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Blockchain-Enabled Supply-Chain in Crop Production Framework

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***Abstract**: The purpose of this paper is to propose an approach to blockchain-enabled supply-chain model for a smart crop production framework. The defined tasks are: (1) analysis of blockchain ecosystem as a network of stakeholders and as an infrastructure of technical and logical elements; (2) definition of a supply-chain model; (3) design of blockchain reference infrastructure; (4) description of blockchain information channels with smart contracts basic functionalities. The results presented include: a supply-chain model facilitating seeds certification process, monitoring and supervision of the grain process, provenance and as optional interactions with regulatory bodies, logistics and financial services; the three level blockchain reference infrastructure and a blockchain-enabled supply-chain supporting five information channels with nine participants and smart contracts. An account management user application tool, the general descriptions of smart contract basic functionalities and a selected parts of one smart contract code are provided as examples.*

***Keywords**: Blockchains, blockchain-enabled supply-chain, smart contracts, smart crop production, EOSIO platform.*

1. Introduction

The evolution of blockchain technology has so far evolved over four generations. The first is associated with cryptocurrencies (Bitcoin, Litecoin, Dogecoin, etc.). The technology is designed for transaction processing. The network is peer-to-peer, decentralized, anonymous and transparent. The second generation is associated with the smart contracts – autonomous computer programs that run automatically under predetermined conditions – introduced by Ethereum. The third generation blockchains (Cardano, Nano, IOTA, EOSIO, and others) are associated with decentralized Applications (dApps). They feature wider functionality and better design and allow avoiding problems as poor scalability, the ability to process cross-chain transactions, inbuilt compliance and governance and improved mechanism of smart contracts. When it comes to the fourth generation of Blockchain, it means that the third generation of Blockchain can be used in real business scenarios in

Industry 4.0 – supply-chain management, approval workflows, financial transactions and conditional payments, IoT collection data, health management and asset management, etc.

Blockchains in agriculture provide many opportunities to improve the sector. The increased use of mobile broadband devices, smart grids, big data analysis and artificial intelligence provide tools for developing smart farming systems. Supply-chain management is one of the most intensively developing areas for the application of blockchains. Perspective is determined by characteristics that can facilitate the incorporation of various functionalities such as: (1) provenance as a guarantee of quality and traceability; (2) improving performance through indicators such as reducing the time a product requires at each of its stages, cost of manufacturing a product, and production yield; (3) quality control and compliance of a product, production or supply-chain with different requirements of stakeholders or regulatory agencies; (4) transparency in access to information from trading partners, shareholders, consumers and regulators; (5) data privacy and confidentiality of sensitive data, such as financial records, for which access should be limited to interested parties only [1].

The purpose of this paper is to propose an approach to blockchain-enabled supply-chain model for a smart crop production framework. To achieve this goal, the following tasks are defined: (1) analysis of blockchain ecosystem as a network of stakeholders who share different goals, connections and processes and as an infrastructure of technical and logical elements; (2) definition of a supply-chain model as an application of blockchain technology; (3) design of a blockchain reference infrastructure; (4) description of blockchain information channels with smart contracts basic functionalities.

The smart crop production is a suitable area for practical application of Industry 4.0 technologies. The National Research Program "Smart crop production", part of whose implementation are the ideas and preliminary results presented here is at an early stage of development. They are going to be incorporated into a common framework for management, information and communication infrastructure, with its technical and expert capacity, coordinated policies and stakeholder agreement.

2. Related works

Two groups of challenges are identified in the implementation of the blockchain in the supply-chains management. The first group are technical challenges, such as data security and privacy issues [2, 3], performance capability [4], digital integration [5], link between physical product and digital record [6], implementation of smart contracts and updates of digital profiles [4], etc. The second group are industry and policy making (e.g., procedure standardization), such as compliance between different parties [7, 8], lack of regulations [7, 2], standardization of quality requirements, standardization of traceability processes [9, 2], etc.

Blockchains are applied to various supply-chains both in industry and in Business-to-Biasness (B2B), Business-to-Customer (B2C) networks. Examples of areas of application are supply-chains for aviation parts, clothing and textiles, diamonds/art/valuables, drugs and pharmaceuticals, food and agriculture, insurance, laptop parts manufacturing, shipping and transportation, trade finance.

The application of blockchain in supply-chain management is being constantly studied and developed both at conceptual level [10-13] and as implemented solutions and examples of implemented ones [14, 2].

There are different solutions when choosing platforms and permission rights when implementing blockchains in supply-chain management. For prevailing cases of permissioned networks are used Ethereum platform, Hyperledger Fabric, Stellar. However, there are solutions that are platform-independent [14, 15]. For permissionless networks this is Ethereum platform. Hybrid solutions prefer Ethereum, but there are cased of Unspecified platform [16, 17].

Most Blockchain supply-chain systems are based on Ethereum or its variants because they support smart contracts. The specifics of these supply-chains and the block ecosystem are different: food safety traceability, food trading, Farm-to-Fork (F2F) model, real-time tracking and tracing of logistics, etc. A food safety traceability system based on blockading and EPC information services is presented in [18]. A food trading system aiming to eliminate information asymmetry in the food trade and establish a sustainable and credible trading environment is proposed in [19]. The system includes the Blockchain consortium, the web server and the client browser. It is designed with Ethereum architecture. The Farm-to-Fork (F2F) model currently used in the European Union is applied in [20]. Hyperledger Sawtooth is used as the main architecture of Blockchain, the applications are developed in Python 3. The application subsystem consists of a web client, a mobile client, off-chain storage and a set of REST APIs. A pilot system of a cloud-based portal for real-time tracking and tracing of logistics and supply-chains is proposed in [21]. This portal is formed of RFID (Radio Frequency Identification), IoT and blockchain technology. RFID and IoT provide real-time information or data and a blockchain provides immutable transactions. The architecture of the portal is connected to transport companies, tracking devices, consolidation points and suppliers. An implementation of a custom, private and enabled blockchain from scratch with hardware aspects of the system, nodes, clearing server and smartphone application is presented in [22]. Another solution for tracking system based on a blockchain and detailed description of its design is presented in [23].

Despite the growing interest in scientific research on blockchain technology and its application to supply-chains the technical details are rarely provided. The characteristics and problems of integrating a blockchain with other technological tools (such as sensors, IoT configurations, etc.) in supply-chains also are rarely presented in details. The dominant research question is how a blockchain approach can be applied in the supply-chain [10].

3. Blockchain ecosystem

A blockchain ecosystem can be represented as a network of participants or as an infrastructure of technical and logical elements. The representations are complementary and are therefore briefly presented.

As a network of participants, a blockchain ecosystem represents stakeholders who share different business goals, relationships and processes. This network can create and transfer value. The participants have different views about how to achieve their goals, different business models and different contributions to the ecosystem. It is quite possible that some of the participants in the ecosystem are competitors, because everyone is in the ecosystem because of the business value he/she receives.

The roles of stakeholders are the following: (1) leader: this is the organization that designs the ecosystem and its business value. These are usually the creators of the project and the main beneficiaries; (2) core group: these are active or leading organizations that manage, control, streamline and optimize operational activities; (3) active participants: they are responsible for contributing and managing workflow and data; (4) users: participants who benefit from the network with the ability to access their own data. They are not responsible for the active management of the network; (5) third party service providers: IT support, infrastructure or application support services together with other services, usually for a fee.

At this stage, only the leader, core group and a part of active participants are stated. More details are presented in Section 5.

As an infrastructure of technical and logical elements, blockchain ecosystem refers to: (1) digital ledger technology (DLT): a digital database system for recording asset transactions. It can be blockchain based or non-blockchain based; (2) access rights: the permissioned/private blockchain requires participants or validators to be invited by an administrator to access the system. The permissionless/public blockchain does not have this requirement. A combination of both is a consortium blockchain. (3) blockchain platform; (4) consensus algorithm: the procedure by which partner nodes reach a common agreement to validate the current state of the distributed registry. The consensus algorithm in most cases goes with the platform. (5) integrated development environment: a package that consolidates the essential tools needed to write and test software; (6) development testing tools and libraries: provide support for developing applications that interact with Blockchain; (7) programming languages: blockchain development uses a wide variety of programming languages, including specific ones; (8) storage applications: the storage of transaction-related data can be on-chain or off-chain depending on the level of sensitivity or volume. Most of the off-chain storage applications are the same as before with big data; (9) applications and usage: the two main categories of blockchain-based applications are business to business and business to consumer. Table 1 presents a short introduction of blockchain ecosystem.

When developing the blockchain-based supply-chain model, the first task that has to be solved is the choice of a platform. The following criteria have been set to select the blockchain platform: to be open-source, to support smart contracts and decentralized applications (dApps), to allow use of object-oriented programming languages. Table 2 lists the blockchain platforms that support smart contracts.

Table 1. Blockchain ecosystem (modified form [24])

<table>
<tr><td>Applications and use cases</td><td colspan="6">Asset/Security tracking (Provenance), Digital Identification, Document digitalization, Trade Settlement, Data Sharing, Product manufacturing, Live Stock, Ownership management, Minerals and Metals, Cross Border Payments, Agri-Products, Tracing, Land Record, Intellectual property, Automobiles, Manufacturing</td></tr>
<tr><td rowspan="2">Storage appli-cations</td><td colspan="2">IPFS, File Coin, SIA, Storj</td><td colspan="4">Swarm, BigchainDB, MongoDB, RocksDB, CouchDB, Level DB, Post-chain</td></tr>
<tr><td colspan="2">On-Chain</td><td colspan="4">Off-Chain</td></tr>
<tr><td rowspan="2">Programming languages</td><td>C++, JAVA, JavaScript, Python, Go</td><td>Solidity, Simplicity, Ride, Vyper, Rholang</td><td colspan="2">JavaScript, Go/Golang, Solidity, Simplicity</td><td colspan="2">Rholang</td></tr>
<tr><td>General-purpose</td><td>Blockchain-specific</td><td colspan="2">Object-oriented</td><td colspan="2">Procedural</td></tr>
<tr><td>Integrated development environment</td><td colspan="6">Remix, ATOM, EthFiddls, Superblock Lab, Intellij-Solidity, YAKINDU, Atra Management console, Buible</td></tr>
<tr><td>Consensus algorithms</td><td colspan="6">Delegated PoS, Practical BFT, Federated Byzantine Agreement, Libra BFT, Proof of stake and trust, Redundant BFT, Proof of Work, Proof of Stake, Proof of Elapsed Time, Byzantine Fault Tolerant, Proof of Authority, Stelar, Tendermin</td></tr>
<tr><td>Blockchain platforms</td><td colspan="6">XDC Network, TEZOR, Dragonchain, Ethereum, Hyperledger Sawtooth, Hedera Hashgraph, Hyperledger Iroha, Corda, OpenChain, Ripple, NEO, Stellar, Hyperledger Fabric, EOSIO</td></tr>
<tr><td>Access rights</td><td colspan="2">Permissioned/Private</td><td colspan="2">Permissioned/Public</td><td colspan="2">Federated/Consortium</td></tr>
<tr><td rowspan="2">DLT types</td><td>Directed Acyclic Graph</td><td>Hashed-DAG</td><td>Monax</td><td>Multichain</td><td>Hyperledger</td><td>Ethereum</td></tr>
<tr><td colspan="2">Non-Blockchain based</td><td colspan="4">Blockchain based</td></tr>
</table>

Table 2. Blockchain platforms supporting smart contracts

No	**Platform**	**Industry focus**	**Ledger Type**	**Consensus Algorithm**
1	XDC Network	Global Trade finance	Permissionless	XDC Delegated Proof of Stake (XDPoS)
2	TEZOR	Cross-Industry	Permissionless	Delegated Proof of Stake
3	Dragonchain	Cross-Industry	Public, Private and Hybrid	Context-Based Verification with five levels of consensus
4	Ethereum	Cross-Industry	Permissionless	Proof of Work
5	Hyperledger Sawtooth	Cross-Industry	Permissioned	Pluggable FrameworkPoET (Proof of Elapsed Time)
6	Hedera Hashgraph	Cross-Industry	Permissioned	Asynchronous Byzantine Fault Tolerance
7	Hyperledger Iroha	Cross-Industry	Permissioned	Chain-based Byzantine Fault Tolerant
8	Corda	Cross-Industry	Permissioned	Asynchronous Byzantine Fault Tolerance
9	OpenChain	Digital Asset Management	Permissioned	Partitioned Consensus
10	Ripple	Cross-Industry	Permissioned	Majority Voting
12	NEO	Smart Economy	Permissioned	Delegated Byzantine Fault Tolerance
13	Stellar	Financial Services	Both public and private	Stellar Consensus Protocol
14	Hyperledger Fabric	Cross-Industry	Permissioned	Pluggable Framework
15	EOSIO	Cross-Industry	Permissioned	Delegated Proof of Stake

The blockchain platform selected is EOSIO (**https://eos.io**). This is an open-source platform, leveraging C^{++}, EOSIO's development environment configurable and optimized for private and public networks. The blockchain is configured as a *permissioned consortium blockchain* with 3 nodes. Accounts are created for all users of the blockchain with a unique public/private key pair, with its own smart contract and corresponding functions (actions) [25].

4. A Blockchain reference framework

The National Research Program "Intelligent Crop Production" and the project "BG PLANTNET establishment of national information network genebank – plant genetic resources" research the potential for implementation of blockchain technology in smart crop production. The studies so far have been related to aspects of risk management issues [26-38], impacts on internal audit procedures and control in companies adopting blockchain [29], the approach to blockchain software selection [30], text mining in the domain of Plant Genetic Resources [31]. The researches related to the application of the blockchains are presented in [32, 33, 25].

The blockchain reference framework is presented on Fig. 1 and includes three levels: a blockchain level, IT infrastructure services level and a supply-chain level. The blockchain network with a working abbreviation SCPBC (Smart Crop Production Blockchain) is decided to be a consortium type of three nodes situated at the University of Plovdiv "P. Hilendarski", at the Institute of plant genetic resources "Konstantin Malkov" – Sadovo and at IICT – BAS. At the moment, a node is installed in University of Plovdiv, on a virtual machine. The operating system is Ubuntu 20.04 and blockchain is EOSIO 2.1. A user application tool has been developed for blockchain accounts management, as well as for generating and linking user authorizations and smart contracts and their actions (Section 5).

Access to the blockchain is intented to be trough dApps (decentralized applications). From user's point of view the dApp looks and operates the same as a regular application. The difference is that dApp communicates in P2P protocol with more than one endpoint (e.g., blockchain nodes). For the user, this is transparent and allows finding of the least loaded node, the nearest or just a working node. This approach guarantees security, continuity of work with the blockchain and storage of information.

The blockchain level will be used to exchange critical information and to control interactions between participants in the supply-chain through the smart contracts layer. Critical information is formed in the layer of IT infrastructure services [34]. Here all analytical functions included in the platform such as big data analytics, artificial intelligence, machine learning [35, 36] are provided

The supply-chain level includes all potential participants, according to their functions and relationships of interaction. They are described in detail in the next section. Different types of IoT networks are supposed to be connected both to the individual participants of the supply-chain level and to the blockchain level.

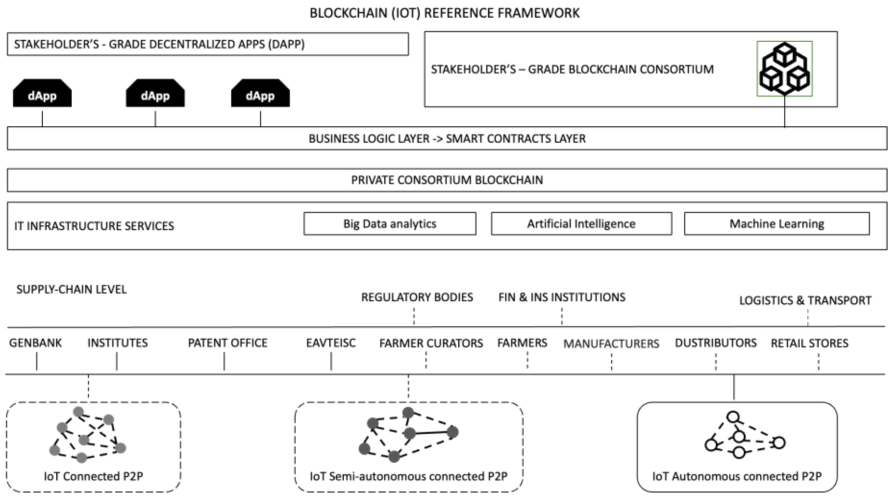

Fig. 1. Blockchain reference framework

Given that the research and the platform and the related blockchain-based supply-chain are under development, this reference infrastructure continues to be improved, detailed and supplemented. The purpose here is to explain where the blockchain belongs and to describe the ideas for its application.

5. A blockchain-based supply-chain model

The design of the supply-chain presented here takes into account the experience of developments described in scientific articles, research, studies and cases. They mainly focus on implemented industrial case systems (most widely used in the literature), conceptual frameworks for case studies, discussions on the applicability of technology, theoretical analyses of the benefits, challenges and/or limitations of technology in supply-chain management.

The supply-chain model represents a network of participants involved in the manufacturing, production, distribution and retail of a product and goods to the end customer. A blockchain-based supply-chain aims to facilitate management by storing records about certification, quality, quantity, price, time, location and other relevant data. Uploaded on-chain such information can increase the traceability of the raw materials and products, reduce losses by elimination of intermediaries, improve visibility, enhanced trust, guarantee timely payments, etc.

The supply-chain model includes nine participants [9]:

- *The GeneBank*: Bulgarian national genebank of Institute of plant genetic resources "Konstantin Malkov" – Sadovo where the plant germplasm are stored under controlled conditions according to the FAO/Bionversity standards (1980-1995-2014). "Gene Bank – Plant Genetic Resources" includes PGR collections of all national institutes.
- *State regulators*: supply-chains' regulatory and control bodies.

- *Farmer-curators*: farmers, authorized to purchase, propagate, distributor and retail the varieties of seeds from the GenBank to other farmers.
- *Farmers*: grain and forage crop producers.
- *Manufacturers*: grain processing companies.
- *Distributors:* wholesale and retail of products intermediaries.
- *Store network*: retail companies.
- *Logistics and transport* companies.
- *Financial and insurance bodies* (banks, insurance companies, etc.).

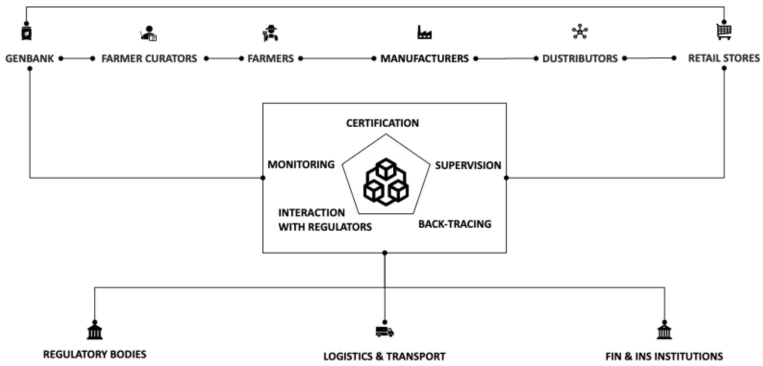

Fig. 2. A supply-chain model

The blockchain-based supply-chain model (Fig. 2) is suggested to facilitate: certification of new seed varieties; supervision on the grain process: planting, growing, harvesting, threshing, yielding, storing the grains; monitoring on processing and/or distribution and retail of certified seeds and grains; interactions with regulatory bodies; back-traceability of the seeds, grains and grain products by QR codes.

The participants have built a *consortium blockchain*. All transactions are governed by smart contracts. Smart contracts are the foundational framework for agreements made across Web3. These are self-executing contracts that are written in code, with fully transparent terms and transactions between buyers and sellers. Any smart contract built on a blockchain can be replicated and reused by anyone else.

In practice, there are also individualized for specific cases smart contracts, which after the execution of certain actions are “killed”. They are mainly used for confidential negotiations management between two or more parties.

6. Information channels

Under an information channel here is assumed the technological infrastructure and data environment for management the processes of monitoring, serves, maintenance, and control over correct performance of the functions and activities of certain participants in the blockchain-based supply-chain. SCPBC Blockchain is suggested to maintain five information channels: GenBank Validator, GenBank Store, Consortium seeds exchange, Consortium Raw Materials and Consortium Products.

The ***GenBank Validator*** (Channel 1) verifies, validates and issues a new plant variety certificate. A certificate is granted when the plant variety is new, different, homogeneous, and stable. The variety must also have a variety denomination identification associated with its genetic designation.

The users of GenBank validator are national agricultural institutes experts (members), the Patent Office, and the Executive Agency of Variety Testing Field Inspection and Seed Control (EAVTFISC). Each participant is provided by an account and a public/private key pair for verification and signing of transactions.

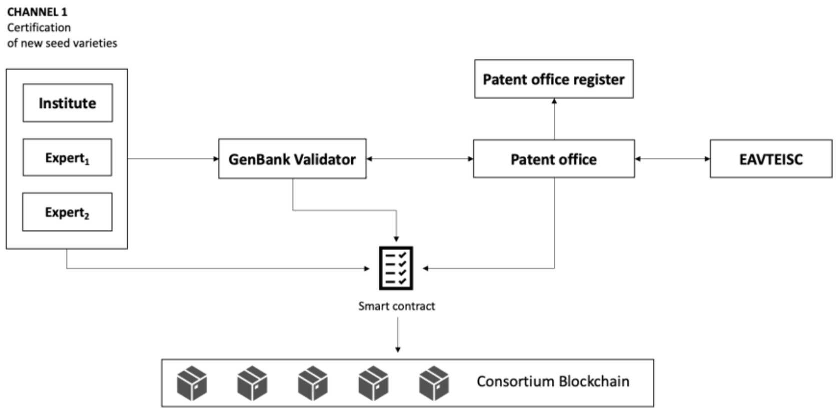

Fig. 3. GenBank validator

The certificate for a new plant variety issuing process is presented on Fig. 3. An authorized expert generates a request and enters the new plant variety data into the system – creates an "asset" and sends the request to a second expert from the same Institute through a transaction.

If the two authorized experts sign the transaction, they agree on the existence of a new plant genetic variety. The "asset" is sent by transaction from the Institute to the Patent Office, together with all required documents.

The Patent Office (within the statutory period) submits the application to the EAVTFISC. EAVTFISC performs the statutory inspections, samples for analysis, documents, etc., and returns its expert assessment to the Patent Office. The Patent Office signs (confirms the validation) the received transaction from the Institute.

The new plant variety is entered in the state register of variety certificates of the Patent Office. The system issues a certificate for a new plant variety to the respective Institute after payment of respective fees.

The ***GenBank Store*** (Channel 2) has three functions: (1) seeds exchange between national and foreign agricultural institutes; (2) seeds donation from Bulgarian Institutes to foreign botanical cities; (3) selling of genetic specimens from Bulgarian Institutes to farmers-curators and propagation technology control of compliance. Here is presented the third function [10]. The users of the channel are the GenBank, farmer-curators, and the regulatory bodies (Fig. 4).

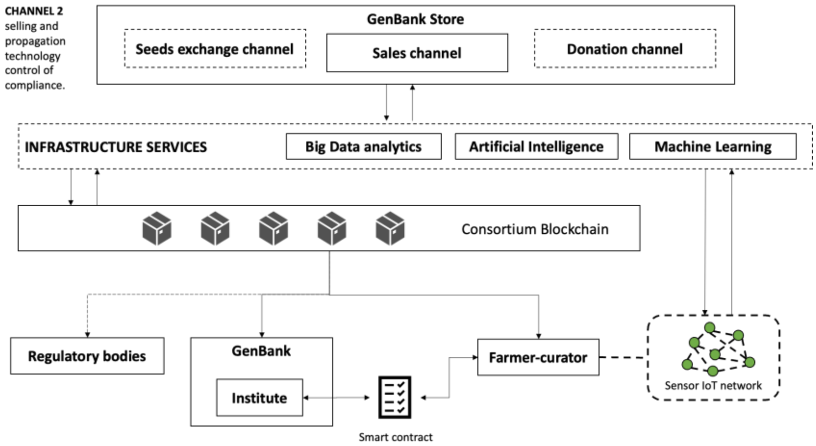

Fig. 4. GenBank store

The Genbank store supports a catalogue of certificated genetic specimens and seeds available to authorized users. A certain amount of seed specimens is set aside for long-term storage at the institute that selected and certified these seeds. The remaining quantity can be uploaded in the GenBank Store.

The farmer-curators chooses the variety for propagation and sends a request to the respective institute. When the institute receives the request, a smart contract is initiated. By singing the smart contract the farmers-curator is agreed to grow the variety according to a specific technology (fertilization time, minimum moisture values, maximum soil oxidation, etc.). The exchange of seeds specimens and certificate of origin, logistics and payments are supported by blockchain.

After harvesting, the farmer-curator enters the yields obtained and data concerning compliance with the cultivation technology in the system. The relevant institute confirms the compliance.

In case the farmer-curator has an established and functioning IoT sensor network (for measuring air temperature, oxidation, soil moisture, etc.), the data obtained and recorded locally can be used for analysis and decision making with machine learning techniques and artificial intelligence. The results of analyses and records of critical data can be stored in a blockchain. They can be used in at least two subsequent processes. First, as a mechanism for monitoring and controlling the requirements for growing the respective crop. Second, to check the correspondence between the estimated yield, the actual yield and the quantities of certified seeds sold by the curator to other farmers.

In case of detected violations in the cultivation technology, the system can automatically revoke the right of the farmer-curator.

The ***Consortium seeds exchange*** (Channel 3) aims to facilitate the sales of certified seeds by farmer-curators to other farmers (Fig. 5). Here standard trade deals are realized through smart contracts. Users of the channel are farmer-curators, farmers and regulatory bodies. The farmer-curators upload in the system the quantities and prices of certified seeds for sale using GenBank validator identification number.

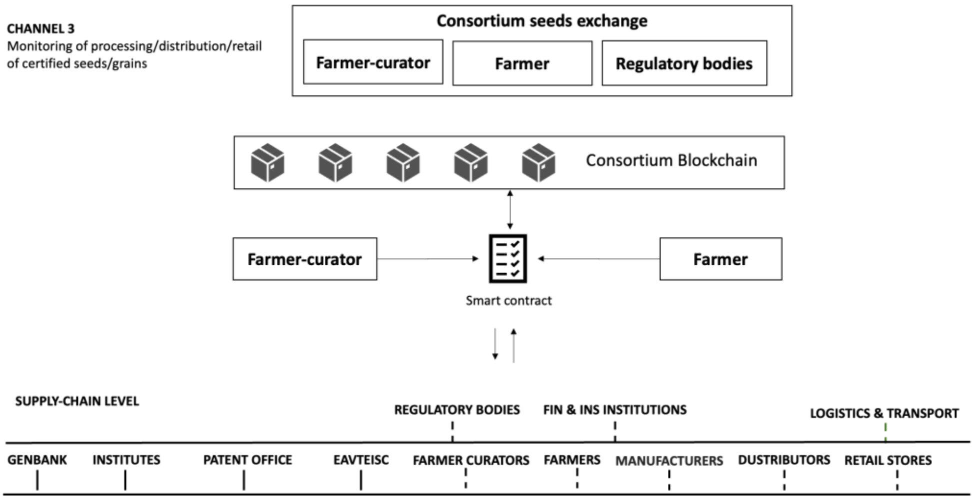

Fig. 5. Consortium seeds exchange

The purpose of the ***Consortium Raw Materials*** (Channel 4) is to exchange grains between farmers and manufacturers or between manufacturers (Fig. 6). The users of the channel are farmers, manufacturers, and state regulatory bodies. The farmer declares the harvest quantity for sale, using the same identification number of the variety received from the farmer-curators. Here, the status of the good being traded is changed from seed to raw material. A manufacturer sends a request for the respective raw material from a farmer or other manufacturer via smart contract. It includes all the terms of the transaction. If a participant does not meet the required terms, the smart contract is not executed. The system automatically deprives the incorrect party of rights after two identified discrepancies.

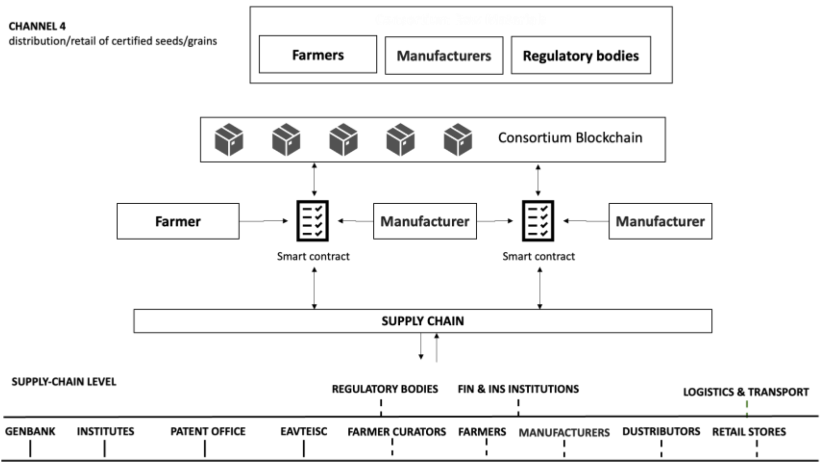

Fig. 6. Consortium raw materials

The purpose of ***Consortium Products*** (Channel 5) is to facilitate the distribution and retail sale of products manufactured from certified grain crops to end customers, as well as to trace the origin of the goods (Fig. 7). The users of the channel are manufacturers, distributors, retail stores, and state regulatory bodies. In order to determine the product identification number, each manufacturer adds raw materials and production process details. The system automatically generates identification number and a certificate of origin. The manufacturer sets the product price. The distributors/grocery stores can initiate smart contract request with a manufacturer/distributor. The supply-chain level is used to facilitate financial and logistics exchange. The customer could back-trace the good with QR Code.

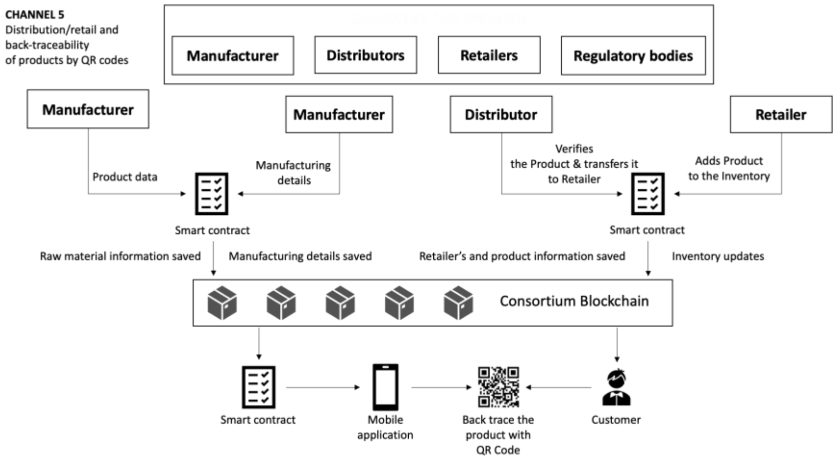

Fig. 7. Consortium products

7. Smart contracts design

A smart contract is a computer program or a transaction protocol intended to execute, control and document legal events and actions according to an agreement or a smart contract.

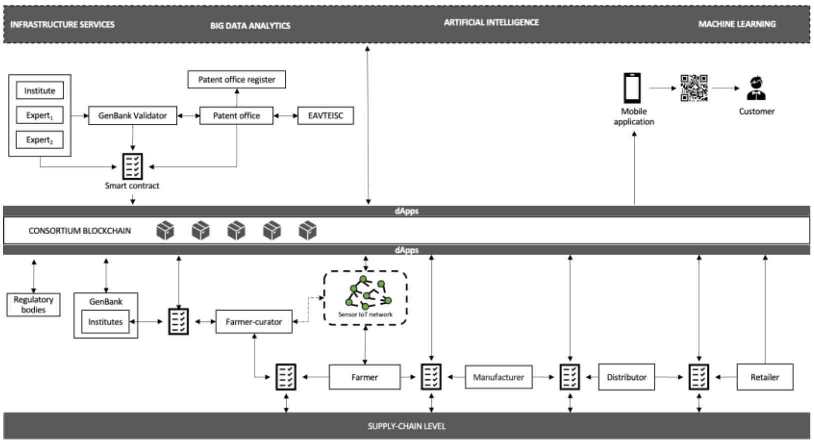

Fig. 8. SCPBC Blockchain smart contract layer

The information channels of SCPBC (Smart Crop Production Blockchain) will be implemented on a smart contract layer (see Fig. 1). At a higher level of aggregation this layer is represented on Fig. 8. The smart contract interactions are indicated, but not specified on the diagram. Participants are also presented as one. However, there will be more than one institute, farmer-curators, farmers, manufacturers, distributors and retailers as well.

It is seen in Fig. 9 which type of contract between which parties is signed and executed:

- *Regulatory bodies* are authorized to use smart contracts 1, 2, 3, 4 and 5;
- *The GenBank* is authorized to use smart contracts 1 and 2;
- *Farmer-curators* are authorized to use smart contracts 2 and 3;
- *Farmers* are authorized to use smart contracts 3 and 4;
- *Manufacturers* are authorized to use smart contracts 4 and 5;
- *Distributors* and *Retail stores* are authorized to use smart contract 5.

The smart contracting with *Logistics and transport* companies and *Financial and insurance bodies* (banks, insurance companies, etc.) is not designed at the current stage of development and is considered as an option. Its implementation requires clarification of many additional conditions, the availability of IT infrastructure and legal regulations.

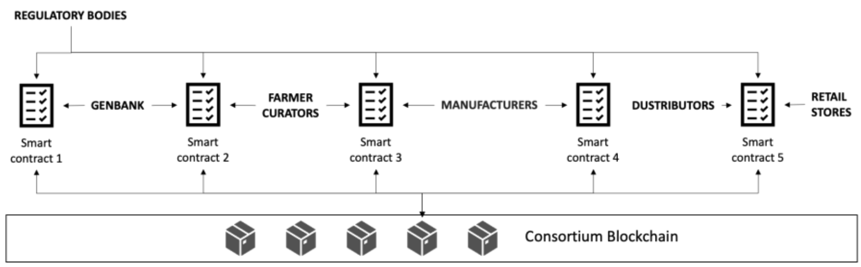

Fig. 9. SCPBC Blockchain smart contracts diagram

Each smart contract contains the following main sections: {multi-index tables – define different registers, with their respective fields and types, as well as the ways to indexing}; {structures – define structures of variables with their respective types}; {actions – executable functions that can be initiated by a user with the appropriate rights (permissions).} They perform various operations with the data processed by the smart contract, as well as communication and interaction with other users and/or (other) smart contracts in the blockchain. Execution time for each action cannot exceed 140 ms.

User accounts can be created with one or more (by type: farmers, farmer-curators, processors, etc.) public/private key pairs. Each account is allowed access to a relevant action (smart contracts).

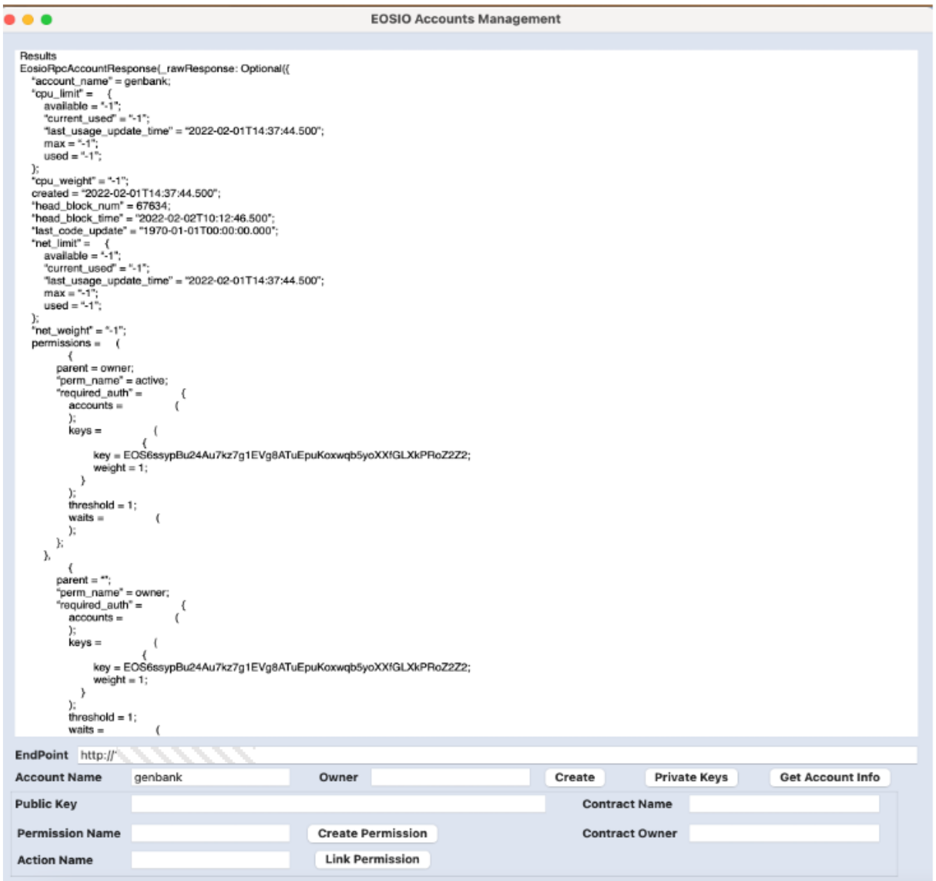

Fig. 10. EOSIO user account management tool screenshot

A universal application (Fig. 10) under OSX has been created to manage the accounts of the participants in the blockchain. The IP address entered in the EndPoint field is used to connect the corresponding node. On the screen shown, for security reasons, the actual IP address of the installed blockchain has been fogged.

Creating an account requires input of AccountName, Owner and Public Key. To get info for account requires the appropriate AccountName. Creating a Permission to use a smart contract requires user AccountName, Contract Owner, Contract Name and Permission Name. The linking of this permission to a particular smart contract action requires specifying an Action Name. The Private keys button displays the list of private keys loaded in the application.

When the entire blockchain network will be installed and operational, this application will have dApp functionality.

8. Smart contract examples

The programming language used for smart contracts in EOSIO is C^{++}. Data structures (objects), multi-index tables with indexing methods, constants, etc. are defined in the contract. It also includes all actions called by users with the appropriate rights/permissions. Actions perform operations both with internal for the contract data as well to communicate with other smart contracts. If it is necessary to process off-chain data, they are submitted as parameters of the actions by a user with the appropriate rights/permissions.

Here are presented general descriptions of smart contracts basic functionalities as a proposal and do not claim to be exhaustive. They present the owner, the participants and some of the main actions.

***Smart contract* 1: "genbank"** account and a smart contract with functionality:

- internal request for certification of a new variety (confirmation by a second expert (multi-signature transaction));
- application to the Patent Office for registration of a new variety;
- application to the Executive Agency for Variety Testing, Field Examination and Seed Control (EAVTFISC) for expertise;
- registration (or rejection) of a new variety;
- registers: {users, approved variety, submitted applications in progress, paid fees}.

***Smart contract* 2: "genbankstore"** account and a smart contract with functionality:

- request for purchase of a variety for propagation;
- yield report on the cultivated variety;
- registers: {users, genetic specimens, seeds inventory, IoT critical data, payments}.

***Smart contract* 3: "seedexchange"** account and a smart contract with functionality:

- purchase request;
- registers: {users, seeds inventory, payments}.

***Smart contract* 4: "rawmaterials"** account and a smart contract with functionality:

- request for purchase of raw material;
- registers: {users, identification number of the variety, harvest volumes, transportation, payments}.

***Smart contract* 5: "product"** account and a smart contract with functionality:

- request for purchase of raw materials for product production;
- request for purchase of products from a distributor/store;
- registers: {users, inventory, certificates of origin, prices, transportation, payments}.

The selected parts of the "genebank" smart contract are illustrated in code. In the example of a smart contract action a user calls the action "addgenebank" from the smart contract validator with parameters of his account name and data structure that describes a new object of the type "gene_bank". The action checks whether the user has required rights/permissions and if so, it adds an entry in the multi-index table containing all objects of the "gene_bank".

```
#include <eosio/eosio.hpp>
#include <eosio/system.hpp>
#include <eosio/time.hpp>
#include <eosio/singleton.hpp>
#include <string>
#include <vector>
#include <validator.hpp>

using namespace eosio;
using namespace std;
using namespace validator;

CONTRACT validator : public contract {
  public:

    ACTION addgenebank (name creator, gene_bank data) {
      check (has_auth (creator), "You have no authority to add gene bank!");
      geneBanksTable geneBankTable(get_self(), get_self().value);
      auto idx = geneBankTable.end();
      auto id = idx.id + 1;
      geneBankTable.emplace( get_self(), [&](auto& new_row){
        new_row.id = id;
        new_row.filename = filename;
        new_row.unique_name = data.name;
        new_row.data = data;
        new_row.date_added = time_point(current_time_point());
      });

      print("Successfully added!");
    };

};
```

In example below, the "gene_bank" object, a multi-index table and the indexing method are defined. Each multi-index table must contain one indexing method related to a field with a unique content. Up to seven secondary indexing methods can be added to other fields in the tables.

```
   struct gene_bank {
         string name;
         string bulstat;
         string address;
   };

struct [[eosio::table, eosio::contract("validator")]] genbank_table {
         uint64_t id;
         string unique_name;
         gene_bank data;
     time_point date_added;

  uint64_t primary_key()const { return id; }
};

typedef eosio::multi_index <
   name("genebanks"),
   genbank_table,
   eosio::indexed_by<
     name("id"),
     eosio::const_mem_fun<
       genbank_table,
       uint64_t,
       &genbank_table::primary_key
     >
   >
 > geneBanksTable;
```

As noted in the outset specific and comprehensive descriptions of blockchain-based supply-chains or other integrated in practice applications of blockchain technology, whether in industry or in academic researches, are rare. The reasons could be different, an early stage of development, copyright considerations or because they are presented mainly at conceptual level. The ideas, results and examples presented here are aimed to be further used in the design of this blockchain-based supply-chain model, to be upgraded and implemented in a prototype for performance testing, analysis and evaluation.

9. Conclusion

This paper proposes an approach to blockchain-enabled supply-chain model for a smart crop production framework. A blockchain ecosystem has been analysed as a network of stakeholders who share different goals, connections and processes and as an infrastructure of technical and logical elements. The analysis helped a supply-chain model to be defined which facilitates seeds certification process, monitoring and supervision of the grain process, provenance and as an option interactions with regulatory bodies, logistics and financial services. The participants are economic and non-economic entities, such as different national institutes, members of the GenBank and regulatory bodies. The analysis also allowed to select a blockchain development platform and to design a blockchain reference infrastructure with three levels: a supply-chain, an IT infrastructure services, and a blockchain. It has been proposed a blockchain-enabled supply-chain to support five information channels and smart contracts. A description of information channels and the corresponding diagrams of various on-chain actions are presented in details. The smart contracts layer, the user application tool for account management, the general descriptions of smart contract basic functionalities and one smart contract code are provided as examples.

Despite the great hopes placed on blockchain technology, as well as the prospects for their implementation in various spheres of life, outside of cryptocurrencies, this technology is still looking for its meaningful place. The problems that remain to be solved are both technical and conceptual. The technology is expensive to implement, requires specific expertise and additional training. It should be treated as a link and basis for the decentralization of interaction and implementation of network services. How developers will synchronize information bridges and compatibility in the future remains a question and a serious challenge.

There are many open problems in supply-chain management. Some of them are related to the technical limitations of distributed book technologies, such as scalability, interoperability between different platforms, IoT integration, immutability and control of off-chain tasks. Others are related to the digitalisation of supply-chains, such as: formulation of regulations and policies, link between physical and digital product, standardization of traceability and quality certification.

The future development of this research is a detailed description of the data model, business model and smart contacts design for supply-chain information channels. These are models, processes, data and information, some of which need to be processed off-chain, but some of their main elements, data and results have an indisputable place on-chain. The blockchain technology itself and the SCPBC Blockchain in particular has the potential to become the basis for a next generation approach for developing an equal economic and regulatory relationships in the cyber-physical environment in agriculture and smart crop production framework.

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