Fuzzy Cooperative Games Usage in Smart Contracts for Dynamic Robot Coalition Formation: Approach and Use Case Description

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Keywords: Fuzzy Logic, Coalition, Coalition Game, Smart Contract, Robot, Dynamic.

Abstract: The paper describes an approach to dynamic formation of coalitions of independent robots based on the integration of fuzzy cooperative games and smart contracts. Each member of the coalition is represented in the form of an independent agent, negotiating at the stage of coalition formation for distribution of joint winnings. A cooperative game with fuzzy core is used to form a coalition allowing coordinating the actions of individual members to achieve a common goal, as well as to evaluate and distribute the overall benefit. To implement the negotiation process and store the responsibilities of individual participants, it is proposed to use the smart contract technology, which now become a part of the blockchain technology. Smart contracts are used as entity where the requirements and expected winnings of each participant are stored. The final agreement is also stored in form of smart contract that contains the distribution coefficients of the winnings given all the conditions of participation in the coalition. The availability of smart contracts to all coalition participants provides joint control over the fulfilment of the task assigned to the coalition. The paper describes a use case based on precision farming to illustrate the main concepts of the proposed approach.

1 INTRODUCTION

The development of robots has reached a level where it is highly important to organize their joint work. There are a lot of existing models of robots joint work such as swarms, flocks, and coalitions that differ by the freedom of single participant. In contrast to robots in swarms or flocks where they are limited in actions by strong rules and actions of nearest neighbors, robots in coalitions calculate their next steps based on the common goal reaching according to the current coalition state and set of alternatives provided by norms of coalition (Klusch and Gerber, 2002). Existing models of task solving in coalition claim that a robot can receive a reward for the successful problem solving according to its contribution. The independency of robots makes it urgent to develop an approach to coalition formation and interaction organization between robots that allows making joint decision during joint solution of the problem the coalition is faced to.

There are many subject areas that require the use of a coalition of robots to solve a complex problem, including industrial cyberphysical systems, precision farming, and remote or local explore of space objects. Complex tasks in each area can be decomposed to small simple tasks (for instance in precision farming it is needed to scan the relief, check the soil composition, select and put plant or seed in the soil, water it) that are solved by single robots (Kardos et al., 2017). To form a coalition robots provide their competences and select tasks that they can perform.

Robots are equipped with different hardware and software as well as expect different levels of reward. Therefore, it is important to consider the heterogeneity and provide common model to consensus reaching during task decomposition and resolution. Each robot is an independent agent with own competencies and goals, which he aims to achieve after the problem solving. In this case, the coalition can be considered as a union of agents with their own interests, which through the negotiation make a decision on a joint solution of the problem and the distribution of the reward.

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Smirnov, A., Sheremetov, L. and Teslya, N.
Fuzzy Cooperative Games Usage in Smart Contracts for Dynamic Robot Coalition Formation: Approach and Use Case Description.
DOI: 10.5220/0007763003610370
In *Proceedings of the 21st International Conference on Enterprise Information Systems (ICEIS 2019)*, pages 361-370
ISBN: 978-989-758-372-8

The dynamic nature of the coalition implies a changes in its composition, depending on changes in the conditions of the problem being solved (Bayram and Bozma, 2015). New robots should be quickly familiarized with the current state of the problem solution and provide description of own competences to help to solve the problem. At the same time, existing coalition members should operate without any changes as defined in their plans. This problem is usually solved by using external knowledge repositories for storing the history of interaction between coalition members. Such knowledge can be stored in centralized or decentralized knowledge bases. Centralized knowledge base usually provides single access point for connecting robots to the data network. Decentralized knowledge base allows to organize a distributed network without any single access point in which the knowledge base is distributed among all participants with a share of the backup, which makes the general information space more resistant to the disconnection of one or more nodes.

Most of the approaches to coalition formation are characterized by the exponential nature of the computations and communications complexity. To transition from hyper-exponential and exponential complexity to polynomial, the following parameters are usually limited: the number of agents in one coalition, the number of coalitions, and the rationality of agents (Jennings et al., 2001). In this case, the additional complexity is caused by the inability to accurately estimate the size of the gain, which introduces fuzziness into the formulation of the problem.

In this paper, the use of cooperative games with fuzzy core to form a coalition of robots is proposed to solve the problems described above. This model provides the following advantages when forming a coalition: robots provide own competencies and the expected individual benefit while actions of every coalition are controlled by one of its member. The existence of a coalition core allows coordinating the actions of individual members to achieve a common goal, as well as to evaluate and distribute the overall benefit. When changing the conditions in which the task was set, a dynamic change in the composition of the coalition is envisaged, if necessary.

To store the rules of the game, competencies and requirements of robots, as well as information about the current state of coalitions and tasks, it is proposed to use smart contracts over blockchain technology. Smart contracts as a computerized protocol which stores and carries out contractual clauses via blockchain become a real tool used in industry (Cong et al., 2017; Delmolino et al., 2016). In this work it is proposed to use smart contracts to contain the rules for forming a coalition and rules for changing the composition of the coalition, defined using the theory of fuzzy sets. The contract code, as well as the current state of the solution of the problem, is stored in a distributed log based on the blockchain technology. This allows to provide a trusted information source for robots to store and search coalition state. Since the data in the block is linked to each other by calculating the hash of the blocks in which they are stored, they cannot be changed. It makes possible to provide unchangeable process logs by which one can trace the history of operations and, if necessary, find a weak point, to enhance the effectiveness of future coalitions.

The rest of the paper is organized as follows. Related work is revised in the following section. A fuzzy cooperative game (FCG) model with core is described in Section 3. In Section 4, different criteria of dynamic robot coalition formation are analyzed. Section 5 provide information about smart contracts and frameworks for robots negotiation during coalition formation. Finally, the possible use case and implementation scheme of a FCG over blockchain-based smart contracts is proposed following by conclusions.

2 RELATED WORK

The cooperative nature of modern robotic complexes causes necessity of considering them within the context of cooperative game theory in order to model and understand their cooperative behaviour. The main questions of coalition formation are: what coalitions will be formed, how the common wealth will be distributed among them and if the obtained coalition structure is stable. Once coalitions are formed and they have a feasible set of payoffs available to its members, the question is the identification of final payoffs awarded to each player. That is, given a collection of feasible sets of payoffs, one for each coalition, can one predict or recommend a payoff (or set of payoffs) to be awarded to each player?

The payoff distribution should guarantee the stability of the coalition structure when no one player has an intention to leave a coalition because of the expectation to increase its payoff. The benefit distribution among the coalition members has proved to be fuzzy, uncertain, and ambiguous (Hosam and Khaldoun, 2006). Using the theory of fuzzy cooperative games (FCGs), the uncertainty is processed by means of the introduction of a fuzzy benefit concept through the bargaining process to the conclusion about the corresponding fuzzy distribution of individual benefits among the coalition members (Aubin, 1981).

The predictions or recommendations of payment distribution are embodied in different solution concepts. According to (Kahan and Rapoport, 1984), cooperative games are divided into two classes based on the way a solution of the game is obtained: games with a solution set and games with a single solution. Games with core considered in this paper, belong to the former class and represent a mechanism for analyzing the possible set of stable outcomes of cooperative games with transferable utilities (Gillies, 1953). The concept of a core is attractive since it tends to maximize the sum of coalition utilities in the particular coalition structure. Such imputations are called C-stable. The core of a game with respect to a given coalition structure is defined as a set of such imputations that prevent the players from forming small coalitions by paying off all the subsets an amount, which is at least as much they would get if they form a coalition (we proceed with a formal definition of a core in the following section). Thus the core of a game is a set of imputations which are stable.

The drawbacks of the core is that, on the one hand, the computational complexity of finding the optimal structure is high since for the game with n players at least $2^n - 1$ of the total $n^{\frac{n}{2}}$ coalition structures should be tested. On the other hand, for particular classes of the game a core can be empty. Because of these problems, using the C-stable coalition structures was quite unpopular in practical applications (Klusch and Gerber, 2002) and only recently has attracted more attention of the researchers, when the concept of fuzzy cooperative games with core was introduced (Mareš, 2001; Shen and Gao, 2010). For realistic applications like collaborative work of groups of robots, additive environments and the absence of the restrictions on the type of membership functions should be considered (Smirnov and Sheremetov, 2012).

For practical applications of FCGs, one of the key problems is the management of the coalition formation and payoff distribution tasks. In our previous work, a negotiation algorithm has been developed [18]. In this paper, we propose a novel approach using blockchain technology.

With regard to the organization of robots interaction, the blockchain is mostly used as immutable storage for information exchange and platform for smart contracts. Information stored in the blockchain could contain records about task and consumables distribution (Dorri et al., 2017; Verma et al., 2017), smart contracts and reward transactions (Zhang and Wen, 2017), as well as global knowledge about coalition previous actions (Ferrer, 2016). In combination with cooperative games blockchain technology can provide more trust for communication between robots, due to the storing information about transactions in immutable log that are verified by every coalition participant. In contrary to existing approaches, blockchain does not require central authority that provide trust for all nodes. All nodes negotiate with each other coming to consensus with one of possible mechanisms: Proof of Work, Proof of Stake, or practical byzantine fault tolerance (Cachin and Vukolić, 2017). The blockchain is used to provide safe and trustiness logging of robots' task distribution and rewarding for task solving.

It is also noted that the combination of the peer-to-peer network and the cryptographic algorithms used in blockchain technology allow for a negotiation process and consensus building without the presence of any controlling authorities. The distributed nature of the blockchain is proposed to be used in swarm robotics to store global knowledge about swarm actions (Ferrer, 2016). At the same time, due to blockchain, the security of the transmitted data is ensured (garbage data can affect the achievement of a common goal), distributed decision making (creating a distributed voting system for the solution), separation of robots behaviour (switching between behaviour patterns depending on the role in the swarm), the emergence of new business models using the swarm. In addition, the availability of a distributed transaction ledger allows new robots to join the swarm and gain all the knowledge they have gained prior to the moment of inclusion by downloading and analyzing the transaction history.

3 FUZZY COOPERATIVE GAME MODEL WITH CORE

A generalized model of a fuzzy cooperative game (FCG) with core was proposed in (Sheremetov, 2009; Sheremetov and Smirnov, 2011; Smirnov and Sheremetov, 2012). As shown in (Smirnov and Sheremetov, 2012), the concept of a core is attractive since it tends to maximize the sum of coalition utilities in the particular coalition structure. The core of a game is a set of imputations, which are stable. The proposed model helped solving the problems of the computational complexity of finding the optimal structure and of the empty core, which enabled its use in practical applications of selecting robots in coalitions.

A FCG is defined as a pair $(Robot, w)$, where $Robot$ is nonempty and finite set of players, subsets of $Robot$ joining together to fulfil some task T_i are called coalitions K, and w is called a characteristic function of the game, being $w: 2^n \rightarrow \mathfrak{R}^+$ a mapping connecting every coalition $K \subset Robot$ with a fuzzy quantity $w(K) \in \mathfrak{R}^+$, with a membership function $\mu_K: R \rightarrow [0,1]$. A modal value of $w(K)$ corresponds to the characteristic function of the crisp game $v(K)$: $\max \mu_K\big(w(K)\big) = \mu_K\big(v(K)\big)$. For an empty coalition $w(\emptyset) = 0$. A fuzzy core for the game $(Robot, w)$ with the imputation $X = (x_{ij})_{i\in I, j\in Robot} \in \mathfrak{R}^+$ is a fuzzy subset C_F of $\mathfrak{R}^+$:

$$C_F = \left\{ x_{ij} \in \mathfrak{R}^+ : \nu f = \left(w(Robot), \sum_{\substack{i\in I,\\ j\in Robot}} x_{ij}\varphi_{ij} \right), \min_{\substack{K_i\in k\\ j\in Robot}} \left(\nu f = \left(\sum_{j\in K_i} x_{ij}\varphi_{ij}, w(K_i) \right) \right) \right\} \quad (1)$$

where x_{ij} is the fuzzy payment of a robot j participating in a coalition i, $i = 1, 2, \dots, I, j = 1, 2, \dots, N$, $\bar{k} = [K_1, K_2, \dots, K_l]$ is the ordered structure of effective coalitions; φ is a fuzzy partial order relation with a membership function $\nu\ f =: R \times R \rightarrow [0,1]$, and φ_{ij} is a binary variable such that:

$$\varphi_{ij} = \begin{cases} 1, if\ robot\ j\ participates\ in\ a\ coalition\ i; \\ 0, otherwise. \end{cases}$$

This variable can be considered as a result of some robot's strategy on joining a coalition.

A fuzzy partial order relation is defined as follows (for more details see (Zadeh, 1971)). Let a, b be fuzzy numbers with membership functions μ_a and μ_b respectively, then the possibility of partial order $a\phi = b$ is defined as $\nu\phi = (a, b) \in [0,1]$ as follows:

$$\nu\phi = (a, b) = \sup_{\substack{x,y\in R\\ x\geq y}} \big(\min\big(\mu_a(x), \mu_b(y)\big)\big) \quad (2)$$

The core C_F is the set of possible distributions of the total payment achievable by the coalitions, and none of coalitions can offer to its members more than they can obtain accepting some imputation from the core. The first argument of the core C_F indicates that the payments for the grand coalition are less than the characteristic function of the game. The second argument reflects the property of group rationality of the players, that there is no other payoff vector, which yields more to each player. The membership function $\mu_{C_F}: R \rightarrow [0,1]$, is defined as:

$$\mu_{C_F}(x) = \min \left\{ \nu f = \left(w(Robot), \sum_{\substack{i\in I\\ j\in Robot}} x_{ij}\varphi_{ij} \right), \min_{\substack{K_i\in k\\ j\in Robot}} \left(\nu f = \left(\sum_{j\in K_i} x_{ij}\varphi_{ij}, w(K_i) \right) \right) \right\} \quad (3)$$

With the possibility that a non-empty core C_F of the game $(Robot, w)$ exists:

$$\gamma_{C_F}(Robot, w) = \sup\big(\mu_{C_F}(x): x \in \mathfrak{R}^n\big) \quad (4)$$

The solution of a cooperative game is a coalition configuration (S, x) which consists of (i) a partition S of $Robot$, the so-called coalition structure, and (ii) an efficient payoff distribution x which assigns each robot in *Robot* its payoff out of the utility of the coalition it is member of in a given coalition structure S. A coalition configuration *(S, x)* is called stable if no robot has an incentive to leave its coalition in S due to its assigned payoff x_i.

It was proved that the fuzzy set of coalition structures forming the game core represents a subset of the fuzzy set formed by the structure of effective coalitions. In turn, this inference allows us to specify the upper possibility bound for the core, which is a very important condition for the process of solution searching, because in this case, the presence of a solution that meets the efficiency condition may serve as the signal to terminate the search algorithm (Sheremetov, 2009).

The game purpose is to generate an effective structure of robot coalitions for executing some task. In turn, the generated structure of robot coalitions represents the optimal configuration of the grand coalition.

Individual robots use the technique of nonlinear fuzzy regression to estimate the parameters of utility functions for their payments (Haekwan and Tanaka, 1999). A "coalition robot" is enabled for constructing membership functions (MF) of coalitions and generating the game core (fuzzy-number generator). The algorithm of fuzzy number summation for obtaining coalition membership functions represents an important element of the model. The sum operation is based on Zadeh extension principle

(Zadeh, 1971) for fuzzy numbers a and b (which are convex sets normalized in R):

$$\mu_{a(*)b}(Z) = \sup_{z=x*y} \min\big(\mu_a(x), \mu_b(y)\big) \quad (5)$$

where * can designate the sum ⊕ or the product • of fuzzy numbers. Each fuzzy set is decomposed into two segments, a non-decreasing and non-increasing one. The operation * is performed for every group of n segments (one segment for each fuzzy set) that belong to the same class (non-decreasing or non-increasing one). Thus, a fuzzy set is generated for every group of n segments. The summation result is derived as superposition of these sets, which gives the membership function as the sum of n fuzzy numbers.

4 CRITERIA FOR DYNAMIC ROBOT COALITION FORMATION

Group problem solving in many problem areas requires a well-coordinated interaction of the participants' actions during the coalition formation. Regardless of the coalition model used, coalition formation process can be considered as three types of interrelated actions:

- Generation of a coalition structure; a formation in which agents within each coalition coordinate their activities;
- Solving the problem of optimization of each coalition; union of agents' competencies for effective problem solving;
- Profit sharing between agents.

Once these actions are performed before problem solving, a static coalition formation is considered. The structure of static coalitions does not change over time. At the time of optimization of the coalition, also a plan for solving the problem is calculated as well as all possible deviations from the plan. In case of a deviation, for example, due to the failure of one of the coalition members, the correction of the plan is carried out by the forces of the last coalition members taking into account the changed conditions in order to return to the original plan with minimal losses.

A more complex, but flexible variant of a coalition formation is the dynamic formation. In this case, during the optimization, a plan of problem solving is formed same as for the static coalition. However, in case of deviation from the plan, a return is made by changing the structure of the coalition, for example, by adding a new participant. To do this, the rules for the formation of the coalition should describe actions for extraordinary situations, and the overall benefit of the coalition, so the plan of action is dynamically recalculated considering the context of the task has changed.

The coalition efficiency can be evaluated by one of the following parameters:

- Minimizing the energy spent. The solution of each task or sub-task can be estimated by the energy (charge of the battery) $E_k(T_i)$ of the robot k that is spent to solve it by using own competencies:

$$E_k(T_i) = \sum_j f_{T_i}\big(b_j^k\big) \cdot \varphi(T_i, k, j) \quad (6)$$

The exact amount of energy spent on solving the problem is not possible to estimate precisely due to the influence of a large number of external and internal factors. However, based on average data on similar problems, it is possible to obtain an approximate estimation, which, however, introduces fuzziness into the final decision to form a coalition. In this case, the robots are interested in spending minimum energy with the maximum efficiency. The coalition efficiency can be estimated as relation of the number of solved problems to the total energy expended:

$$v\big(K_{T_i}\big) = Payoff(T_i) - \min_{K_i \in k} \sum_{j \in K_i} E_j(T_i) \quad (7)$$

- Robot uptime can serve as an analogue of the estimated energy expended. Each of the robot units has the probability of failure, which increases as the operation proceeds. Solution of each task requires a certain time of unit operation. Thus, the estimation of failure probability is the ratio of the time difference between the time of the node work and the average time of uptime of this type of robot units: $P_{C_i} = \frac{T^w_{c_i} - T^m_{c_i}}{T^{avg}_{c_i}}$, where P_{C_i} – failure probability of unit c_i by robot r_j, $T^w_{c_i}$ – total work duration of the unit c_i, $T^m_{c_i}$ – last service time point. The probability of entire robot failure will be evaluated according to the maximum probability of nodes failure $P_r = \max_i P_{c_i}$. An estimation of this probability is also approximate. The efficiency criterion in this case will be the maximum duration of the coalition's overall work to the next maintenance, which requires such a distribution of tasks among the participants, so that the probability of coalition member failure.

- Maximizing the coalition benefit. For example, in relation to precision farming, the coalition's benefit is the cumulative crop of all cultures on the field. This requires coordinated and timely interaction of all robots in a dynamic coalition. The value of the solution of the problem decreases with the passage of time: the longer the task is postponed, the less benefit it can provide. For example, untimely watering due to the lack of robots in a coalition with a sufficient supply of water can cause the death of a crop, which will reduce the potential benefit. Thus, the choice of coalition participants and the distribution of tasks among them should be carried out in such a way as to minimize downtime and, accordingly, to maximize the overall benefit of the coalition.

5 IMPLEMENTATION OF A FUZZY COOPERATIVE GAME OVER SMART CONTRACTS

In this section, the implementation of the rules of the coalition game is proposed by means of smart contracts, that describe the interaction of robots during the coalition formation. This is enabled by the ability of smart contracts within the scope of blockchain technology to describe complex algorithms by using the Turing-complete programming language. Examples include Solidity for the Ethereum platform (Buterin, 2014) or GoLang and JavaScript for Hyperledger Fabric (Androulaki et al., 2018).

5.1 Smart Contract Theory

The idea of smart contract was proposed in 1994 by Nick Szabo. He had defined smart contract as “a set of promises, specified in digital form, including protocols within which the parties perform on these promises.” (Szabo, 1996) The example of resource exchange is presented on Fig. 1.

In scope of the current level of information systems, smart contracts are viewed as decentralized applications that are available to all sides of the contract through the cloud of in decentralized way, for instance, blockchain. Due to the use of Turing-complete language for contract description, it is possible to implement rather complex algorithms. At the same time, it is mandatory to have conditions under which the contract must be executed as well as the list of actions assigned to the submitted conditions. All conditions of a smart contract must be described in a strong mathematical way and provide clear execution logic. In this regard, the first smart contracts in the blockchain are created to formalize the simplest relationships and consist of a small number of conditions.

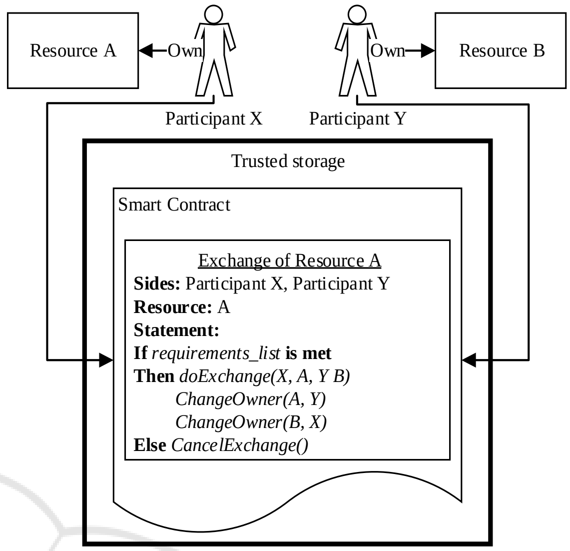

Figure 1: Smart contract usage example.

To be valid and trusted smart contracts have to be signed by all sides with their private key (Goldreich, 2006) and sent as a transaction to be written to in the cloud or decentralized storage. After signing by all contract sides, the smart contract comes into force. To ensure the automated performance of contract obligations, an environment of existence is required that allows fully automated execution of contracts. This means that smart contracts can only exist within an environment that has unrestricted access to executable code of smart contract objects. Having unimpeded access to the objects of the contract, the smart contract monitors the specified conditions of achievement or violation of the points and makes independent decisions based on the programmed conditions. Thus, the main principle of a smart contract is the complete automation and reliability of the performance of contractual relations between participants.

5.2 Smart Contracts for Robot Coalition Formation

Figure 1 shows the scheme of interaction of robots in the coalition by means of a blockchain. It is proposed to use two kinds of chains in the blockchain network system for robot interaction: (i) for storing resources and (ii) for storing contracts. All system resources including consumables, energy, reward, which are represented by tokens, are stored in the resources chains. In the chain with contracts, the rules of cooperative game are stored, which are used by the robots coordinators during the coalition forming and the distribution of tasks. The first contracts in the chain of contracts are rules for processing tasks and assigning coalition core. New task is formed with a program interface outside a coalition by problem manager, or by the cores of another coalition in case of obtaining a new context that cannot be processed by the existing coalition. New tasks are stored in the contract chain of the blockchain, from where they become available for all coalition cores. Tasks contain a formalized description of the goal, the initial parameters and the amount of reward for the solution.

The robot coordinator selects robots guided by contracts that describe their competencies and reward expectations, as well as the rules of the cooperative game, defined for the subject area to which the task belongs. If the robot can participate in several coalitions, each robot coordinator calculates the cooperative game core and win for each of the coalitions, as well as the availability of sufficient resources for the robot successful work. If there are enough resources for robot’s operations, it can participate in several coalitions. Otherwise, the robot is assigned to a coalition for which it can bring the highest benefit. The reward for the successful solution of the problem is distributed among the coalition members based on the reward rules for the cooperative game, described in the code of the relevant contract.

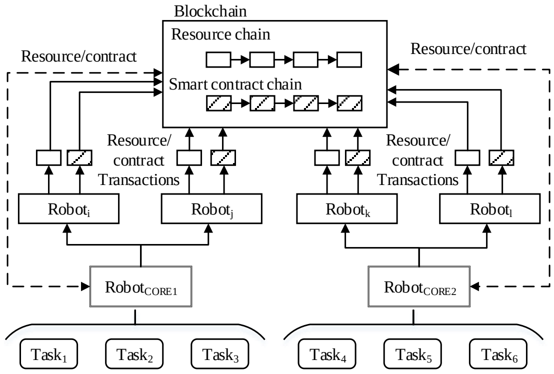

Figure 2: Robot interaction in coalition through blockchain and smart contracts.

6 PRECISION FARMING USE CASE FOR FUZZY COOPERATIVE GAMES WITH SMART CONTRACTS

In this section, an example of solving the problems of precision farming by coalition of robots is considered. Robots are interact through the cyberphysical framework presented in Figure 3. The framework is based on the smart cyberphysical space created on the top of smart space concept (based on the “blackboard”) and blockchain. It provides the ability to organize basic interaction of robots in the physical and cyber (virtual) spaces. The interaction includes solo and joint manipulations with physical objects, information exchange about the current state of robots

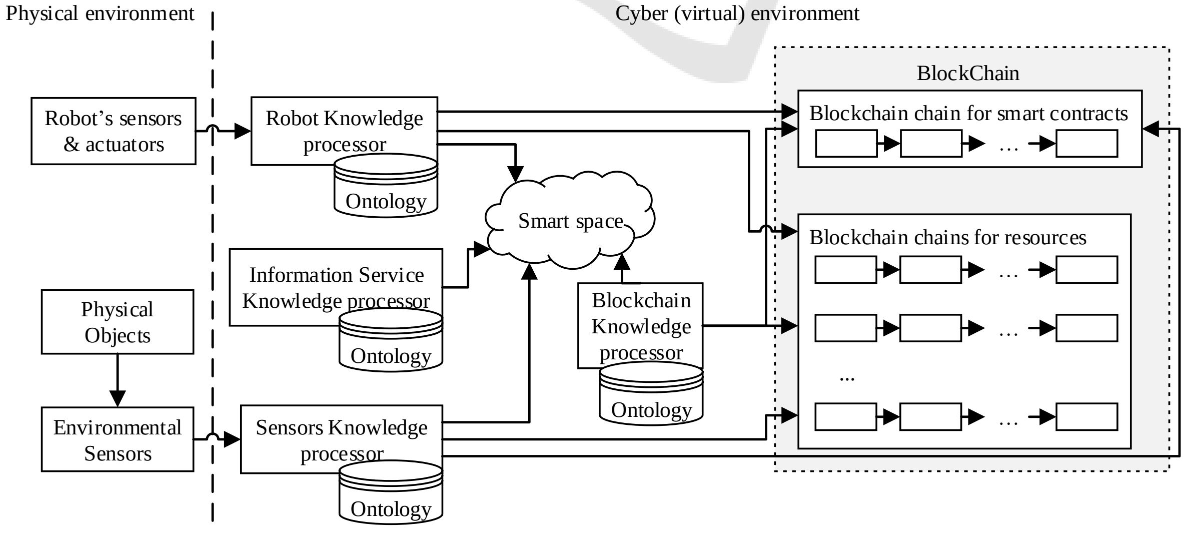

Figure 3: Cyberphysical framework with blockchain support.

and objects for planning further joint actions during the coalition formation.

The problem is stated as follows (Figure 4). There is a field with various geological and ecological characteristics of soils, suitable for growing several crops that require different growth conditions. The field is processed by a number of robots equipped with devices for plowing, loosening, planting, watering, fertilizing and harvesting crops. Each robot is equipped with a set of sensors that allow to explore the soil structure, light and humidity conditions in each sector of the field. Based on the explored data a map of the field is built, where the current conditions are bound with the coordinates. Crops will be selected for each sector based on the sector conditions that are the most favorable in terms of yield, as well as technologies will be selected for their care. The technology of caring for each type of crop requires the use of robots that are capable of carrying out specific operations for the culture chosen, while some robots are capable of performing operations on several technologies, or the technologies can have common steps being solved by the same type of robots. Digital recording and storing of the history of fieldwork and crops can help both in subsequent decision-making and in drawing up special reporting on the production cycle, which is increasingly required by the laws of developed countries. This, as well as the requirement of storing the history of fieldwork requires the presence of a repository, in which the history of actions and the results of field processing will be recorded.

One of the typical coalitional tasks for precision agriculture is the field exploration where different types of robots are engaged. The overall task of the study is divided between them into subtasks, according to the available competences of the robots. In this case, task division is performed using the cooperative game model for the dynamic coalition formation. Within the framework of this model, individual robots interact with each other, putting forward their competencies and requirements on the basis of which the selection of coalition participants is being carried out and their effectiveness in solving the assigned task is estimated.

The blockchain network for the case study has been implemented based on the Hyperledger Fabric platform that is provided by community of software and hardware companies leading by IBM (Androulaki et al., 2018). The platform provides possibilities of wide range configurations: changing of a core database for transactions and block storing, changing of consensus mechanisms, and changing signature algorithms for peers' interaction with blockchain. For the case study presented in the paper, the default configuration has been used that includes Byzantine Fault Tolerate consensus mechanism based on BFT-SMaRT core (Bessani et al., 2017), Apache CouchDB as a database and an internal solution for peer certification. This configuration

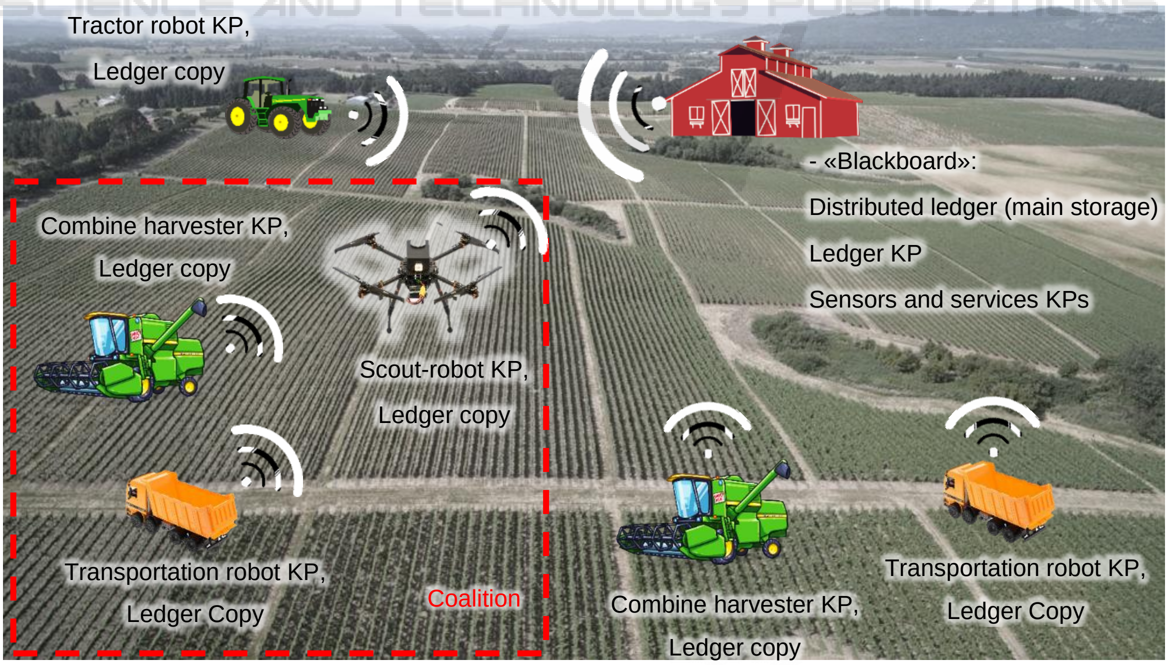

Figure 4: Coalition formation for precision farming task.

provides processing of more than 3500 transactions per second with latency of hundred ms. Also the platform provides possibility to create smart-contracts called chaincodes (program code that describes interaction between resources) using Go or Java programming languages. The chaincodes are running in isolated containers of core peers of Hyperledger based on the Docker technology stack. Each chaincode contains rules for cooperative fuzzy game that used for coalition participants negotiation. The example of chaincode for core calculation is presented at listing 1.

Listing 1: Example of a chaincode for coalition core calculation.

```
var robots []Robot // Robot list
var tasks []Task       // Tasks to be
                     solved
var core []FCG // Fuzzy coalition core
var coreMaxGain FGC  // Core with max
                     gain
func coreCalc(stub
shim.ChaincodeStubInterface, args
[]string) (string, error) {
    robots[i], tasks[j] = args[i],
                      args[j]
    core = FCGCalculation(robots,
           tasks) // according to
                  formula (2)
    for c in core {
       if c.gain > coreMaxGain.gain
           coreMaxGain = c
    }
    for rob in robots{
      // bind task for robot according
      to formula (1)
        stub.PutState(rob,
c.getTask(rob))
   // Estimate and fix processing time
    stub.PutState(c.getTask(rob),
     CalcProcTime(rob))
   }
 }
}
```

7 CONCLUSIONS

Smart contracts as a computerized protocol which stores and carries out contractual clauses via blockchain between humans and machines, or between multiple machines, are no longer just a theoretical concept and are becoming a real tool used in industry. Smart contracts have different future applications in industry, ranging from robot coalitions to the whole supply chain.

In this paper, the novel integrated model of application of games with fuzzy coalitions and fuzzy smart contracts, which can be applied to coalition formation both for humans and robots, and between multiple robots has been described. Fuzziness serves as the fundamental component of realistic cooperation models when there exist fuzzy expectations of player and coalition benefits. When an effective solution is found, individual benefits for players (the agreement efficiency) increase, as well as the capability of the coalition to find an effective and stable agreement. In the definition of a fuzzy core, the efficiency is taken into consideration by introducing binary variables y_{ij} into the fuzzy core. Fuzzy payments $\{(w(I), x_{ij}, w(K_i))\}$ may have any utility function, linear or nonlinear, universal or not, which enables the use of the model in real-world applications. The blockchain model allows one to avoid the synchronization problem, which is critical for distributed negotiation algorithms with large robot populations.

The use of the described FCG model for partners' selection in supply chains has been already reported by the authors. The integration of this model with smart contracts can make coalition formation more transparent and to smooth out the operations of the tasks. The use of Internet of Things (IoT) sensors, which track goods though the chain, from warehouses to manufacturers and suppliers enables that the finished product can be verified at each stage of the task solving. If any stakeholder fails to meet the terms of the contract, for instance if a robot did not perform some operation on time, it would be clear for every party to see and new coalitions can be arranged dynamically.

The future work is aimed in two main directions. The first one is to develop smart contracts for participants changing in coalition. The changing process will be based on the negotiation between coalition core and robots outside the coalition that can perform task instead of failed coalition members. The other direction includes simulation based on the use case scenario and comparison with other methods of coalition formation.

ACKNOWLEDGEMENTS

The present research was supported by the projects funded through grants # 17-29-07073, 17-07-00247 and 17-07-00327 of the Russian Foundation for Basic Research.

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