Architecture & System Design of TERRA+: The wine production use case

Dimitris Karadimas
PIKEI New Technologies GP
Patras, Greece
dimitris@pikei.io

Christos Panagiotou
PIKEI New Technologies GP
Patras, Greece
christos@pikei.io

Orestis Akrivopoulos
Spark Works ITC Ltd
London
United Kingdom
akribopo@sparkworks.net

Ioannis Chatzigiannakis
Sapienza University of Rome
Rome, Italy
ichatz@diag.uniroma1.it

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***Abstract*—The paper presents the architectural design and the technical details of the TERRA+ platform, an Ethereum based Blockchain infrastructure aiming to address the lack of confidentiality among consumers and producers in the agrifood sector. TERRA+ first application on the wine supply chain is presented; aiming to facilitate winemakers to build their brand's integrity via employing blockchain technology as the driving force of the proposed solution. Particularly, the presented approach, empowered by blockchain technology, is expected to (i) increase food confidence by leveraging blockchain technology and IoT, (ii) support brand integrity by providing all involved parties with data insights towards unique characteristics acquired from the vineyard origin and the producers and (iii) digitize food business models by allowing consumers and/or 3rd party services to capture robust data collections about each product.**

Keywords-Ethereum; blockchain; IoT; Ethereum; agrifood; trust; integrity

I. INTRODUCTION

The rural sector is one of the basic pillars for growth and development for most Mediterranean countries as well as for Western Greece Region's (RWG), where the presented work has been initiated. Wine production particularly is one of the main agri-food domains that local authorities have chosen to promote as one of the premium products of high quality that are produced in the RWG. RWG, has vineyards of a unique bioclimate that produce wines of great quality with rare features (holds more than 10 Protected Geographic Indication - PGI and Protected Designation of Origin - PDO) [1].

Given the low trust that consumers have in the food industry, it is hard for the local producers to promote the unique characteristics of their products and claim a bigger share from the European and global market. A solution that would support the winery process to deliver the products along with their production profile in a trustworthy manner would enhance the transparency and traceability that consumers appreciate in their food. By the term product profile, we define all the conditions that were present from the grape cultivation, to fermentation and transportation.

This work addresses the lack of confidentiality among consumers and producers and facilitates winemakers to build their brand's integrity by employing blockchain technology as the driving force of the proposed solution. Particularly, the proposed solution is expected to:

- Increase confidence: by leveraging blockchain all the intermediate stages of the wine supply chain (from vineyard to retail) are recorded.
- Build brand integrity: the presented platform empowers all the parties involved to the production to provide with food integrity data insights and ensure that they are offering their consumers the highest quality wine possible according to the unique characteristics that the origin and the producer introduces to the wine.
- Digitize food business models: Application Programming Interfaces (APIs) interfacing allows consumers and/or 3rd party services to collect data collections about each product

The paper is organized as follows. Section II briefly describes the background regarding similar existing platforms / solutions as well as the communication protocols that the proposed solution relies on. protocols and related work about their utilization. Section III depicts our approach and decomposes our proposed system in its components while Section IV reveals the envisaged functionality of the proposed system. Section V summarizes the progress made so far along with the future steps to follow.

II. RELATED WORK

In an increasingly data-driven world, where information sharing, machine learning, and social networking leads the way, the IoT will be a key technology to deliver person-centric smart services [11]. The current dominant approach for the management of data collected from IoT deployments requires that users trust a third-party, that uses the data to provide a smart service. Various attempts have been made to use blockchain technologies and smart contracts in a way such that the interests of all the participants that participate in a supply chain are protected.

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The use of decentralized blockchains to encode IoT data within a smart contract in order to enforce certain policies and rewards is presented in [9]. Moving from a centralized Client/Server architecture, typical of current implementations of smart service, to distributed blockchains to remove the necessity of trusting central authorities, creates certain challenges from software engineering perspective [10].

In agriculture, Blockchain is being applied for improving food safety, and transaction times. The literature on blockchain technologies for delivering smart services in agriculture has been recently reviewed in [12]. Many ongoing initiatives try to utilize Blockchain technologies towards a transparent supply chain of food, in various food products and food-related issues, but many barriers and challenges still exist, which hinder its wider popularity among farmers and systems [13]. For the case of integrating blockchain technologies within the wine distribution process some attempts have been made (e.g. ISTMOS[2], AGRIOpenData [3]). Such software solutions focus on some limited parameters affecting the quality and the usability of the monitored data.

ISTMOS offers control of the wine distribution process, informs about problems during storage and transportation and assists in avoiding negative consequences of improper storage by indicating trouble spots. These are achieved by real time data recording and automated alert creation, according to pre-defined rules. Although a holistic monitoring of the production and supply chain is described the software lacks in building a mutually trusted environment between involved stakeholders.

AgriOpenData is a powerful software-platform that supports farmers in the traceability and in the certification of agricultural products by using the Blockchain technology and Smart Contracts. This security system allows to make safe and automatic all the transactions along the supply chain, increasing the high-quality production, improving the environmental sustainability, and guaranteeing transparency and safety to the final consumer. Although AgriOpenData claims to provide transparency and usability of traceable data to the consumers it lacks in the establishment of a trusted ecosystem including technology synergies with private companies as well as with regional administration bodies.

The proposed solution differentiates from the competition by enhancing and offering credibility of the first stage of supply chain results (farming) provided with the most up-to-date soil analysis techniques. This analysis is performed in accordance with international standards SSSA, APHA, EPA and ISO specifically targeting to the wine production in synergy with public authorities such as the Soils Laboratory of University of Patras, Western Greece[4]. In that sense, TERRA+ facilitates the manifestation of the certificates that the product owns in a trustworthy manner. An additional feature that TERRA+ delivers is the ability to record the user experience and provide this feedback to the producer. User reviews are also registered on the blockchain providing benefits for both the producer and the consumer. Producers are able to receive the feedback of their customers and make important associations between the user preference and the parameters of the associated wine production.

III. ARCHITECTURAL APPROACH AND SYSTEM DESIGN OF A BLOCKCHAIN-ENABLED WINE LIFECYCLE

Winemaking has been around for thousands of years. In fact, humans have been making wine since at least 4100 B.C. The

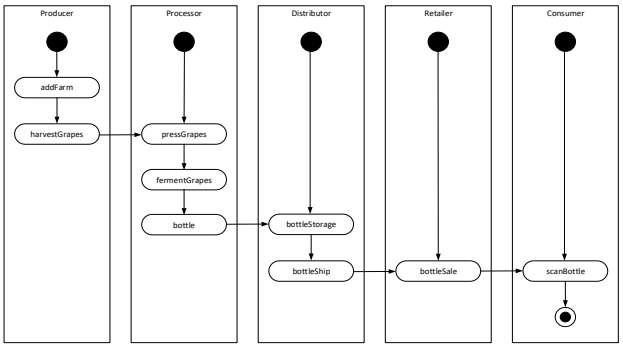

Figure 1 Wine production lifecycle

history of wine reveals that great wine is a complex blend of nature, art, and science. Although winemaking is a complex process, its lifecycle can be modelled as depicted in **Error! Reference source not found.**.

The proposed solution (TERRA+) is a blockchain (BC) based solution for tracking the wine supply chain from grapes cultivation to the retail store. It aims to provide to all the involved parties (producers, distributors, retailers, consumers and authorities) the appropriate tools that will offer all the required data that describe and validate the production, processing and storing process of the wine. The key aspects of this solution are the transparency and the integrity that the BC technology inherently delivers.

TERRA+ is based on the Ethereum BC [6] to benefit by the Smart Contracts that Ethereum supports. Within such smart contracts, physical goods, such as the wine, are represented as non-fungible tokens allowing to unique describe single products, or unique batches. The TERRA+ solution aims to facilitate the producer to build the digital profile of his product to highlight its unique characteristics and present them to the consumers in a trustworthy and transparent way. Consumers will increase their trust on final products and will allow them to have a better evaluation of a product that is highly dependent on various parameters during its production, process and distribution.

A. *TERRA+ Architecture*

The system is realized mainly by 3 distinct layers, the Application Layer, the Service layer and the Blockchain Network. These layers and their interconnection are depicted in Figure 2.

Application Layer (AL): This layer considers the web and mobile applications that the system actors use to interact with the TERRA+ platform. For example, the producer will use the respective web application to register the start of a new wine production, to enter the characteristics of the grapes, to mark the end of cultivation, etc. On the other hand, the consumer through the mobile app, will scan the QR code on the final product label (bottle of wine) and will fetch its digital profile. In the same layer

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operate the sensor devices deployed on the grape yards, or at the fermentation infrastructure.

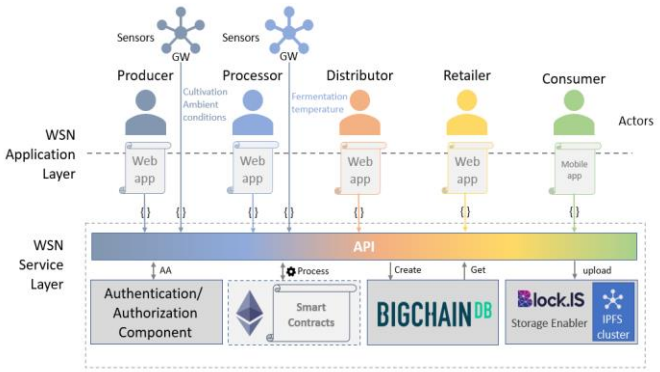

Figure 2 TERRA+ system architecture

Service Layer (SL): This layer is responsible to bridge the application layer with the blockchain network. The sensor devices and the actors reach the API of the TERRA+ Service Layer to forward their requests. The service layer consists of several components apart from the API and its controllers for delivering ID Management with AAA support, file storage (e.g. photos of the product, certification files), etc..

Blockchain Network (BN): On the bottom layer of the presented layered architecture lies the TERRA+ Blockchain Network. BN is the core of the TERRA+ platform and its current version, it is deployed as a private Ethereum blockchain network that implements all the business logic. The support for implementing our business logic is given by the Smart Contracts technology that Ethereum offers. A more detailed description of the component that operate in each of the 3 layers follows.

B. Components Analysis

User Applications: User applications comprise of the web applications used by all the actors of the supply chain, along with the mobile application used by the consumers. The actors of the supply chain use the respective web applications to execute their actions during the production of the wine. A non-exhaustive list of such actions comprises of: (i) Registering a new grape cultivation yard (executed by the producer), (ii) Registering a new grape cultivation (executed by the producer), (iii) Updating the status of cultivation, e.g. harvesting (executed by the producer) and (iv) Registering the start of must fermentation (executed by the processor).All these actions are executed through respective web interfaces responsive to most common displays.

Sensors: Sensor devices depending on the use case may be deployed in various locations of the supply chain and record data that are critical for the wine production. These sensors could be deployed at grape yards, cellars, warehouses and sense metrics such as: Yard latitude/longitude, Ambient temperature, Ambient humidity, Ambient light, Soil humidity, Barrel temperature and Barrel Pressure or even the carbon footprint of the production. All these devices facilitated by the latest advances in cyberphysical systems (CPS) and IoT are equipped with communication interfaces that make them capable to communicate through dominant wireless protocols and finally reach the Internet. The TERRA+ Platform supports integration with such sensors aiming to collect measurements and feed smart contracts that will be responsible to certify that certain rules are not violated during all the processes of the supply chain. The current implementation of the TERRA+ Platform prototype is based on the popular ESP32 [5] hardware platform capable to communicate either through Wi-Fi or Bluetooth to a local gateway. The device is responsible to receive the values that are transmitted by the attached sensor through a serial connection and send them to the TERRA+ platform through a respective API. Moreover, integration with 3rd party IoT platforms is considered during the architectural design of TERRA+ aiming to add versatility and increase the level of adoption from wine supply chains that adopt precision farming techniques. Such an integration that is in progress is with a prominent platform coming from SPARKWORKS LTD. and encompasses state of the art technologies applied and validated in a wide range of application fields [14].

API: The TERRA+ API is the public entry point that web and mobile applications and sensor devices reach to interact with the TERRA+ Platform and issue transactions. This API aims to give an abstraction layer over the blockchain network and all the supporting services (e.g. Authentication, Authorization and Accounting - AAA, file storage, form data submission, IoT data, etc.). In other words, the API is responsible to map API requests coming from the interfaces and devices to Smart Contracts functions. With that architectural choice we decouple the user applications from the blockchain network facilitating in that sense configuration adjustments, new features deployments and scaling. Another significant benefit of this approach is the fact that the TERRA+ platform is agnostic on the underlying Blockchain technology that is used allowing to be independent on the blockchain network.

Authentication: As already described, TERRA+ Platform is required to support multiple actors with various levels of permissions. Hence, the service to provide such authentication and authorization mechanisms in the context of a blockchain based supply chain solution is a fundamental requirement. TERRA+ solution incorporates an Identity Management component with AAA based on the dominant OAuth2 and OpenID standards.

File Storage: The Storage component incorporated in the TERRA+ platform is a distributed file system based on IPFS [7] and aims to allow actors (e.g., producer) to encrypt and store files (e.g., photo of the crop. In parallel the storage component collaborates with the underlying Blockchain infrastructure for registering the file storage transactions and the IPFS distributed file system for storing files. These interactions are facilitated by an API that exposes respective services to be consumed by the TERRA+ API Controllers. Storing files in the BC can increase the size of the chain very fast and the operation of the BC will become resource consuming reflecting to the overall performance and cost as well. With the adoption of a distributed file system, the storage of large files (certificates, images, etc.) is delegated to the IPFS while the BC is only responsible to store the unique fingerprint of the file (cryptographic hash) (Figure 3).

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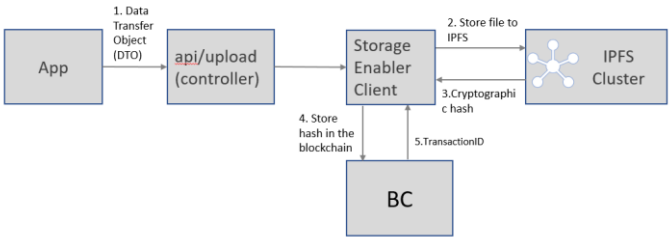

Figure 3 File storage flow

Smart Contracts: Smart contracts are the heart of the TERRA+ platform. This is the key component that implements and delivers the business logic of the application. Smart Contracts in the Ethereum ecosystem are programs that run on the Ethereum Virtual Machine (EVM) and are written in the Solidity scripting language. With a smart contract, TERRA+ represents a supply chain for each production batch. In this smart contract as a wine production batch is described in terms of fields, functions and events. Each instance of such a smart contract is the digital profile for the wine production batch. The most important fields of this digital profile, among others, are: (i) *Farm*: Describes the grape yard of the producer, (ii) *Location*: Location is used to place the exact coordinates of the farm on the map. The location characteristics of wine are on of key elements that consumers pay attention on, (iii) *Grapes*: Another important struct that encapsulates characteristics of the grapes such the year of cultivation and the farm they are cultivated and (iv) *Wine Bottle*: The wine bottle is the struct that describes the final product of the supply chain. The wine bottle carries the QR code on its label and inherits all the unique characteristics of the farm, the grapes and the cultivation in general.

IV. OPERATION CONCEPTUAL MODELS

This section provides the conceptual description of the main functionality of the TERRA+ solution, envisaged as a web application. All actors and stakeholders have roles to the following screens and are presented with moderated views. However, the following mockups visualize a quick overview of the conceptual functionality of the TERRA+ WebApp.

In more details the TERRA+ WebApp provisions the registration and management at farm level with proper information including location. A set of data providers are then registered per farm, as depicted in Figure 4. The farmer is then empowered to cultivation and bottle management, whereas certain API for bottle management also correlate them with other stakeholders (i.e., Processors, Distributors and Retailers). Finally, the consumer of the product can verify product's quality and validate through Smart Contracts, as described in Figure 5.

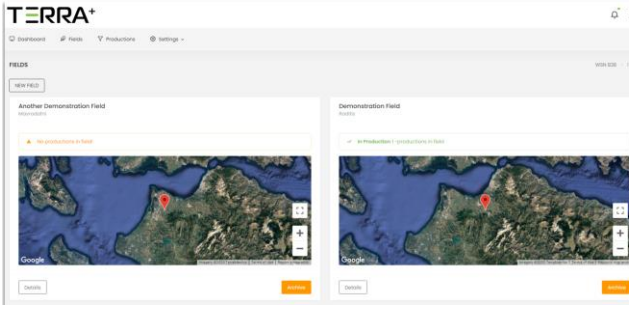

Figure 4 Producer View (grape yard management)

The above functionality allows the treatment of the low trust of the consumers, including local and foreign consumers, regarding food industry in general and wine-related products specifically by empowering even micro-producers and small vineyards with pure or significantly limited market penetration to leverage and promote the unique characteristics of their products and claim a bigger share from the Regional, National, European and global market.

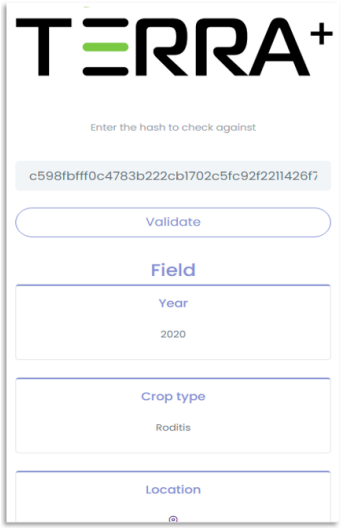

Figure 5 Wine digital profile view

V. CONCLUSIONS

TERRA+ solution, presented in this paper, addresses the lack of confidentiality among consumers and producers by empowering winemakers to build their brand's integrity via employment of blockchain technology, which is the driving force of the proposed system. All the parts of TERRA+ register their data in the chain during the wine production and life cycle. Therefore, all information related to the wine, from raw material to the bottle are recorded in a safe immutable way guarantying data integrity and product traceability. The proposed solution will protect the related information to be tampered while the multi-modal sources of data will give a more holistic view on the product's profile. The solution will integrate in the chain data given by sensor nodes (sensing the climate conditions), 3rd party services (weather) along with

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data related to the traditional "production line" of wine (e.g. origin of cultivation, packing dates, transportation duration, routes, etc.). Moreover, the availability of such data will give the ability to apply data analytics and extract valuable information from trustworthy sources of data and well-defined APIs (AI & ML is highly depended on the data availability). TERRA+ platform is a work in progress where more features and functionalities are added. In parallel, the platform approaches more beneficiaries of the agri-food sector aiming to broaden the use cases and facilitate the digitization of rural businesses.

VI. ACKNOWLEDGEMENT

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