transport must be available at any time from everywhere to the consumer who want to know how his/her products are transported including reliability, safety and security aspects. The transport is very important for in-time delivery under specific conditions of food products. The transport module will provide means of tracking the product, by sensors, geographic information systems, weather forecast and so on.

The consumer will be able to order and monitor the customized food products specifying the source, quality, quantity, speed, time and place of delivery and other specific requirements. They will also be informed of various product discounts, due to their close expiration dates. The soon-to-expire food could also be donated. This way, food waste will be greatly reduced by following the shelf life deadline of the food products.

Beneath the surface, reporting tools and customer behaviour analysis algorithms will process big amounts of data and provide consumers with tips and offers. These tools will also help farmers better understand consumer cognitive behaviour and adapt accordingly.

The consumer management module will provide web interfaces. It will be accessible by laptop or mobile devices both by the farmers and possible consumers.

The roots of circular economy are efficient and innovative collaborative production, consumption and reuse models.

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Rather than the simply linear production/consumption traditional process, the circular economy is founded on the principle of maximizing the efficiency via reusing, renting, lending, swapping, bartering and giving through a multitude of circular processes—facilitated by the distributed decentralized peer-to-peer platform (based on a blockchain protocol), [26].
Food waste reduction will be possible via the creation of specific process for following the shelf life deadline of the food products; furthermore other wasted materials produced during the different stages of the life cycle of food can find new potential uses that guarantee an economy value and a reduction of environmental impact.
Finally, trusted food traceability along the whole product lifecycle (from production, transformation, packaging, sales, transport to delivery) including quality, quantity, adulteration and authentication is a paramount tool of consumer to control the whole food supply chain activities. Block-chain has huge potential in many areas, it can make possible radical transparency on provenance, mobile payments, credits, and decreased transaction fees, real-time management of supply chain transactions and involved processes. The value of block-chain here is its ability to make the supply chain entirely transparent and rich with immutable provenance data from farm to table.

Trust plays significant role in the sector and may significantly contribute to greater degree of vertical and horizontal collaboration. Important elements contributing to trust among the stakeholders include assurance of the products' quality and the reliable products delivery, which leads to winwin situations across the socio-economic, organisational, regulatory and environmental domains.
Recent developments in areas such as Open Data, Open Infrastructures, Social Networks, Cloud Computing, the Internet of Things, Big Data technologies, RFID and NFC tags, block-chain and various innovative applications on top of them may all be used as instruments for building trust and cognitive confidence among the stakeholders. It is therefore essential for the cognitive food-supply chains management to understand and start using these emerging technologies as support for building trust among the stakeholders. Moreover, such advanced, ready-to-use technologies can be used to gain an in-depth insight into linkages and interactions between the stakeholders, including understanding of their perception and behaviour with respect to sustainability, objectives and cooperation, potentially resulting in the design of new processes within the agro-food chains and thus leading to new business models and better performing value chains.

This research focusses on fresh fruit-vegetables products, the quality of which is specifically difficult to observe – from farm production up, through the packaging and transport, up to its adequate storage by various companies and waste re-use in the supply chain. Our case study provide an illustration for grapes farm, but this study is quite generic and could be applied for any fresh fruit-vegetables product.
A key innovation problem tackled by this research is the significant differences between the subjective Quality of Experience (that could be also expressed as awareness), judged by both end users (consumers) and experts for quality, and the objective assessments obtained through standards-based certification schemes for products and processes.
The key goal of the present proposal is therefore to make use of advanced, state-of-the-art ICT for the benefit of the food supply chains and holistically use them to foster high quality of products and processes and thus contribute to trust and awareness building measures beyond what is possible to be achieved under current standard-based certification schemes.

B. ***Methodology***

Real-world smart environments will be used for the purpose of the study. This will include a grape farm near the City of Skopje. Small farms need sophisticated sensing activities at soil and plant level. Sensors will be configured to collect data for various applications. Spatially-enabled mobile sensing technologies will provide detailed analysis of field conditions such as the humidity in different soil layers, the amount of nutrients in the soil, temperature, luminosity, solar visible radiation, rainfall, wind direction and speed, atmospheric pressure, leaf wetness and fruit or trunk diameter measurement (dendrometer).
Precision agriculture follows the crop growth cycle in all its steps from seeding, planting, application of fertilisers and pesticides, through harvesting.
It is important to note that technology alone is not enough to derive the best benefits for precision farming.
Customer profiling will be provided by social network analysis [1]. Farm production is based on digital agriculture [2]. Request for supply is sent to potential farmers according to the food on demand model [3]. Food transport quality model is based on tracing information, sensors, and open data by applying quality of transport - five-star model [4]. Quality of packaging (five star models) will be applied for RFID-based packaging [5]. Five-star model of storage quality will be also applied for food warehousing [6]. Quality of Experience (QoE) metrics based on food provenance and traceability will provide subjective and objective measure of food quality perception and awareness [7]. Cross Sectorial supply chain management security module will ensure security of operation, quality of the processes and interfaces [8].

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ICT – cloud/fog/edge infrastructure for data and computations will be developed to serve all needs of the system by relying on container (e.g. Docker) based cloud technologies and orchestration capabilities such as Kubernetes. The supply and implementation of sensors in the overall food supply chain under investigation will be integrated cooperatively within the cloud infrastructure. The design and development of the overall smart distributed information and decision support system will be included in the proposed solutions.

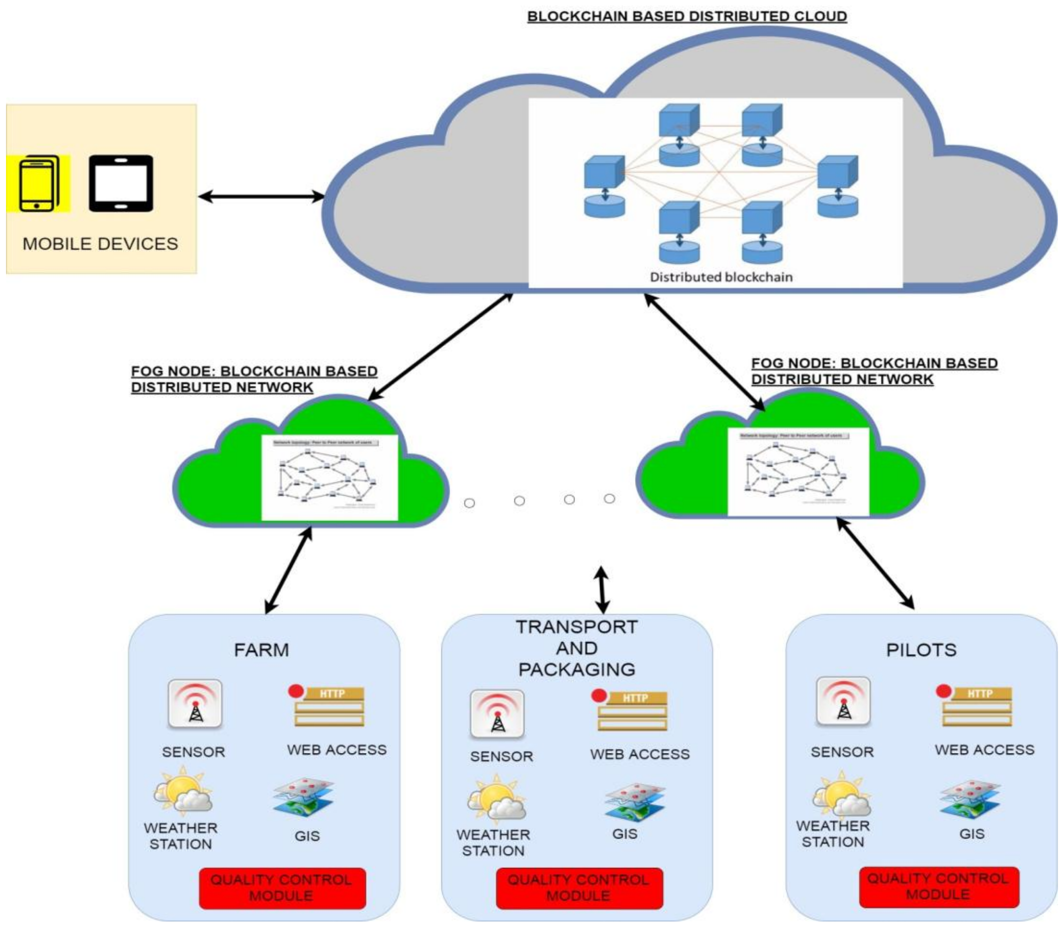

Figure 1 Supply chain management architecture

III. RELATED WORK

In [9] and [10] the architecture and infrastructure for time-critical cloud applications are given. Technologies for handling IoT and Big Data, Cloud federations and Software Defined Data Centers are also presented.

High-precision forecast of agro-meteorological parameters are given in [11], while useful information about what and when to plant and as well as other vital details for farmers are given in [12].

In [13], new generation of probiotic drinks with impact on the gastrointestinal health is presented.

The support of European SMEs in the agrifood value chain to simultaneously access knowledge, technology, capital and markets covering the entire ecosystem, agriculture, food production and emerging industries is described in [14]. A platform that will enable wholesale buyers and local horticulture farmers to find each other easily, and help farmers to create business relationships through the creation of informal cooperative farmer groups is presented in [15].

The authors in [16] provide a pro-active and personalized citizen-centric public service application that will encourage citizens' involvement and will harness the cooperative power of ICT networks (networks of people, knowledge and sensors) to raise awareness on flood risks and enable collective risk mitigation solutions and response actions.

The authors in [17] develop new scientific approaches to strengthening our societies' addictiveness, resilience, and sustainability and combining these with the best established methods in areas like multi-scale computer modelling, social supercomputing, large-scale data mining and participatory platforms.

The combination of the Internet of Things with Blockchain Technology and Complexity Science creates entirely new opportunities to address our challenges in all areas. In [18] especially the management of scarce resources is elaborated.

A system to collect and consolidate observation data from different meteorological stations networks, which are processed in real time and tagged according to their quality, is given in [19], while the best agricultural practices for Climate Change are given in [20].

Integrated automation and telemetry solution for resource management in precision agriculture, considering criteria related to energy efficiency and economics is given in [21]. Consumer demands in connection with the existing needs of food manufacturers, policymakers, public health nutritionists and other stakeholders are elaborated in [22].

IV. MODELLING AND IMPLEMENTATION ISSUES

This study introduces new food on demand cognitive model and a high level of trust and quality control on the entire food supply chain.

This research will implement a distributed (decentralized) hyper ledger platform based on blockchain technology.

It could be considered as decentralized, distributed database where all transactions from all modules are recorded, replicated and available for all modules and consumers. The platform has been specifically addressed to be exploited in the fresh food area due to the need to reach the widest community of citizens even in remote regions of Europe and beyond, where agriculture sustainability is a urgent problem to address. The new business and economic model of the circular economy will provide food and waste management through a multi-layered supply chain networks. The users will be involved in a cooperative and collective awareness process where they will be not simply food customers. Quantifiable improvement in cooperation could be achieved by using the Quality of Experience (QoE) models and metrics in both subjective and objective ways.

About the social innovations, collective awareness platform and new market opportunity connected to this research, please see the discussions in [27]-[29].

Special attention will be given to the consumer behavior model based on social networks data as well as the modelling of the Quality of Experience (QoE). The data from these cognitive-based model are very important feedback from consumer to the all other supply chain actors.

V. CASE STUDY

On the grape farm near the City of Skopje (near to the river Vardar) we instaled a group of sensors as shown on Fig. 2. The global connection of the LoraWAN sensors with the Base Station and IoT services in the Cloud is shown on Fig. 3.

Sensor node is equipped with sensors for measuring air temperature, air humidity, leaf wetness and soil moisture. LoraWAN protocol uses CSS (Chip Spread Spectrum) modulation that gives us the ability for data transmission of up to 10km in line of site while providing low power consumption [23, 24].

The sensor node uses the ATMega328p microcontroller [23, 24] as processing unit. The purpose of the microcontroller is the coordination of the sensor node i.e. to collect, transform and encode the data from the sensors, activate and connect the transmission module with the network base station and send to the Cloud for further predictive analysis by corresponding IoT Cloud applications and services as can be seen on the same Fig. 3.

To achieve low power consumption we designed the cyclic measurements collection by using the ATMega328p inner watchdog timer. It was setup to execute single operation on every 18 minutes for 5 seconds runtime.

On Fig. 4, we presented the workflow diagram of the sensing process.

The instalation was recently done, so the first pleriminary results from the applications are expected on the beginning of September 2018 when the grape will be ready.

Fig. 2 Sensors on the grape farm

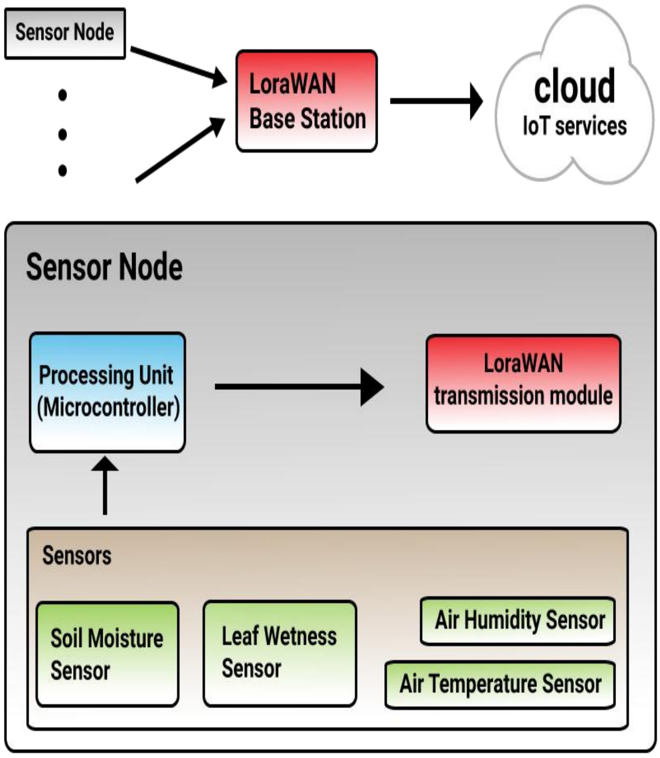

Fig. 3 Connection of sensor nodes to the Base station and Cloud (IoT services)

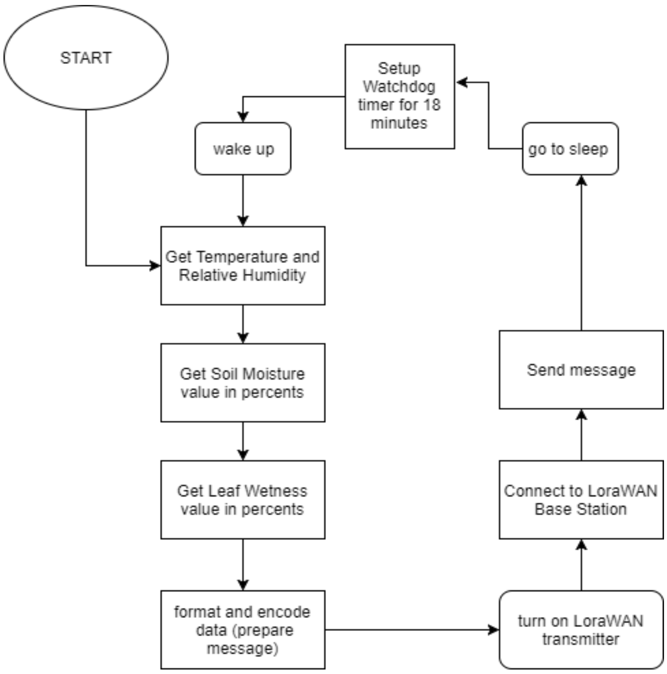

Fig. 4 The workflow diagram of the sensing process

VI. AWARENESS STUDY

We provided an awareness qustionaire for fresh food products (FFP) for a group of 30 students from the University of Skopje. This study showed that the majority of students are aware and focused just on few common FFP aspects without deeper knowledge of FFP quality (see TABLE I).

VII. CONCLUSION

It is especially important to mention that the proposed project is generic. It means that it is applicable for any agriculture and food production. The grape was taken just as a case study to prove the possibility of cooperative and collective awareness platform for cognitive food supply chain. It is worth to mention that the production of wine is a natural extension of this process.
The blockchain technology will provide transparent and secure supply chain system as well as trust in the origin and entire process of production, transport and distribution of the food on the market. The feedback from the customer will be provided be analyzing his/her social behavior on the market.

Last, but not the least, we plan to reduce the waste of food by applying the circular economy as basic model for the cognitive supply chain.

In our future work, we plan to present all details of the secure cooperation among the IoT applications including the sensors' data processing in the cloud/fog/edge. QoE metrics, trust, security and customer cognitive social behaviour will be of special interest. To improve the awareness about different aspect of food quality is a paramount objective.

TABLE I. AWARENES QUASTIONAIRE

Marks / Questions	1 (low)	2	3	4	5 (high)
Are you aware of the origin of the fresh food product (FFP)? Is it important for you?		x			
Are you aware of the possible environmental problems on the farm?	x				
Do you care about packiging of FFP? Are you aware of possible problems?		x			
How important is the brand of the production and packiging company?				x	
Are you aware about the transport of the FFP?	x				
Are you aware about the distribution company, werehousing conditions etc.	x				
Do you take care about the shelf life deadline of the FFP			x		
Are you aware of the meaning of the FFP chemical & other characteristics?		x			
Are you aware of the conditions in the shop where you bay the FFP (temperature, humidity, cleareness)?			x		

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