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BLOCKCHAIN-BASED SYNCHRONIZATION OF PERSONAL ASSISTANTS

ABSTRACT

of a dissertation for the awarding an educational and scientific degree of Doctor (PhD)

Field of Higher Education 4. Natural Sciences, Mathematics and Informatics,

Professional Direction 4.6. Informatics and Computer Science,

Doctoral Program: Informatics

Scientific supervisor: Prof. Stanimir Stoyanov, PhD

Plovdiv 2024

The dissertation was discussed and directed for defense before a scientific jury at a meeting of the Department of Computer Systems at the Faculty of Mathematics and Informatics of Paisiy Hilendarski University of Plovdiv on 15.12.2023.

The dissertation contains 139 pages. The List of references includes 150 sources. The list of author's publications on the topic consists of 4 titles.

The defense of the dissertation work will take place on 15.03.2024 at ……… in the Meeting Hall of the New Building of University of Plovdiv.

The defence materials are available in the Dean's office of the Faculty of Mathematics and Informatics - Office 330 in the New Building of Paisii Hilendarski University of Plovdiv every working day from 08:30 to 5:00 p.m.

Scientific jury:

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Plovdiv, 2024

CONTENT

LIST OF FIGURES

INTRODUCTION

Trends in contemporary development indicate that closely related technologies such as the Internet of Things (IoT), cyber-physical systems (CPS), and cyber-physical social systems (CPSS) are increasingly playing a significant role. The Virtual Physical Space (ViPS) is an Internet of Things ecosystem developed in the laboratory of the "Distributed e-Learning Center (DeLC)" at Paisii Hilendarski University [20]. Due to its flexibility, the reference architecture of the space can be applied in various areas, including smart agriculture, tourism, smart cities, and education.

In contemporary development, data security is a key theme requiring increasing attention. This provides a basis for the widespread use of Blockchain technologies, which can minimize the risk of manipulation of already stored data. Integrating these technologies into cyber-physical systems would provide opportunities for a more comprehensive and successful realization of global goals in the digital era.

MAIN GOAL OF THE DISSERTATION RESEARCH

The main goal of the research is ***to analyze and conduct experiments on the integration of intelligent personal assistants with blockchain technology***. Additionally, an **auxiliary goal** is ***to develop and test blockchain-based models synchronized with personal assistants for various adaptations of the Virtual Physical Space (ViPS)***.

We formulate the thesis that in many applications, enhancing personal assistants with a suitable blockchain is meaningful, effective, and usable. This enhancement provides an opportunity to elevate the level of credibility in interactive communication among intelligent components in a multi-agent system. To substantiate this thesis, we will employ a constructive approach by creating an architecture and prototype of a multi-agent system that utilizes a purpose-built blockchain. Additionally, we will summarize the results obtained from the conducted experiments.

For the realization of the main goal, the following **sub-goals** have been formulated:

- Development and testing of an "Electronic School Diary" model, built on the basis of synchronization between intelligent agents and the use of blockchain technologies within the framework of adaptation of the reference architecture in the field of secondary education.
- Development and testing of a model for the application of the technology in the adaptation of the ViPS architecture in intelligent agriculture.

The general approach and the methodology of scientific research are based on a step-by-step approach that goes from: getting to know the problem; creation and testing of various approaches and models related to the application of blockchain technologies and their synchronization with personal assistants in various problem areas such as education, smart agriculture, etc.

For the implementation of the **first sub-goal**, a research methodology was formulated using several approaches:

- Storing change-sensitive content such as student test scores using **blockchain**.
- Creation of a **Data Module** where current information about parent meetings, student behavior notes and more will be maintained.
- Synchronization of these two data stores, by means of **intelligent agents**.

For the realization of the second sub-goal, it is necessary to develop a prototype system for validation and distribution of genetic types of seeds related to the Gene Bank of the Republic of Bulgaria. Implementation uses a step-by-step approach, including system modeling; implementation of Blockchain communication channels and communication mechanisms in a multi-agent system.

MAIN TASKS RELATED TO THE STATED GOALS:

1. After studying various aspects and approaches in the development of Blockchain technologies, to create a general concept of their use in synchronizing information so that personal assistants can use it.
2. To create models for the application of this concept in the adaptation of the reference ViPS architecture in the spheres of education and intelligent agriculture.
3. To create prototypes and test the application of these models.

In order to present the main ideas in the development of the models, it is necessary to describe in more detail what the main properties and characteristics of personal assistants are and what Blockchain technology is, as well as what the ViPS environment is.

DISSERTATION STRUCTURE

Предложеният изследователски труд е разделен на няколко логически компонента, които биват разглеждани в отделните глави на дисертацията:

Introduction - The introductory part of the dissertation presents the problem under consideration, the main goals and tasks of the dissertation work. The general approach and methodology of scientific research are presented.

Chapter 1. Motivation and state of the research problem. This chapter motivates the need to conduct the current research. The characteristic features, advantages and disadvantages of blockchain technology are presented and summarized. Additionally, features of cyber-physical and cyber-physical-social systems are addressed, discussing the ViPS Virtual Physical Spatial reference architecture through which to model target systems such as education and smart agriculture adaptations**.**

Chapter 2. Application of blockchain technologies in a multi-agent system and adaptation of ViPS in education. This chapter describes the software architecture and models the BLISS educational multi-agent school platform. Blockchain-based synchronization with personal assistants in the construction of the electronic diary is presented. A model application that manages and coordinates the use of factory-numbered documents in a secondary school is also presented.

Chapter 3. Application of blockchain technologies in a multi-agent system and adaptation of ViPS in agriculture. The third chapter presents the application of the considered concept in creating a system for intelligent agriculture in two directions: implementation of a validator of new seed samples in the national GenBank (GenBank Validator) and a store for the sale or exchange of seed samples and their use in real production (GenBank Store).

Chapter 4. Conceptual models and future plans. This chapter presents some conceptual models for applying the proposed concept in system development in the field of agricultural supply chain and tourism. An analysis is made and directions for future research are identified**.**

Conclusion – the result obtained in the dissertation research are summarized.

CHAPTER 1. MOTIVATION AND STATE OF THE RESEARCHED PROBLEM

Modern development raises the question of ensuring trust and confidentiality between agents in multi-agent systems [1]. This problem can largely be solved through the use of Blockchain technologies. In [11], a blockchain-based method for managing trust between agents in a multi-agent system (MAS) is proposed, achieving three objectives: trust, cooperation, and privacy. Blockchain can provide a secure and decentralized framework for autonomous agents. It is also used to protect agents to increase their trust in MAS. In [14], a consortium blockchain-based trust management system (BTMS) in a multi-agent system is proposed. BTMS is based on game theory that improves the cooperative behavior of agents.

1. Blockchain technologues

Blockchain technologies manage to achieve integrity and trust in a pure peer-to-peer (P2P) system that consists of an unknown number of nodes (peers) with unknown trustworthiness. The P2P architecture is a distributed software system that consists of peer nodes. Through fast and secure transactions, participants exchange information and assets with each other, without the intervention of various intermediaries. Nodes cooperate together using a communication medium to achieve a certain goal without having a central element for coordination and control. A key role in building and maintaining the blockchain is the use of cryptographic and security technologies to achieve integrity, which is the ability to make true claims of ownership. Blockchain technology is based on a distributed system of registers (ledgers) that maintain ownership information and store the entire history of transaction data in the chain. Each node owns its own copy of the registry, and the blockchain algorithm allows individual nodes to collectively and consistently establish ownership [3]. The purpose of the blockchain is to store a huge amount of data and have it remain unchanged after its creation, or in the event of an attempt at manipulation, these changes can be detected quickly and easily [24].

The block chain widely uses a public-private approach of asymmetric cryptography, which is the basis for identifying users, transferring ownership, and protecting them from unauthorized access to the system. Blockchains can be classified, according to their ownership, into public and private. Public blockchains are "open" - they are open source and no rights are required to be included. Private blockchains are owned by a separate organization. All these characteristics of Blockchain technology enable its application in various spheres of public life, education, tourism, and also in agriculture. Guaranteeing security and quickly detecting data manipulation attempts can be successfully applied in the development of an electronic diary, a system for tracking the movement of documents with factory numbering, building systems in agriculture and tourism.

Blockchain technology and features. To access the Blockchain, each user receives a public and private key that serves to identify him in the network. Public keys are used to identify participants and encrypt data, and private keys are needed to decrypt and create signatures. Let's assume that entity A wants to transfer an Asset (tangible, intangible or financial) to entity B. Entity A initiates a transaction in which it adds the relevant Asset, the address of entity B (its public key), as well as the price it will pay for the processing of the transaction and its validation by Blockchain. Subject A signs his transaction with his private key and generates a hash of the transaction. The transaction is sent to Subject B, who verifies it (decrypting it with Subject A's public key) and, if he agrees with the data in it, also signs it with his private key. In this way, the two agree to the details of the transaction. The new transaction is added to the Transactions Pool, which contains all transactions awaiting approval and validation. A fraction of nodes in the network have the right to validate blocks in the chain. Each of them selects a part of the transactions from the Transactions pool, which it adds to its private pool. Checks each added transaction for its formal, semantic correctness and authorization (Fig.1).

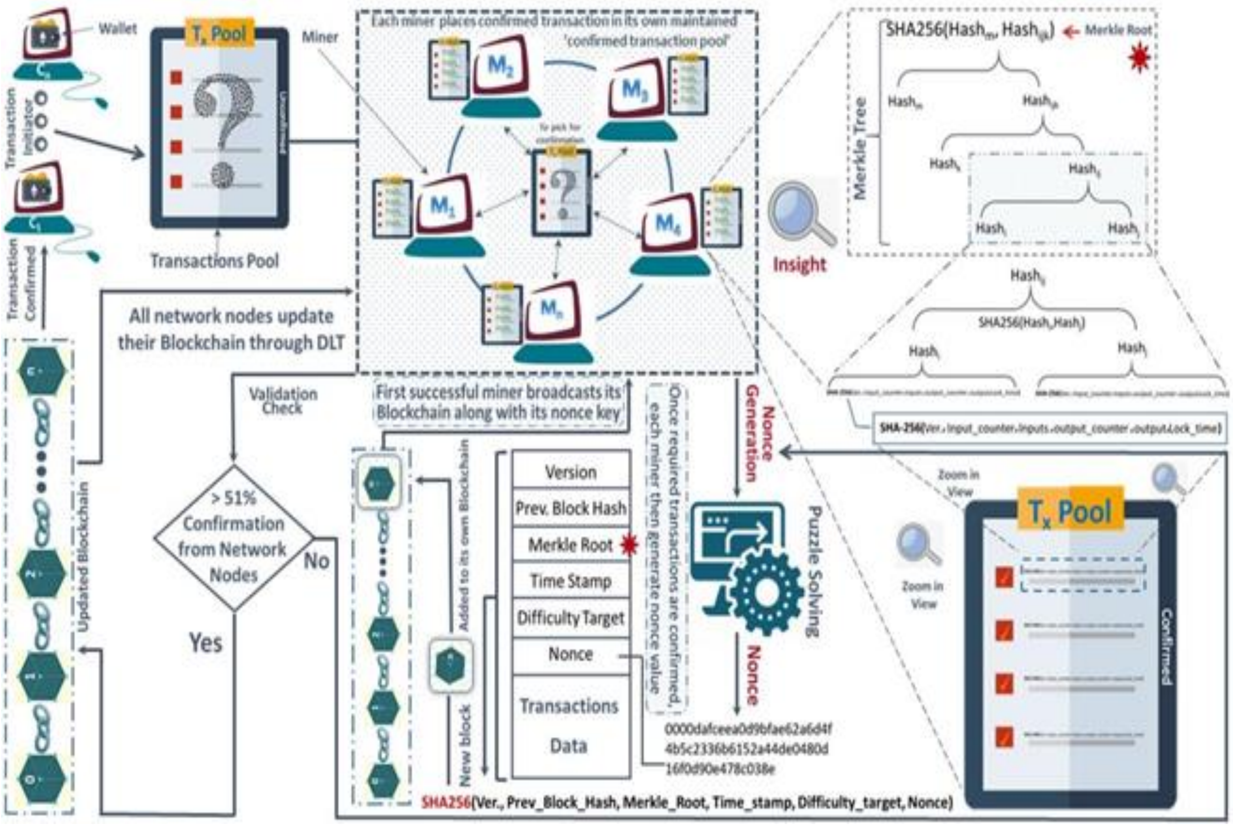


FIGURE 1. **TECHNOLOGY OF OPERATION OF THE BLOCK CHAIN**

Depending on the consensus mechanism [16] that is chosen by the respective Blockchain, one of these nodes will earn the right to validate a block, with the transactions it has selected and verified. All transactions, with their corresponding hash values, are added to the Merkle tree and hashed pairwise until a single hash value, not called the root of the Merkle tree, is reached. This tree root is added to the block header of the future block, as well as the hash value from the previous block's data, a timestamp, the difficulty level, to solve the hash puzzle, and the nonce value (in a PoW consensus algorithm) that solves the hash puzzle. Next, the node announces the future block to the network. All competing nodes check whether all the data in the block is correct (transactions and nonce) and if they find no inaccuracies, they approve it. In order for a block to be attached to the chain, it needs to receive 51% approval from the other nodes that have the right to validate blocks. All nodes eligible to validate blocks compete to win the reward (cryptocurrency) that each validated block brings with it, and for that they strive to find inaccuracies in the competitor. After the block is validated, all ledgers in the network are updated with the transactions that the new block contains. Subject A and Subject B's balances are updated to reflect the successful transaction, with all network participants seeing their updated balances.

A **smart contract** is a program that is self-verifying, self-executing, tamper-resistant and runs on a Blockchain platform. The main components of a smart contract are a set of executable functions and state variables. Each transaction has input parameters that are required for contract function. During the execution of a function, the state of the variable changes depending on the logical implementation. Smart contract code can be written in a variety of high-level languages. Once the code compiles without errors, the contract can be uploaded to the Blockchain network. Each contract will be assigned a unique address by the Blockchain network. Any user on the network can trigger the functions to send any type of transaction. Smart contracts, as described in [10], can send a message to other contracts. The message consists of the sender's address, the recipient's address, the transfer value, and a data field that contains the recipient's contract input.

In essence, smart contracts provide the business logic of a decentralized application (Dapp) deployed on Blockchain and enable participants to enter into various agreements with each other. Smart contracts include logic, data, properties, and events. They are event-driven, meaning they can be activated when certain conditions are met. Furthermore, they can only work with resources available inside the blockchain network and cannot interact with external data.

What is Oracle Blockchain? The smart contract receives information from an external agent program called an "Oracle" about the occurrence of an event in the physical world. Oracles are essentially a form of communication between the outside world and the Blockchain world. Because Blockchain and smart contracts are closed systems, oracles represent a way to securely provide data off-chain to the Blockchain network. They are components (agents) that reside **outside** the chain, and for this reason the trustworthiness properties of Blockchain do not apply to them.

Cryptlets are components in the Blockchain network provided by Microsoft that enable decentralized applications (DApps) to communicate with external systems and services in a secure manner. They are one of the key concepts of the Azure Blockchain Workbench and represent off-chain code. They run in a secure, trusted container and communicate using secure channels. Cryptlets can be used in Smart Contract systems when access to external resources, additional functionalities or other off-chain information is required without compromising the security and trust of the Blockchain network. The idea behind Cryptlets is to provide greater flexibility and functionality for blockchain applications while maintaining data integrity and security. Through them, the advantages of Blockchain technologies can be combined with the power of cloud services. This is an important step towards expanding the potential of Blockchain in various spheres of business and social aspects.

The main challenges faced by Blockchain technology are: scalability problem; network latency issue; low throughput; integration with existing legacy systems; data privacy, etc.

Potential solutions to the problems are: the development of systems with hybrid architectures and the use of centralized databases; the use of cloud services, and to further improve the privacy and security of Blockchain, a hierarchical Blockchain-based system [9] consisting of from private blockchains, through which better data privacy characteristics are achieved, and a consortium blockchain, in which data will be stored for the implementation of economic relations between various actors, as well as data storage required by legislative or regulatory authorities [8].

2. Cyber-Physical (CPS) and Cyber-Physical-Social Systems (CPSS)

Cyber-physical systems (CPS) refer to the integration of processes and computations between the physical and digital worlds. According to the National Science Foundation (NSF) [15] definition, cyber-physical systems (Cyber-Physical Systems - CPS) provide integration between computational, network and physical processes. Embedded digital components and networks monitor and control physical processes, providing continuous feedback and control. The term Cyber-Physical-Social System (CPSS) was first introduced in [23]. They are seen as systems providing intelligent human-machine interaction in cyberspace to achieve management and control of complex socio-technical systems.

Virtual Physical Space (ViPS) is an ecosystem of the Internet of Things, which is being developed in the laboratory of the "Distributed Center for Electronic Learning (DeLC)" of PU "Paisiy Hilendarski". The ViPS architecture is built as a reference architecture that can be adapted for various CPSS applications in various application areas such as smart agriculture, tourism, smart cities, and also in education. Typically, when building a specific ViPS application, only individual components of the architecture are adapted, adding and integrating modules specific to the subject area being addressed. We can define the following aspects of ViPS:

- Users are the focus of attention that defines a space like CPSS.
- Physical "things" are virtualized by being processed in a unified way.
- Integration of the virtual and physical worlds is ensured.

The reference ViPS architecture is multi-agent, as agent-oriented approaches are suitable for building CPSS applications. Due to the nature of ViPS, users are at the center of attention. The development of personal assistants (PAs) in ViPS is based on the BDI software architecture, which tries to mimic the way humans think. Each PA should perform two main tasks: support and prevention and possess the following properties: be autonomous, reactive, proactive and social. The specification of the environment in which agents operate is essential to their operation. Any action on the environment would lead to a change in the agent's beliefs, and from there to a change in his intentions, and he could go back to the phase of deliberation and change of the plan to achieve the goal. Its beliefs can also be changed by communication with another agent.

In addition to personal assistants, in the ViPS space there are also assistant guards who ensure the interaction between the physical and virtual worlds, as well as operational assistants who help the implementation of plans, ensure the implementation of various services and maintain a connection with the subspace of digital libraries where data is stored and the knowledge of the relevant area of adaptation of ViPS.

CONCLUSIONS FROM CHAPTER ONE

1. Blockchain technologies are a distributed cryptographic system that guarantees ownership, eliminates intermediaries, ensures transparency and traceability when managing processes with more participants. They are suitable for accountability and trust in the interaction of agents in a multi-agent system.

2. Synchronization between agents in a cyber-physical and social environment with a system built on block chain technology can be implemented using a specialized Oracle blockchain agent.

CHAPTER 2. APPLICATION OF BLOCKCHAIN TECHNOLOGIES IN A MULTI-AGENT SYSTEM AND ADAPTATION OF VIPS IN EDUCATION

BLISS is an adaptation of the ViPS reference architecture to support the learning process in secondary school [22]. BLISS is implemented as a multi-agent system. The core of the system is built by personal assistants that interact with each other. The environment of the agents consists of two parts – a BLISS server, driven by events, and a SchoolDiary, implemented as a Blockchain [6]. New types of specific personal assistants have been developed as an instance of the genetic personal assistant [29], [30]. For the purposes of our research and development of the BLISS module, we have defined several personal assistants.

PAStudent. A personal assistant assisting students in carrying out their daily duties in accordance with an established curriculum. PA informs about all upcoming events that affect student such as exams, lessons, study sessions, consultations, etc. The assistant monitors and reminds the student what to prepare before the upcoming event. For example, if a notification of an upcoming event (exam in mathematics) L1=<Mathematics, Exam, attr(20.10.2023, time(10:00,10:45))> is received, it is necessary not only to inform the corresponding user, but and be in a position to perform anticipatory actions and prevention, i.e. having a prevention interval embedded in its knowledge base, for this type of event, for example 15 days, PA should prepare a plan how to support the student to participate in the event and to achieve the goal. It can provide him with the necessary resources for self-training and support him in the learning process. The PA is able to prepare analyzes of the results of the student's participation in the learning process.

PATeacher. This assistant is designed for teachers. In a similar way to the student assistant, it can also remind you of upcoming events and necessary preparation. Its main function, however, is to help teachers track and analyze the participation and progress in the learning process, as well as the results of their students. Analytics can be used for various improvements. So, for example, if the teacher notices that a large number of students have failed a certain part of the exam, but at the same time they have spent a considerable amount of time on self-training on that topic, then he may conclude that he needs to make some adjustments to the material, to ensure that it will be easier for students to digest.

PAParent. The assistant provides information to parents about their child's participation and progress in school. A parent can see information about grades, events their child has to attend and notes made by teachers. Thanks to the constant internal communication between the agents and analysis of the information received by the student's personal assistant, the parent can be warned about dangerous behavior or a change in the student's behavior. For example, if a child has been an excellent student and starts getting lower grades, the parent will be alerted. If the child starts to ignore the recommendations they get from their assistant, then it will send a notification to the parent assistant and the parent can react.

PAPrincipal. The purpose of this assistantship is to assist the principal of the school in effective management. The assistant is mainly intended for help in planning, conducting and controlling the learning process. This is the most difficult personal assistant to implement.

The assistants' environment consists of a BLISS server and a school diary. In the BLISS server, all information objects (such as schedules, lessons, exams, consultations, self-training, meetings) are represented as domain-specific events. Authorized teachers and moderators supported by the

BLISS-server can create, update and remove events. The server stores these events, controls access to them, and provides students with a personal assistant to generate, manage, and control personalized study programs and schedules. Any change in the server is automatically perceived by all "interested" assistants. In the environment of the assistants, the school diary (School Diary), realized with the help of Blockchain technologies, is also located..

1. Electronic School Diary. By its very nature, the "Electronic School Diary" module is a multi-agent system. For the needs of the present development, we define four types of roles of participants in the system, which are described in the BLISS module. Each role corresponds to a group of users who have the same functionality and rights. For each of the roles, genetic personal assistants are modeled to support users' work with the system. The goal we have set ourselves is to record change-sensitive content such as student grades that will remain unchanged over time using a blockchain, while also taking full advantage of the Data Module located at The BLISS server where information about parent meetings, student behavior notes and more will be maintained. We will use both approaches when building an Electronic School Diary. To build the School Diary, we use a private (closed) blockchain developed through the Hyperledger Fabric blockchain platform. This platform is open source [25], provides an opportunity to use and develop smart contracts (chaincode), through which certain business logic is provided to be executed on the Blockchain network. It also provides an opportunity to develop separate communication channels through which certain groups of participants communicate and send transactions to each other. A Hyperledger Fabric channel is part of the blockchain network, but has its own chain of blocks visible only to its participants. This allows organizations on the network to perform transactions and maintain proprietary data that is unavailable to other channels on the network. In one communication channel, one or several smart contracts can be executed, depending on the logic of the application.

A communication channel **"channelSD"** has been created for the Electronic School Diary. Teachers join it only after special permission from the school principal. After the access is allowed, the system provides a public and private key to the respective teacher, the public key will also be recorded as the unique identifier of his personal assistant, and the private key will be contained in it as a corresponding pair

Because Blockchain and smart contracts are closed systems (on-chain), Blockchain Oracles (BOs) provide a way to securely provide data off-chain to the Blockchain network. To record the ratings from the Data Module of the Electronic Diary (DMSD) in the blockchain, we will use Blockchain Oracle (BO). An oracle is an external data agent that observes real-world events and transmits them to the Blockchain network via a smart contract. On occurrence of a "Valuation Entered and Confirmed" event in the database, the oracle invokes a smart contract developed for the purpose and submits the data. Through the Smart Contract, transaction data is created in the block chain. After transactions are created and signed, the blockchain checks them for formal and semantic correctness and authorization. Only correct transactions are completed in a block and validated in the block chain. After a block is validated, all ledgers in the system are updated with the new data.

As already mentioned, ledgers maintain ownership information and store the entire history of transaction data that has ever occurred on the block chain, in particular the communication channel. The server where the SchoolDiary data module (DM) and personal assistants will be located will be a node on the blockchain and will store the blockchain ledger.

To link the Blockchain oracle, Data module school diary (DMSD) and the different groups of personal assistants, a specialist assistant (SA) is created, which is an intelligent agent and aims to respond to a change in the electronic diary environment. Upon approval of transactions in the communication channel of the chain, upon their entry into the server's ledger, the Blockchain oracle extracts this data and informs the Specialist Assistant (SA) that a change has occurred in its environment. Then he reacts and informs all assistants affected by this change. The oracle writes the information (the hash value of the transaction with the evaluation) into the data module, which is accessible to all personal assistants as well as the SA.

The SA environment consists of three modules (Fig.2) – DM of Electronic Diary (DMSD), DM of **School Main Book (DMMB)**, and DM **of Individual Student Cards (DMISC).** Only term and annual grades, as well as matriculation grades of regular students, are recorded in the School's Main Book. For students in an independent form of education, up to and including the 7th grade, only their annual grades are recorded in the Main Book. The information recorded in the individual student Cards (DMISC) is the same as in the School Main Book, but applies to students in 8th grade and beyond.

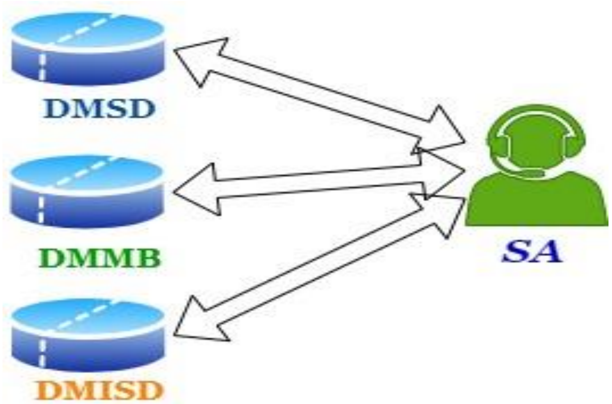


Figure 2. *SA Environment*

The environment of the Blockchain Oracle (Fig. 3) is the DMSD, the Blockchain ledger and the Blockchain itself, invoking a smart contract.

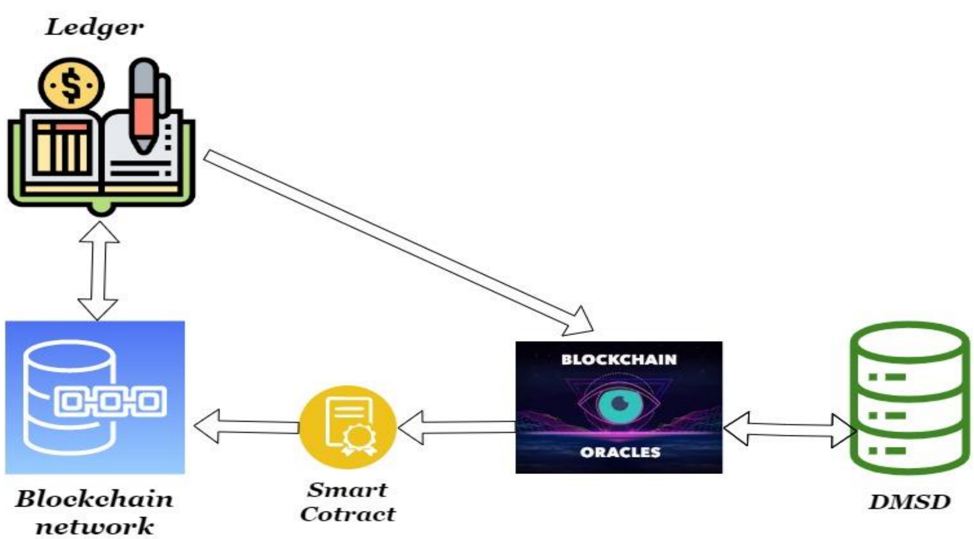
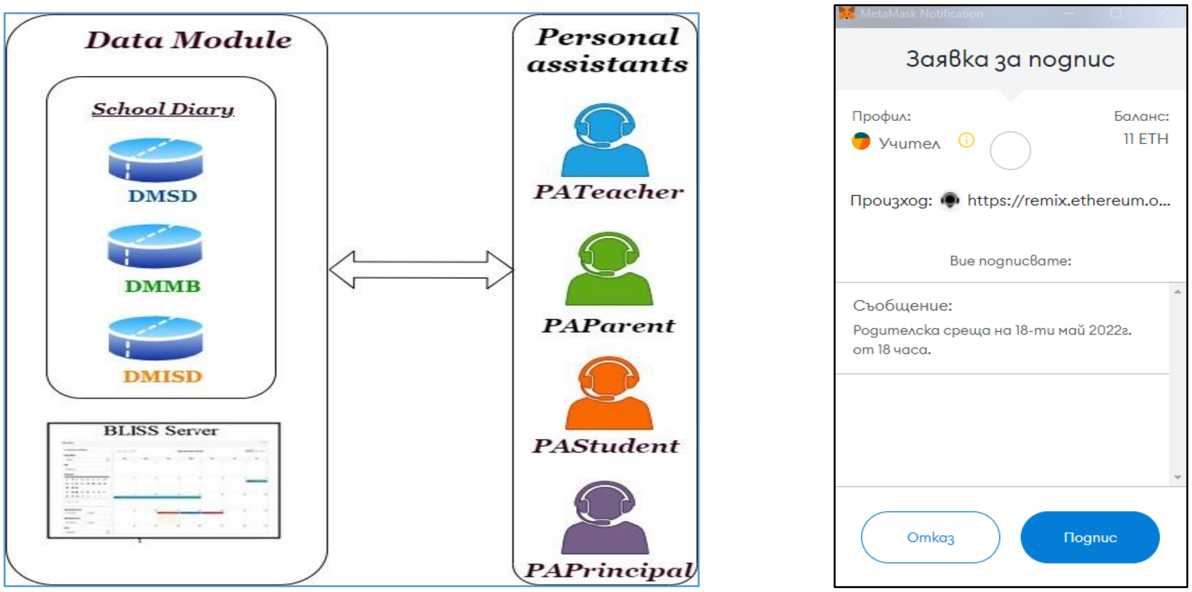


Figure 3*.BO Environment*

The environment of all Personal assistants (Fig.4a) is DMSD and event-driven BLISS server. Examples of such events are teacher consultations, exams, online content discussion, meetings, announcements, etc. In the following Figure 4b, a teacher's message generated based on the blockchain channel of the electronic diary is presented.



(a) (б)

Figure 4. *PA environment. A message from a teacher generated on the E-Diary blockchain channel*

As shown in the UML diagram of Fig.5, we distinguish four types of grades that are recorded in the electronic diary: current, term and annual and matriculation grades (including national external assessments). Each grade contains the following variables: the date it was entered, the subject for which it was set, the student who received it, the value of the grade, status - entered or confirmed, as well as the hash value of the transaction itself after the validation of the grade in the block chain.

As we described above, each personal assistant in VIPS must possess the following properties: autonomy - to operate independently and independently in the interest of the user; reactivity – to react to changes in its environment; proactivity – to take initiative in favor of the user and sociality – to interact with the user and other agents in the system.

When a teacher enrolls an assessment in DMSD, it is automatically assigned an "entered" status. The PATeacher environment in DMSD is changing. The teacher's personal assistant checks the average grade of the student in the given subject. If it detects a serious deviation (2 units of difference), compared to the current obtained grade, it sends this information to the teacher. In order for the grade to be sent to the blockchain for validation, it needs to be in the "Verified" status, so PATeacher queries the teacher if the grade is valid. If the teacher has made a mistake during the entry, he can change it or delete it from the log before confirming the validity of the grade. If the teacher confirms the grade, PATeacher sends the confirmation to the SA, which changes the status of that grade from "entered" to "confirmed".

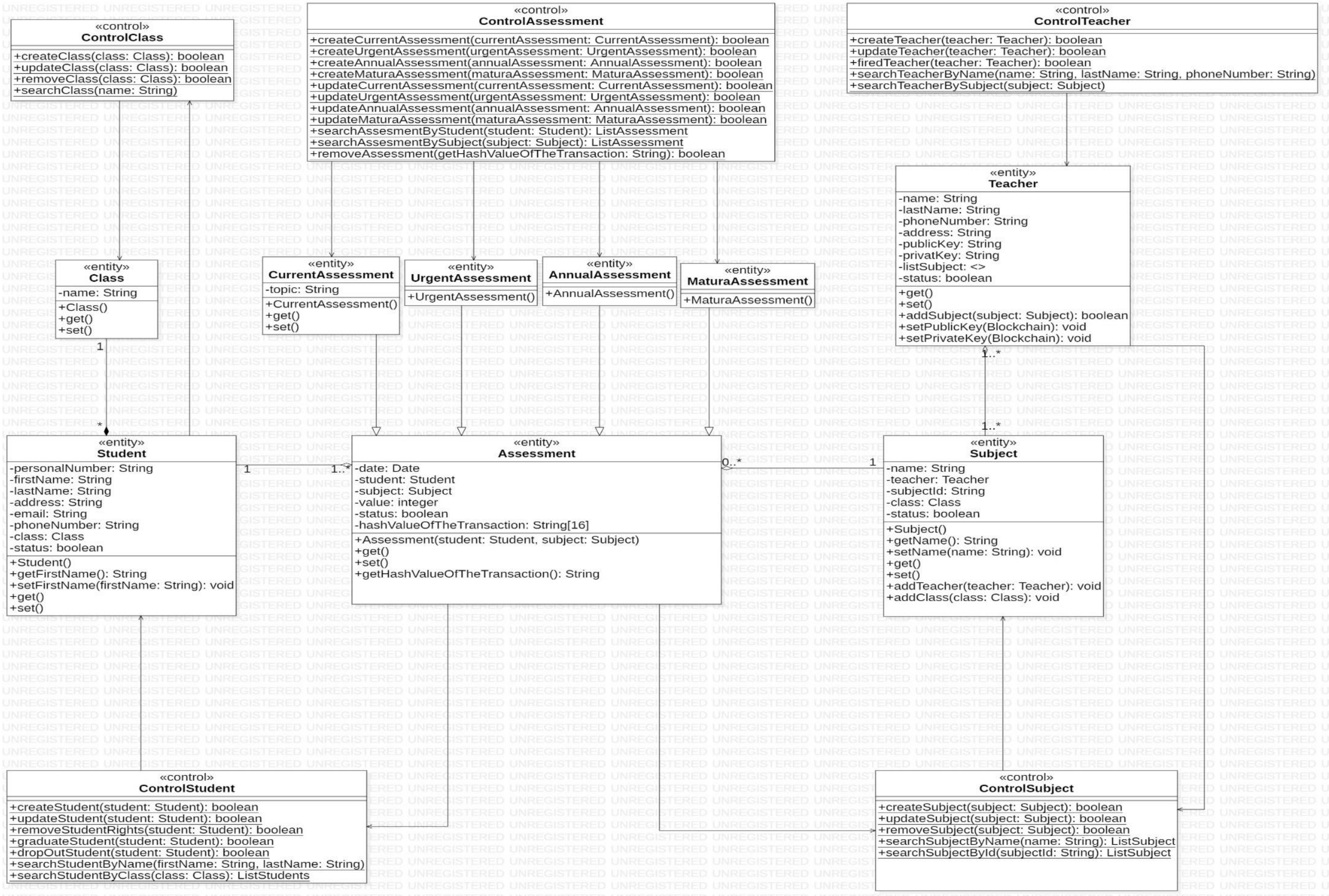


Figure 5. *Class diagram of the module with grades*

The oracle (BO), monitoring the DMSD, mainly monitors the change in the status of the grades, when it changes to "confirmed", it calls the smart contract, which completes the transaction data, signs it with the private key of the teacher and the private key of the school principal, as recipient and broadcasts it to the blockchain. After the data is checked for formal, semantic correctness and authorization, the transaction is validated in a block and recorded in the ledgers of the Blockchain nodes. The Oracle, monitoring the server's registry, knowing which evaluations it submitted for execution from the smart contract, after receiving this data, records the hash value of the transaction from the registry in the DMSD in field hashValueOfTheTransaction. Fig. 7 visualizes the sequence of actions in the implementation of this scenario.

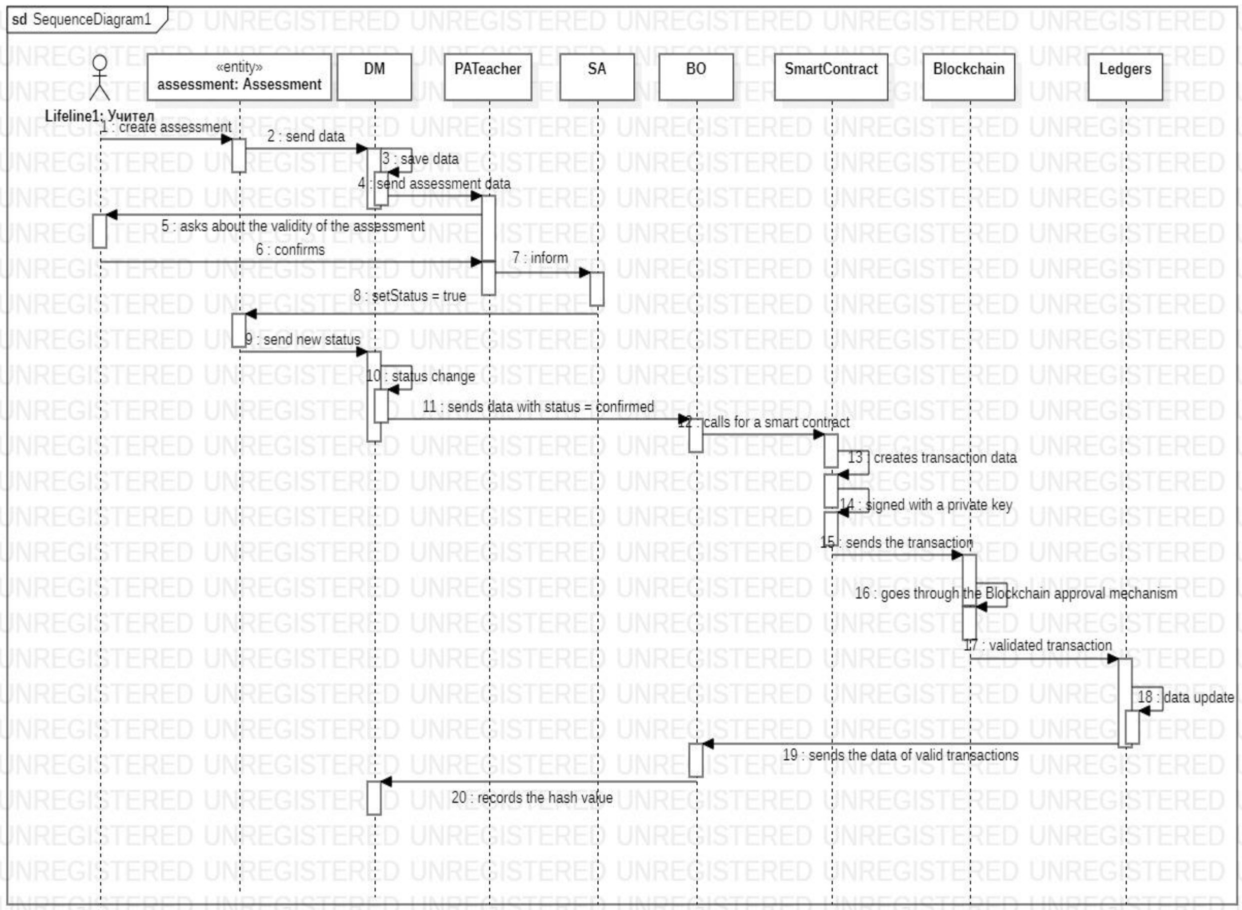


Figure 6. *Sequence diagram of the assessment validation process*

A very important part in building a multi-agent system is communication between assistants. By definition, based on these messages, they may change their perception of the world around them, and during the next deliberation stage, they may choose another plan to achieve a given goal or subgoal. The communication between the agents in the electronic School Diary are presented in Fig. 7, and for better clarity we have included only the communication of the SA with the other assistants in the system [4]. Another important clarification is that the environments in which these agents operate may overlap.

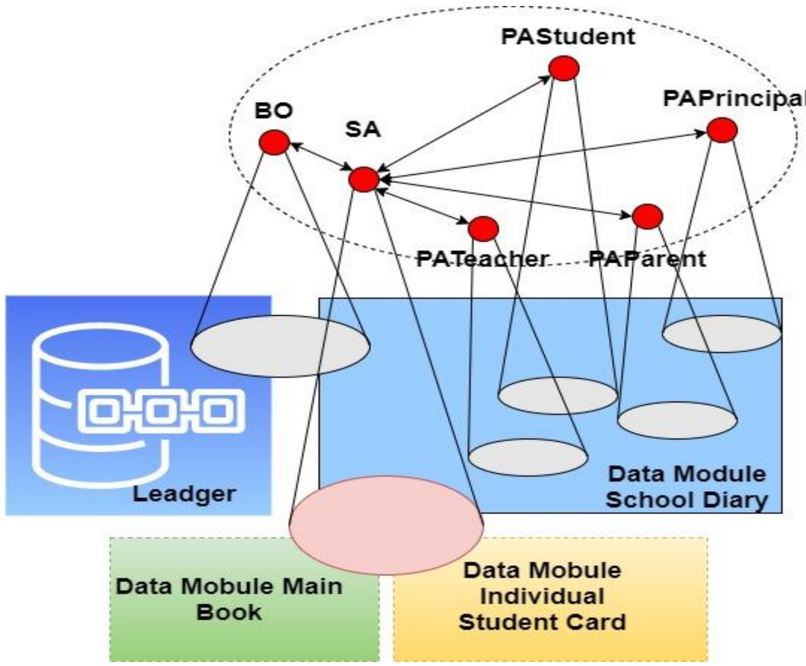


Figure 7. *Communication between agents in an electronic School Diary*

Another important point is that although the blockchain is decentralized, the system has a central element for communication and control. If a technical or communication problem occurs in the server that supports the system, the system will stop working. For this reason, we think it is right that it should also be maintained in the cloud space as a backup copy. The mental notes that the assistants add to their knowledge base are extremely important to the system, as the agent can recall them at a later stage.

After applying a value to **hashValueOfTheTransaction** in DMSD against each grade, the SA distributes the grades to the students' notebooks and notifies all personal assistants affected by this change of a new event in their environment. After the personal assistants inform the users (students and parents), they record the grades in their knowledge base. Every personal assistant remembers how it was created. It stores the received information in its knowledge base and monitors the student's progress.

Upon receipt of an annual grade or matriculation grade, for each student, the SA transfers these grades and their blockchain-derived hash values to the school's Diary (DMMB) or electronic Individual Student Cards (DMISC). SA monitors data changes in DMMB and DMISC. Only he can write information about grades in them. If a data change occurs, during a manipulation attempt, it reacts, synchronizes the data with the Blockchain oracle and records the correct values. Thus, we guarantee that the ratings recorded in these documents guarantee the truth and cannot be manipulated.

By communicating with the School Main Book (DBMB) and Individual Student Cards (DBISC) data modules, factory numbered documents can be issued for completed grade and degree.

2. A model of a system that manages and coordinates factory numbered documents. Another important point in education is tracking the movement of documents with factory numbering. Obtaining, using and, if necessary, destroying diplomas, certificates and others is a process that requires continuous tracking, verification and security.

The use of Blockchain technologies is a reasonable and appropriate choice when building such a system. They allow us to transfer and track factory numbered documents (which we'll call assets) between different organizations in a secure, reliable and integrity way. Our idea is to build a private block chain (closed) between the Ministry of Education and Science, a printing house for documents with factory numbering, the Regional Department of Education-Plovdiv and all schools in the Plovdiv region. All participants in this chain are known in advance and have certain rights and responsibilities. Thus, we will provide a secure way to process and transfer documents with factory numbering. Each individual organization will be a separate node in the system, as:

- **Each school** becomes a node in the system to store, on its own server, the entire history of transactions in the network, located in the Blockchain ledger. Each director sends a request for access to the system of Regional Department of Education -Plovdiv. Once access is granted, the system provides a public and private key to the respective director, through which he can verify and sign transactions for receiving and sending factory numbered documents.
- **The printing office of the documents with factory numbering,** enters the printed documents as assets in the system and sends them, based on the preliminary requests made by the schools to Regional Department of Education -Plovdiv, to the relevant schools.
- **The principal of the respective school** verifies and accepts the document transactions by signing them with his own private key obtained from the system.

Once documents become assets in the school e-wallet, they can go through various states: available, used, transferred, unusable, misplaced, scrapped. The blockchain verifies each transaction for formal and semantic correctness and authorization. Only correct transactions are recorded and completed in a block and validated in the Blockchain. This enables us to track the movement of all factory numbered documents ever created in the system, as well as guarantee their provenance [28].

Conclusions from Chapter Two

1. The presented synchronization model between the personal assistants of the different groups of users and the embedded blockchain channels in a cyber-physical and social ViPS-based school educational platformt ensures integrity and trust in the process of their interaction.
2. The developed prototype confirms the possibility of applying the presented blockchain-synchronization model with personal assistants, facilitating the work of individual groups of users without requiring additional control mechanisms when working with sensitive information.

CHAPTER 3. APPLICATION OF BLOCKCHAIN TECHNOLOGIES IN A MULTI-AGENT SYSTEM AND ADAPTATION OF VIPS IN AGRICULTURE

In this chapter, a concept is proposed for using the **personal assistant-blockchain model** to solve problems related to smart agriculture [7], including verification of new seed samples in the national Genebank, as well as their distribution.

The National Genebank of the Republic of Bulgaria was established in 1984. The main task is the implementation of the scientific program for long-term and medium-term storage of germplasm through seeds under controlled conditions, observing international standards. The National Genebank at the Institute of Plant Genetic Resources in the town of Sadovo, region Plovdiv carries out exchanges with over 100 genebanks, botanical gardens, and international centers for plant and genetic resources in the world. The National Genbank is a network of agricultural institutes that create, maintain, and distribute new varieties of plants. Each institute has its experts in a given culture, who are called curators. They are the people who create the new genetic species.

In the next part, two applications of the discussed model of synchronization between personal assistants and blockchain are presented: the creation of a validator of new seed samples in the Gene Bank and the development of a multi-agent system for distribution and seed production of genetic species from the Gene Bank of Bulgaria [13].

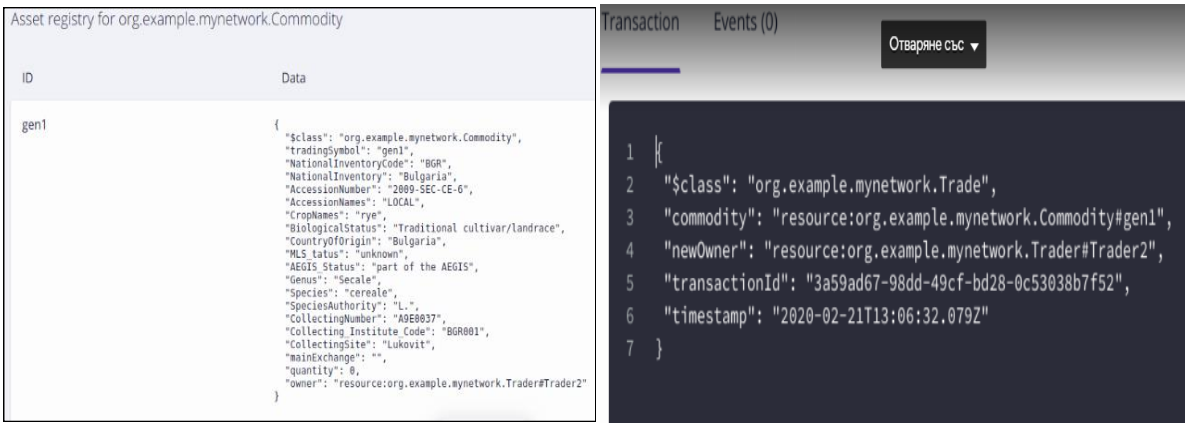
1. IMPLEMENTATION OF GENEBANK VALIDATOR

The new seed sample validator is distributed as a separate blockchain channel **GeneBank Validator**. This channel is being developed as a closed system implemented as a blockchain using the Hyperledger Fabric Blockchain, which aims to verify and validate each new plant variety. Experts from all agricultural institutes on the territory of the Republic of Bulgaria, the Patent Office, and the Executive Agency for Variety Testing, Approbation, and Seed Control are participating in it. They all get their own public and private keys, with which they can verify and sign transactions on the blockchain. Fig.8 shows the creation of a GeneBankValidator channel.

Figure 8. Creating a GeneBank Validator Channel

A new plant variety certificate is granted when it is new, different, homogeneous, and stable. The variety must, in addition, have a varietal name that links to its genetic designation and serves to identify it.

Determining the characteristics and certification of a new variety is a long process that requires the participation of experts from various scientific agricultural institutes in our country, who are registered in the blockchain channel. To request the certification of a new plant variety, an expert from a relevant institute enters its passport data into the system, according to the EURISCO international standard (see Fig. 9a). After creating the "asset" in the system, the expert sends it to a second expert from the same Institute, through a transaction (see Fig. 9b).



(a) (б)

Figure 9. *Registering a new plant variety in the GeneBank system and sending a transaction between two experts*

If the two authorized experts sign the transaction, they agree to the existence of a new genetic plant variety. This Asset is sent by transaction from the Institute to the Patent Office, together with all the necessary documents. Within the statutory period, the Patent Office forwards the request to the Executive Agency for Variety Testing, Approbation, and Seed Control (ИАСАС) for substantive expertise. IASAS performs statutory inspections, samples for analysis, documents, and others. After that, he returns his expert assessment to the Patent Office. If it is found that the variety does not meet the requirements for a new one, the Patent Office informs the Institute using a message and official mail. Upon a decision in the Executive Agency report to recognize the variety as new, the Patent Office signs the transaction received from the Institute, thereby confirming the validation. After making a decision to issue a certificate and paying the relevant fees, 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 relevant Institute (Fig.10).

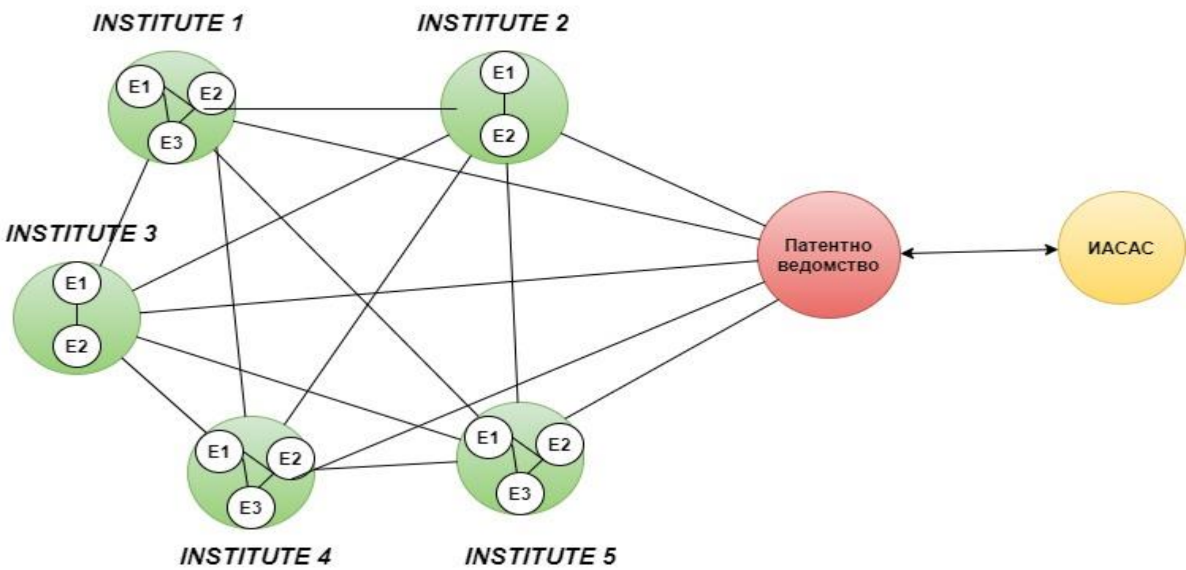


Figure 10. *GeneBank Validator*

2. GENEBANKSTORE IMPLEMENTATION

"Agriculture 2.0 - Plovdiv" is an adaptation of the reference ViPS architecture, which is divided into three main components, which are implemented within three separate sub-projects - Construction of the Operative Center, Data Center, and Guards Network (Fig. 11). Almost all components from VIPS are adapted to build these three subsystems [21].

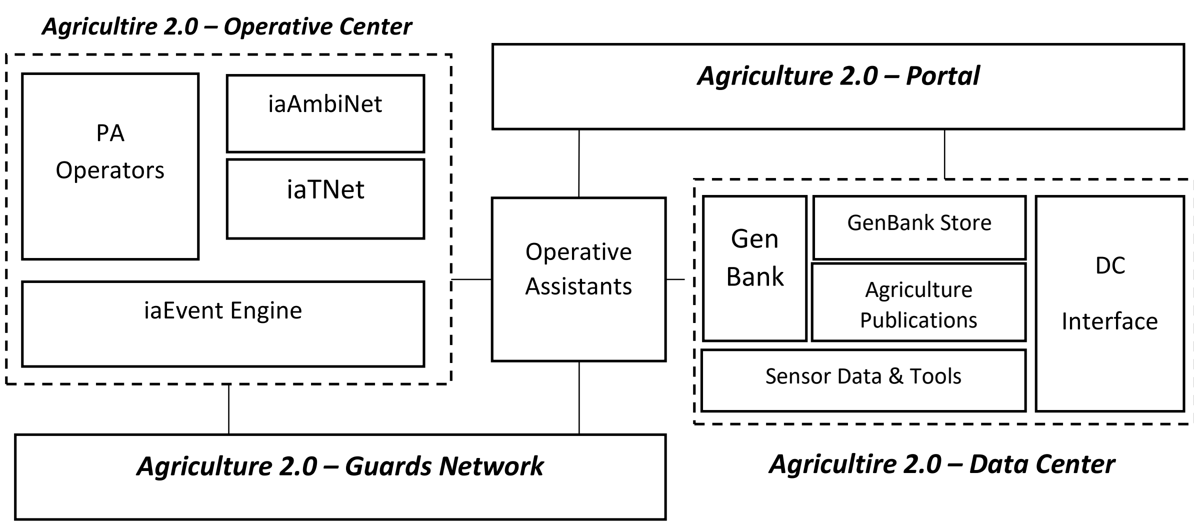


Figure 11. *Architecture of "Agriculture 2.0-Plovdiv"*

Part of the Data Center is the GeneBank Delivery Store, which is closely related to the Gene Bank. This store is being developed as an automated warehouse system to fulfill seed delivery orders. The GeneBank store is implemented as a consortium blockchain using the Hyperledger Fabric Blockchain [12].

The system provides access to enter passport data of new genetic specimens, only to a certain circle of previously known users. We use a public-private approach of asymmetric cryptography, which is the basis for the identification of users, transfer of ownership, and their protection from unauthorized access to the system, presented in Fig.12. Each of these users will have the right to register and add specimens, under the conditions of long-term storage, to three types of collections:

- **Basic collection** - maintained under conditions for long-term storage of seed samples, which are stored in hermetically sealed packages, at low seed humidity and temperature - 18ºC.
- **Working collection** - guarantees safe storage of seeds from three to ten years at + 6ºC.
- **Exchange collection –** provides materials for free exchange with national and international partners.

Figure 12*. Creating a certificate with a public and private key*

The GeneBank store is being built as a consortium blockchain, which itself consists of three different communication channels:

- **Seed exchange channel** through which Institutes (I) on the territory of the Republic of Bulgaria will be able to exchange seeds with other agricultural institutes from around the world, as well as provide seeds for long-term storage to other national Genbanks.
- **Donation channel** through which Institutes on the territory of the Republic of Bulgaria will donate seeds to botanical gardens (BG) from all over the world.
- **A sales channel** through which the Institutes on the territory of the Republic of Bulgaria will sell genetic specimens created by them to seed producers.

In each individual channel, the logic of operation will be different, which will require the creation of different smart contracts. The installation of a smart contract in the donation channel is presented in Fig.13.

When an institute receives a certificate for a new plant variety it owns, through GeneBankValidator, it keeps some of the seeds for long-term storage and enters the rest into the sales system.

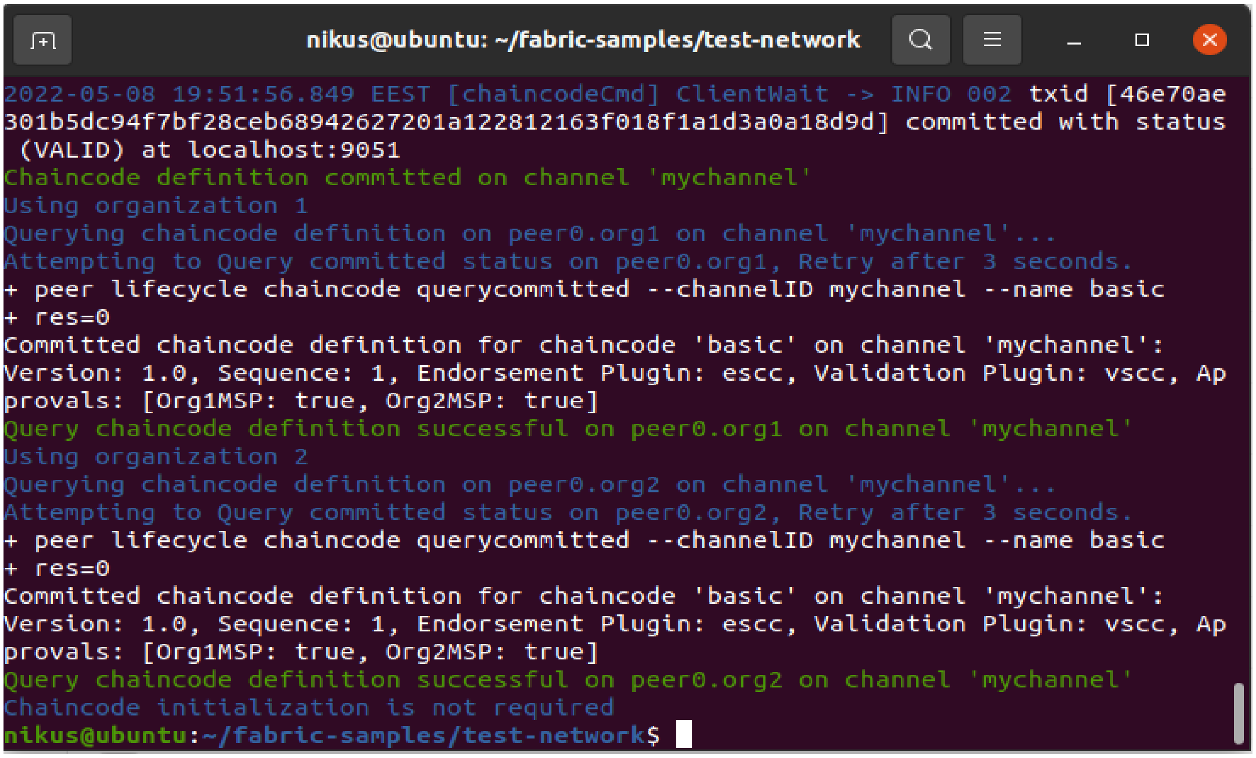


Figure 13. *Installing a smart contract in a channel*

To access the corresponding channel, an application is sent to the "GeneBankStore" system. Genbank grants permission to the specific organization to join the relevant channel, as the system provides a public and private key, as a corresponding pair, to the relevant participant, through which they can sign transactions. In Fig.14. an implementation of the user and wallet creation process is presented.

Figure 14. *Create a user and wallet*

In the seed sales channel, seed producers choose which variety to propagate and send a request, through a transaction, to the respective institute that owns it. After receiving the transaction, a smart contract is concluded between the institute, part of the Genbank, and the seed producer, through which the latter undertakes to grow the variety according to a precisely defined technology. After carrying out the relevant logistics and payment, through the Supply chain level, which is modeled in the next chapter, the institute sends a transaction signed by the relevant private key, through which it transfers the ownership of the seeds to the relevant seed producer. Along with the documentary transfer of the seeds, the system generates a proof-of-origin certificate, along with providing cultivation technology.

Since GeneBankStore is developed as a multi-agent system, we define three types of agents**:**

Blockchain Oracle (BO) – it is an intelligent agent that serves to transfer information content from ledgers to the various channels in the blockchains in the DataModule. Its environment consists of the GeneBank Validator ledger, the GeneBank Store ledger, and the Data Module, all located on the system server, as shown in Fig.15. When there is a change in its environment, i.e. updating the information in one of the ledgers it monitors, it reacts and records the information in the Data Module of the server, which is part of the GeneBankStore.

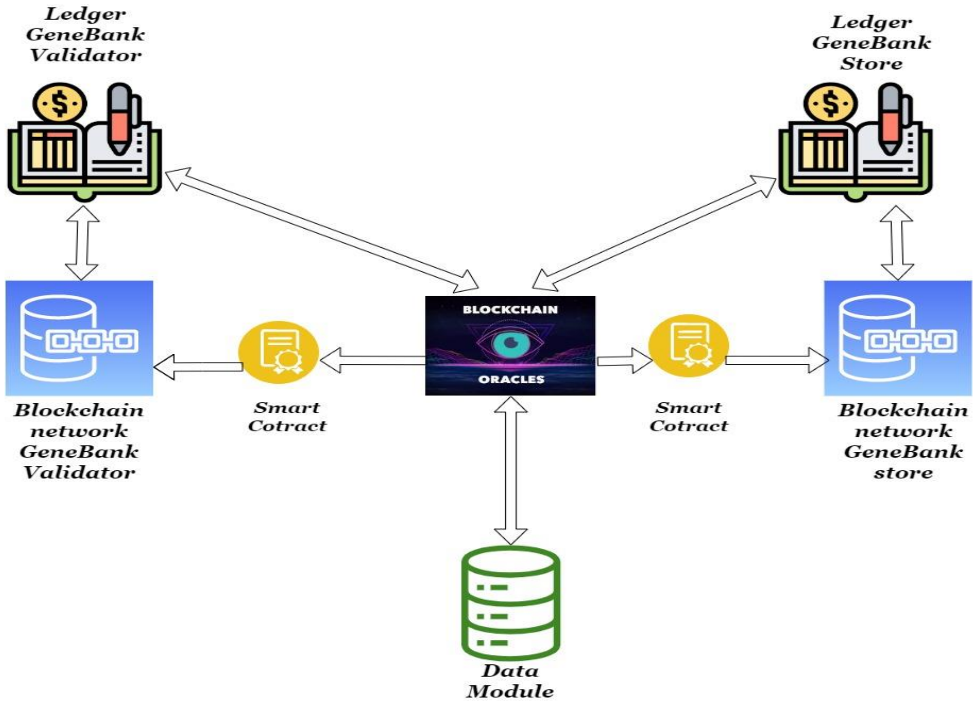


Figure 15. *BO environment*

PAGen – a personal assistant assisting the Institute representatives who will process requests in the GeneBank Store on behalf of the Institute. The environment of this assistant is the Data Module. After the BO writes the information in the DM from the GeneBankValidator ledger, i.e. a new genetic instance is created, the corresponding PAGen reacts and informs the representative of this Institute, who will operate the store, about the need to enter a quantity that can be sold from the given Asset, as well as additional information on the method of cultivation, schedule for watering and fertilizing, etc.

PAClient – a personal assistant assisting GeneBankStore customers in growing the species they purchased. This personal assistant is generated the moment a user registers, taking their public key as a personal identifier. Its environment consists of a Data Module in GeneBankStore. After a customer acquires given seeds, through any of the three channels in Blockchain GeneBankStore, the oracle transfers the information from the corresponding ledger to DM – the public key of the user, as well as the specific Asset that he purchased. When a DM changes, PAClient reacts by updating its knowledge base. He begins to follow the schedule for the cultivation of the respective plant variety. Each assistant performs prevention, i.e. before an event occurs in the cultivation of the corresponding specimen - watering, spraying, fertilizing, he notifies the client to prepare for this event. Also, when it is time to harvest, the PAClien can feed back to the representative of the respective Institute, through his PAGen, what the yield was obtained and under what conditions the plant was grown.

The personal assistant is bound not only to the public key of the respective user but also to information about the node. If the user is no longer a node in the system, he will not receive information from his personal assistant.

As we mentioned, together with the purchase of the seeds, each seed producer also receives an exact technology of their cultivation (recipe) - when it is necessary to fertilize, what are the minimum values of humidity, the maximum of soil oxidation, etc. Using an established IoT infrastructure, each farmer begins to collect data from the various sensors - for air temperature, oxidation, soil moisture, and others. This data can be stored locally and in the cloud. The aim is to analyze them, draw conclusions, and use them to make intelligent decisions about growing the relevant crop. A UML class diagram of the intelligent smart contract in the sales channel is presented in Figure 16.

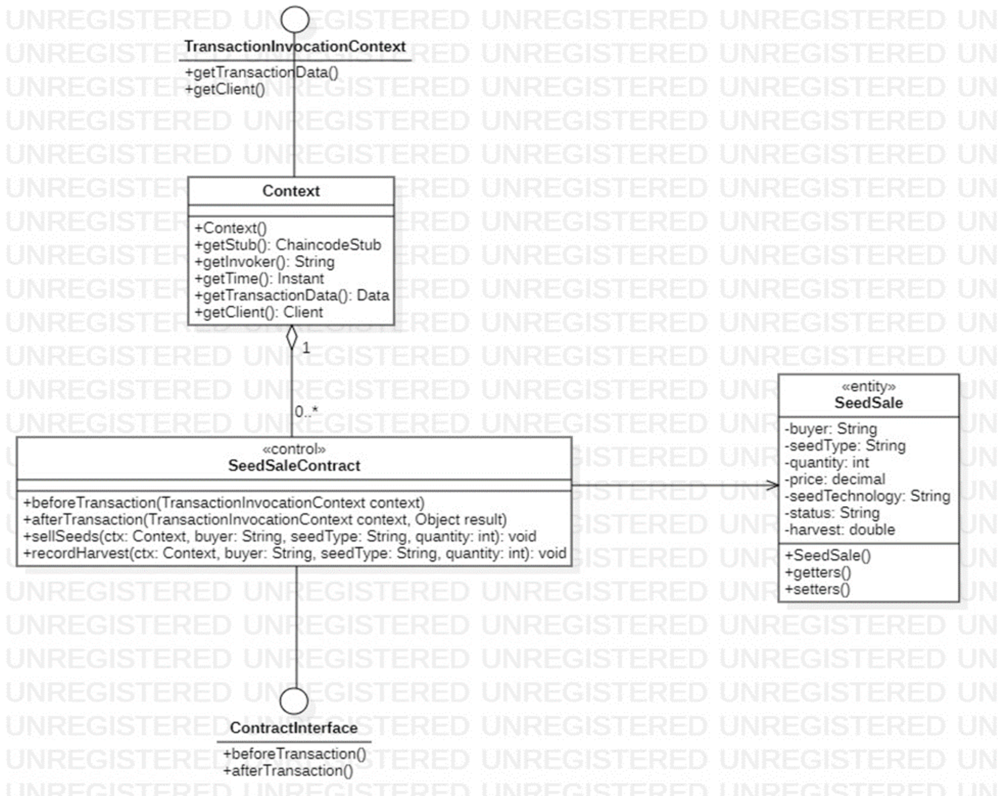


Figure 16 *Class diagram of a smart contract in the Sales Channel*

The **SeedSale class** includes seed sale data such as: buyer, type of seed being purchased, quantity, price, seed technology, yield obtained by the buyer (harvest), and status.

The **SeedSaleContract** class is a smart contract for Hyperledger Fabric. It implements the **ContractInterface** interface, which provides the necessary functionality for integration into the Hyperledger Fabric Blockchain. The **sellSeeds() method** is used to sell seeds to the buyer. Upon receiving production, at the end of the life cycle of the respective variety, the buyer records the harvest it produced using the **recordHarvest method** of its SeedSaleContract smart contract. When the SeedSale is updated in the ledger, then the smart contract is considered closed.

The **Context class** is used by the Hyperledger Fabric Java SDK and provides multiple capabilities for managing transactions in the Hyperledger Fabric Blockchain, implementing the **TransactionInvocationContext interface**. Through the **getStub() method**, which returns a **ChaincodeStub**, access to methods for interacting with the ledger is provided. The **getInvoker()**

method returns information about the calling station (user) of the current transaction. The **getTime() method** returns the current timestamp of the block.

Obtaining production at the end of the life cycle of the respective variety, the seed producer informs the Genbank of the yield obtained and sends evidence of compliance with the cultivation technology. Then the smart contract is considered closed.

AnyLogic [2] is a powerful event and multi-agent systems simulation and modeling platform that is used to create and analyze various types of simulations. The system was developed by the company AnyLogic and is a popular tool in the field of operational and business simulation software. Using the AnyLogic software, we modeled the scenario in which the various seed producers make a purchase of seeds from the GeneBank store, and when a request is made, the goods are moved to them. Fig.17 shows this process after compiling and running. In the upper left corner, you can see how many orders have been placed and how many have been fulfilled.

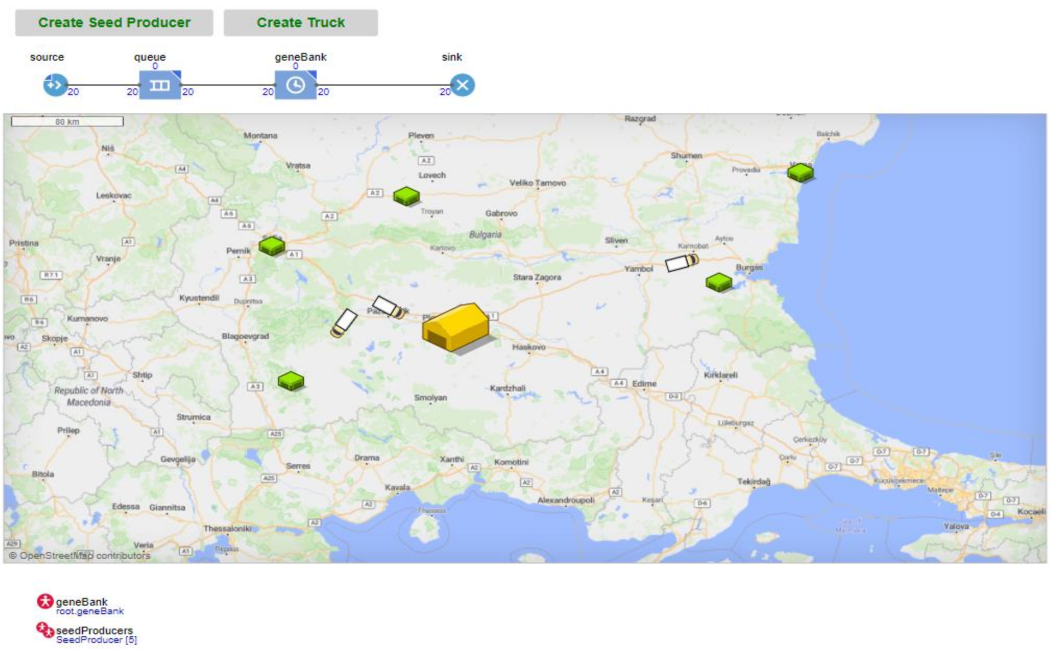


Figure 17. *A prototype model of a delivery system in the GeneBank store*

CONCLUSIONS FROM CHAPTER THREE

1. The presented model of blockchain synchronization with personal assistants CPSS – based ViPS adaptation for smart agriculture enables the implementation of services and scenarios requiring a higher degree of security, trust and integrity.
2. The developed prototypes confirm the applicability of blockchain-based integration with agents in the considered multi-agent environment.

CHAPTER 4. CONCEPTUAL MODELS AND FUTURE PLANS

In the 80s of the 20th century, as an extension of the logistics concept, the concept of "**Supply-chain management**" appeared, considered as the integration of all activities related to the transformation of products from raw materials and materials into goods for the end user, as well as related with this information flows to achieve sustainable competitive advantage. The use of Blockchain technologies in the construction of supply chains can help to easily manage them, providing us with security and traceability of data [18].

This part briefly describes a model of a supply chain, using blockchain technologies, which will consider the process from the receipt of the seed from the Bulgarian Genbank to its realization. Participants in the supply chain are GeneBank, Seed Producers, Farmers, end-product manufacturers, logistics and transportation, financial and insurance institutions, distributors, and government regulators. In the model, five different supply chain channels are defined in which value is added to the product (see Fig.18*):*

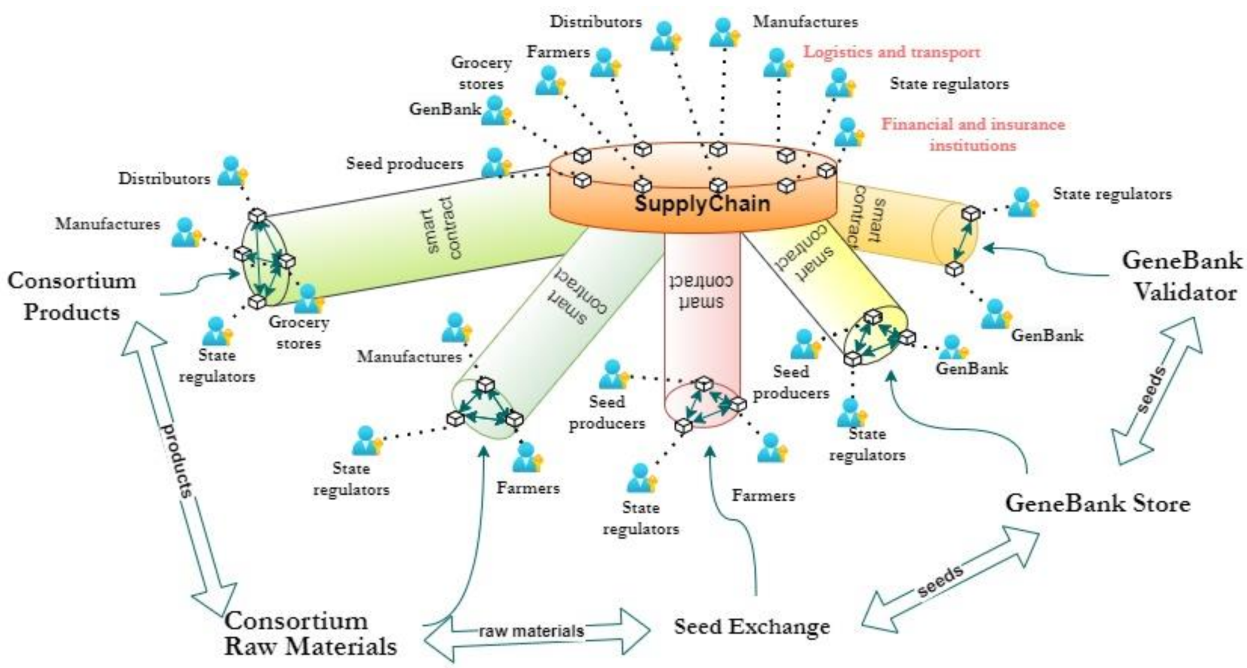


***Figure 18**. Blockchain channels of the supply chain*

The supply chain is planned to be built using various communication channels based on Hyperledger Fabric technology. The desired system logic will be implemented using smart contracts, which are self-executing computer codes, enabling the exchange of assets between participants without the need for an intermediary. It states all the terms of the deal, and if the participants fulfill them, they automatically receive what they need.

Each registered user in some of the Blockchain channels will receive their own public and private key to verify and sign transactions. All processed, sent, and received requests, depending on the logic in the respective channel, are checked for formal and semantic correctness and authorization by the system. All valid transactions are compiled into a block and written to the blockchain of the respective channel. After block validation, the distributed registries of the nodes are updated with the new data. In addition to the GenBank Validator and GenBank Store channels presented in Chapter 3, this chapter presents a description of the remaining channels belonging to the supply chain: Seed Exchange channel; Consortium Raw Materials, and Consortium Products.

The tourism [5] and smart city [19] adaptations of ViPS also raise questions related to the need for blockchain synchronization with personal assistants. A blockchain chain synchronization model for wine production and distribution developed by the Personal Tourist Guide - PTE team was considered. The implementation of this service uses blockchain synchronization to guarantee the origin of the wine bottle with the user's PTE. Another model for blockchain synchronization with PTE is considered in [26] for the provision of a variety of tourism services. When adapting the reference ViPS architecture for the development of an intelligent tourism CPSS platform, it is often necessary to work in integrated domains. A baseline scenario of an equestrian service in this system implemented through blockchain-based synchronization with PTE is developed.

CONCLUSION

The thesis presents research on the conceptualization and modeling of blockchain-based synchronization with personal assistants. In the developed models, the information is structured appropriately so that it can be used to solve various tasks requiring the integration of blockchain technologies in a multi-agent cyber-physical platform. The reference ViPS architecture is reviewed and several adaptations are proposed for secondary school and smart agriculture. Some additional conceptual models for translation of the developed synchronization approach to the field of supply chains related to the national Genbank are shared and plans for future research are outlined.

MAIN TASKS SOLVED IN THE DISSERTATION RESEARCH

Task 1. A study was made of various aspects and approaches in the development of Blockchain technologies, based on which a general concept was created for their use in synchronizing information so that personal assistants could use it.

Task 2. Models have been created for the application of this concept in the adaptation of the reference ViPS architecture in the spheres of education and intelligent agriculture.

Task 3. Prototypes were created to test the application of these models in the field of secondary education and smart agriculture.

RESULTS (CONTRIBUTIONS) OF THE SCIENTIFIC RESEARCH

When performing the tasks to achieve the main goals, we can determine the following actual results (contributions) of the scientific research:

Result 1. A general concept has been created for blockchain synchronization of information and interaction with personal assistants within a cyber-physical multi-agent system.

Result 2. Concrete models have been created for the application of the developed concept in the adaptation of the reference ViPS architecture in the fields of education and intelligent agriculture.

Result 3. Prototypes were created to test the application of the developed models.

The relationship between the results, the tasks, the structure of the dissertation and the publications involved in the procedure are presented in the following table.

Task	Result	Chapter	Publications
1	1	1	1, 2
2	2	2, 3, 4	1, 2, 3, 4
3	3	2, 3	1, 3

PLANS FOR FUTURE DEVELOPMENT

Based on the research conducted, the following plans for future development can be formulated:

1. The developed model of an intelligent environment for the secondary school makes it possible to claim that synchronization is possible between the "Factory numbered document system" and the "Electronic school diary system" presented in Chapter 2.

2. Creation of prototypes of the blockchain channels of the model presented in this chapter for a supply chain of seeds from the national Genebank.

3. The developed models of blockchain synchronization with the Personal Tourist Guide enable the development of service prototypes in a multi-agent CPSS-based tourism platform.

PUBLICATIONS ON THE DISSERTATION WORK

The results of the work on the Dissertation research have been published in the following jornals, per-reviewed publications and refereed conferences

1. J. Todorov, **I. Krasteva**, V. Ivanova, E. Doychev, BLISS-A CPSS-LIKE APPLICATION FOR LIFELONG LEARNING", 2019 IEEE International Symposium on INnovations in Intelligent SysTems and Applications (INISTA), DOI: 10,1109/INISTA.2019.8778363, (***IEEE, Scopus)***

2. **Krasteva, I.,** Glushkova, T., Stoyanova-Doycheva, A., Moralivska, N., Doukovska, L. and I. Radeva, BLOCKCHAIN-BASED APPROACH TO SUPPLY CHAIN MODELING IN A SMART FARMING SYSTEM, 2021 Big Data, Knowledge and Control Systems Engineering (BdKCSE), 2021, pp. 1-6, doi: 10.1109/BdKCSE53180.2021.9627309. ISBN:978-1-6654-1042-7 (***Scopus***)

3. **Krasteva I. K.,** Glushkova T. A., Stoyanov S. N., MODELING AND DEVELOPMENT OF A MULTI-AGENT SPACE FOR THE SECONDARY SCHOOL. Informatics and education. 2020; vol. 4, pp. 53-62, ISSN 0234-0453, https://doi.org/10.32517/0234-0453-2020-35-4-53-62, https://info.infojournal.ru/jour/article/view/536

4. Tabakova-Komsalova, V., **Krasteva, I.,** Glushkova, T. BLOCKCHAIN BASED MODEL FOR DOCUMENT PROCESSING WITH FACTORY NUMBERING IN SECONDARY SCHOOL, Education and Technologies, vol.10/ 2019, issue 1, 113-119, ISSN 1314-1791 (Print), DOI: http://doi.org/10.26883/2010.191.1479

REFFERENCES

[1] Akundi, A., Euresti, D., Luna, S., Ankobiah, W., Lopes, A., & Edinbarough, I. (2022). State of Industry 5.0—Analysis and identification of current research trends. Applied System Innovation, 5(1), 27.

[2] Borshchev, A. (2014). Multi-method modelling: AnyLogic. Discrete-Event Simulation and System Dynamics for Management Decision Making, 248-279.

[3] Drescher D., Blockchain basics a non-technical introduction in 25 steps, Frankfurt am Main, Germany ISBN-13 (pbk): 978-1-4842-2603-2 ISBN-13 (electronic): 978-1-4842-2604-9 DOI 10.1007/978-1-4842-2604-9, Apress, (2017).

[4] Glushkova, T. Stoyanov, S., Krasteva, I., Tabakova-Komsalova, V., Intelligent school educational environment for distance and blended learning, Katowice, Poland (to print in the monograph "E-learning and STEM Education", ISSN 2451-3644 (print edition), ISSN 2451-3652 (digital edition), ISBN: 978-83-66055-05.

[5] Glushkova, T., Miteva, M., Stoyanova-Doycheva, A., Ivanova, V., Stoyanov, S. Implementation of a Personal Internet of Thing Tourist Guide, American Journal of Computation, Communication and Control, Publication Date: May 10, 2018, Pages: 39-51, ISSN 2375-3943.

[6] Glushkova, T., Stoyanov, D., VIRTUALIZATION AND MODELING OF SERVICES IN A SCHOOL EDUCATIONAL PLATFORM, Proceeding book from 5th International African Conference on current studies, ed. Dr. Sheeba S. A., Samira K.O., February 2-5, 2022, Cairo, Egypt, ISBN: 978-625-7464-76-5, pp. 263-270

[7] Glushkova, T., Stoyanova-Doycheva, A.(2022). An approach to modeling of smart agricultural services and scenarios, 2022 IEEE 11th International Conference on Intelligent Systems (IS), Warsaw, Poland, 2022, pp. 1-8, doi: 10.1109/IS57118.2022.10019723..

[8] Huang, H., J. Lin, B. Zheng, Z. Zheng, and J. Bian, When blockchain meets distributed file systems: An overview, challenges, and open issues, IEEE ACCESS, vol. 8, pp. 50 574–50 586, March 2020.

[9] Kan, L., Wei, Y., Hafiz Muhammad, A., Siyuan, W., L. C. Gao, and H. Kai, ''A multiple blockchains architecture on inter-blockchain communication,'' in Proc. IEEE Int. Conf. Softw. Qual., Rel. Secur. Companion (QRSC), Jul. 2018, pp. 139–145.

[10] Karamitsos, I. et al. "Design of the Blockchain Smart Contract: A Use Case for Real Estate." Journal of Information Security 09 (2018): 177-190.

[11] Khalid, R., Samuel, O., Javaid, N., Aldegheishem, A., Shafiq, S. and N. Alrajeh, "A Secure Trust Method for Multi-Agent System in Smart Grids Using Blockchain," in IEEE Access, vol. 9, pp. 59848-59859, 2021, doi: 10.1109/ACCESS.2021.3071431.

[12] Krasteva, I., Glushkova, T., Moraliyska, N., Velcheva, N., a Blockchain-based model of genbank store system, 2020 IEEE 10th International Conference on Intelligent Systems (IS), Varna, Bulgaria, 2020, pp. 606-611, https://doi.org/10.1109/IS48319.2020.9200133

[13] Krasteva, I., Glushkova, T., Stoyanova-Doycheva, A., Moralivska, N., Doukovska, L. and I. Radeva, "Blockchain-based approach to supply chain modeling in a smart farming system," 2021 Big Data, Knowledge and Control Systems Engineering (BdKCSE), 2021, pp. 1-6, doi: 10.1109/BdKCSE53180.2021.9627309. ISBN:978-1-6654-1042-7

[14] Moritz P., McBurney, P. Sybil in the Haystack: A Comprehensive Review of Blockchain Consensus Mechanisms in Search of Strong Sybil Attack Resistance", Algorithms, 16(1), pp.34, 2023.

[15] National Science Foundation (US), https://www.nsf.gov/pubs/2008/nsf08611/nsf08611.htm, посетен на 20.02.2023

[16] Nguyen G. and Kim, K. "A survey about consensus algorithms used in blockchain." Journal of Information processing systems, vol. 14, no. 1, 2018.

[17] Pilkington M., Blockchain technology: principles and application, Research Handbook on Digital Transformations, Editors: Xavier Olleros, F., Majlinda Zhegu, Edward Elgar Publishing, pp. 225-264 (2016)
[18] Radeva, I. and Popchev, I. "Blockchain-Enabled Supply-Chain in Crop Production Framework" Cybernetics and Information Technologies, vol.22, no.1, 2022, pp.151-170. https://doi.org/10.2478/cait-2022-0010
[19] Stoyanov, S., Glushkova, T., Stoyanova-Doycheva, A., Ivanova, V. A Reference Architecture Supporting Smart City Applications, Lecture Notes in Business Information Processing, Volume 353, 2019, Pages 463-474, ISSN: 18651348, ISBN: 978-303020484-6.
[20] Stoyanov, S., Stoyanova-Doycheva, A., Glushkova, T., Doychev, E. Virtual Physical Space – An Architecture Supporting Internet of Things Applications, 20th International Symposium on Electrical Apparatus and Technologies (SIELA) DOI: 10.1109/SIELA.2018.8447156, https://ieeexplore.ieee.org/abstract/document/8447156.
[21] Stoyanov S., Glushkova T., Popchev I., Doukovska L. (2022) Virtualization of Things in a Smart Agriculture Space. In: Sgurev V., Jotsov V., Kacprzyk J. (eds) Advances in Intelligent Systems Research and Innovation. Studies in Systems, Decision and Control, vol 379. Springer, Cham. https://doi.org/10.1007/978-3-030-78124-8_16.
[22] Todorov, J. Krasteva, I., Ivanova, V., Doychev, E., BLISS-A CPSS-like Application for Lifelong Learning", 2019 IEEE International Symposium on INnovations in Intelligent SysTems and Applications (INISTA), DOI: 10,1109 / INISTA.2019.8778363 - https://ieeexplore.ieee.org/document/8778363
[23] Wang, G., Z. J. Shi, M. Nixon, and S. Han, "Sok: Sharding on blockchain," in Proceedings of the 1st ACM Conference on Advances in Financial Technologies (AFT'19), 2019, pp. 41–61.
[24] Zyskind, G., Nathan, Oz., Alex 'Sandy' Pentland, Decentralizing Privacy: Using Blockchain to Protect Personal Data, DOI: 10.1109/SPW.2015.27 , ISBN: 978-1-4799-9933-0, 2015 IEEE Security and Privacy, pp.180-184, 2015.
[25] Официален сайт на Hyperledger Fabric: https://hyperledger-fabric.readthedocs.io/en/release-2.5/, посетен на 03.12.2023г.
[26] Стоянов, И. Кръстева, И., Тодоров, Й., Русев, К., Персонален туристически екскурзовод в интегрирани домейни, V-та Национална научна конференция с международно участие – TechCo 2021, Ловеч, 2-3 юли 2021г., ISSN 2535-079X, стр. 91-96.
[27] Глушкова, Т., Русев, К., Тодоров, Й., Стоянов, С., Пространствените аспекти при моделирането на интелигентен град Ловеч, Сборник научни доклади от Национална научна конференция TechCo'21, 2-4.07.21, Ловеч, https://www.tugab.bg/images/documents/Techko-Lovech-2021.pdf, ISSN 2535-079X, 116-122.
[28] Табакова–Комсалова, В., Кръстева, И., Глушкова, Т. Блокчейн-базиран модел за обработка на документация с фабрична номерация в средното училище, EduTech- Education and Technologies, vol.10/ 2019, issue 1, 113-119, ISSN 1314-1791 (Print), DOI: http://doi.org/10.26883/2010.191.1479.
[29] Тодоров, Й., Дисертационен труд „Изграждане на персонални асистенти във Виртуално Образователно Пространство", защитена във ФМИ на ПУ "П. Хилендарски" на 22.12.2020.
[30] Тодоров, Й., Кръстева, И. „Персонален асистент за подпомагане на учебния процес в средните училища", сп. TechCo – Lovech 2019, vol.2, 217–222, ISSN 2535-079X, 2019