A blockchain-based technique for making swarm robots distributed decision

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A blockchain-based technique for making swarm robots distributed decision

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Abstract. The paper considers the problem of distributed decision making in the robot swarm. The enhancement technique of the related study approach is proposed using the data transmission distance constraints and the weighted voting strategy. The decision making process is organized by means of distributed ledger usage. The information propagation through the swarm is implemented via spreading randomized rumor. The avoidance of routing in the swarm improves the overall energy efficiency of the system. The weighted voting transactions take into account the positions of the robots relating to the unknown objects or obstacles, as well as the voting history, which is stored in a distributed ledger

1. Introduction

Nowadays the swarm robotics (SR) is the intensively growing field in terms of science and practice, inspired by lots of nature phenomena, such as flocks of birds, ant colony behaviors, etc. [1-3].

The application areas of SR are also various: cartography, activities within the hazardous environments, including observation and supervision, and many others.

The paramount features of the robot swarm are as follows:
- all elements are equal in terms of capabilities;
- peer-to-peer communication;
- possibility of decentralized control.

Robot swarms (RS) are supposed to be fault-tolerant by design [4] and highly robust, but still the key issue of such systems is distributed collective decision making. In general, distributed decision making problems in terms of RS include two wide classes of problems: the task allocation and consensus achievement. The task allocation problem is to maximize the overall swarm performance by assigning the subtasks to its different members. Consensus achievement problem for swarm is to agree upon one and the same alternative amongst the set of them. The problem of consensus achievement is of a high importance in lots of RS functioning situations, for example, to agree on a type of obstacle, or to agree on a type of object to be tracked, and there is a wide range of studies, which consider related problems, such as [4-7]. Yet the distributed consensus problem for the RS is still open in academic society.

Having emerged in the previous decade, Distributed Ledger Technology (DLT) is an outstanding achievement in terms of security, transparency and decentralization [8,9]. Launched with the advent...
Bitcoin cryptocurrency, DLT has found quite different application directions from targeted material delivery to healthcare insurance [9,10]. One of the future applications of the DLT, which is very promising and developing intensively, is robot control, including RS. The combination of DLT, in particular, the blockchain, with such distributed systems, as RS, can provide the necessary capabilities to make robotic swarm operations more secure, autonomous, flexible and even profitable [11].

In the current paper we consider the RS distributed decision making problem, which relates to the consensus achievement in decentralized and distributed systems.

As the field of blockchain application to the RS functionality is still in the very beginning of its existence, the studies devoted to the subject are seldom and poorly detalized. In particular, the blockchain application to the consensus achievement is described in [11], yet no attention is paid to such RS issues as energy consumption and data dissemination methods through the swarm.

In this paper a Blockchain-based technique for swarm robots distributed decision making is proposed. The novelty of this technique is to consider the data transmission distance of robots as constraints for the transactions and blocks dissemination through the network and to use a “donation” principle in the process of the voting, making it weighted. The remainder of this paper is organized as follows:

- the brief review of the swarm robotics and distributed consensus problem;
- the Bitcoin data dissemination algorithms analysis and its applicability to the robot swarm distributed decision making;
- the Blockchain-based technique for swarm robots distributed decision making description;
- discussion and conclusion.

2. Swarm robotics and distributed consensus problem
The area of swarm robotics has emerged from the fields of swarm intelligence and multirobot systems. It considers the physical embodiment and interactions among the elements of the systems and between the elements and environment. The definition of the “swarm” can be formulated as follows: it is a large group of locally interacting individuals with common goals. Swarm intelligence is the collective intelligence that results from interactions among groups of autonomous individuals [1].

Swarm robotics is often inspired from biological systems, e.g. insect colonies, flocks of birds, schools of fish, bacteria colonies, human cells.

The swarm robotics obvious advantages are [4]: the possibilities of large groups sensing capabilities, situational awareness, high level of robustness, workload distribution possibilities, simple and cheap robots can implement complex tasks.

Robot swarms have a high potential in such application areas, as: nuclear, chemical and biological attack detection, battlefield surveillance, space exploration, pollution detection, search and rescue. Yet the area of swarm robotic has multiple issues, such as: a need to choose between homogeneous and heterogeneous architectures, centralized and decentralized, an issue of energy consumption, and many others, including the consensus achievement within the decentralized swarms.

As was mentioned earlier, the distributed decision-making is an integral part of decentralized swarm behavior. The distributed decision-making problem is subdivided into two classes of problems [2], which are task allocation and consensus achievement. The latter is in the scope of this paper.

Consensus achievement in a distributed environment is quite an old problem.

There are a huge number of consensus algorithms and protocols, which have been developed by now. Consensus methods emerge relating to the fields of application: some of them are used in distributed database systems (Zookeeper, Raft) field [12,13], some others are in cryptocurrency (Proof of Work, Proof of Stake, etc.) [14,15]. For example, a good and comprehensive review of the consensus methods in the IT is given in [16]. According the classification elaborated, the consensus algorithms are subdivided into groups, as is shown in figure 1.
Consensus algorithms classification.

Besides, there are consensus algorithms, which emerged from the multiagent/robotics research field, for example [16,17]. The latest studies consider the prospectiveness of blockchain technologies application to the distributed consensus problem of the RS, and one of the paramount studies in this intensively growing area is presented in [11]. The major approach presented in the paper, considers the blockchain as a means of providing the swarm element with the overall view of the environment, as is shown in Figure 2. Yet there is no information about the data dissemination through the network. If it is supposed to apply the essential blockchain mechanisms of data dissemination, it can be an issue in terms of energy consumption of the swarm elements.

Figure 2. Blockchain-based distributed decision making.
In Figure 2 the possible stages of the distributed decision making in the swarm with the usage of distributed ledger are shown. Firstly, if an autonomous robot (AR) cannot make a decision regarding the nature of an unknown object (or obstacle), it generates transactions with optional opinions and addresses them to other robots in the swarm. After the transactions having been distributed among the robots, they generate answer transactions and put them into the block. So, the block containing all transactions shows the voting results of the swarm regarding the unknown object. Finally, outputs of transactions in the block reflect the voting results.

This scheme is quite promising, but has an issue, which consists in relational equality of transactional values. If one AR is near an obstacle, and the other is at a distance, the weights of their votes are equal, but the more remote AR can make a wrong classification of the object.

3. Data dissemination algorithms for the swarm

As is mentioned in [18], the structure of Bitcoin network is a random graph. When a node joins the network, it queries the DNS server, and gets knowledge about other nodes from its neighbors, and they get the information from theirs. As is estimated, a running bitcoin node has an average 32 connections, which is much more than default pool size of 8 connections. Those connections do not depend on the geographical location of the nodes, and the transactions and blocks are spread according to the randomized rumor spreading concept. The general scheme of the information spreading is shown in Figure 3.

![Figure 3. Block dissemination process in the bitcoin network.](image)

This mechanism prevents the duplicating block propagation; message inv allows to get preliminary information if the node has the block or not. If there is no block on the node, the node sends the message “get data”, and after that receives the block. After that the node sends the “inv” message to its neighbors and continues the data propagation if it is needed.

As for robot swarm, such information dissemination has its obvious disadvantage in terms of energy consumption. If the robot sends information to the random neighbors, there can be situations, where the routing is needed. So, it is expedient to modify the information propagation method adapting it to the physical constraints of the data transmission distances in the robot swarm.

4. A blockchain-based technique for swarm robots distributed decision making

The method proposed combines two key features:

- data propagation, considering the distance of possible signal transmission constraint. So routing and the workload of data transition through the nodes are averted;
- the weighted voting.

It is expedient to mention that we do not consider the byzantine robots behavior, leaving this outside of the scope of this paper.

Using the randomized rumor spreading with the constraints, a single AR transmits transactions only to those ARs, which are nearer than the maximum distance of data transmission, determined by the type
of the network and the communication environment. As the number of ARs in the swarm is known, so the upper time estimates of gossip spreading can be precalculated and be taken into account during the voting process. The example of data propagation with the data transmission constraints is shown in Figure 4.

![Figure 4. Data propagation through the swarm.](image)

When the transaction with the optional opinions about the unknown object has been spread and put into the block, every AR must commit the answer transaction according with its own point of view on the object. In study [11] it is supposed for the ARs to move towards the unknown object and after that to commit a voting transaction. We do not presuppose the ARs to change their locations, but to vote with their current opinions, using the following assumption: the vote of the AR, which is situated nearer to the unknown object, has more weight.

So, if we imagine, that the answer transactions “donate” some money to the AR, which has initialized the voting, those ARs, which are near the unknown object, donate more money than those ARs which are located in a considerable distance.

Another parameter, which we propose to use for weighted voting, is the usage of authority of the AR. Assuming that all robots in the swarm have a fair behavior, and every robot has its own copy of the ledger, we consider the AR to be of a high authority, if this AR voted in a manner of majority through the history of the RS mission, as is shown in Figure 5.
Figure 5. The dependency between the AR authority ratio and the history of the voting.

It must be mentioned that the latter authority-based voting parameter is possible for the blockchain usage only.

The weight of every answer transaction of the AR is as follows:

\[ S_{ar} = DAS, \]

where \( D \) – a distance ratio,
\( A \) – a authority ratio,
\( S \) – a considered sum of money issued to the answer transaction.

So, resuming the explanation of the technique proposed, its general differences from the analogues are: data propagation with the constraints of the data transmission distance without routing and data transmission through the transitional nodes, and weighted voting, which considers the distance between AR and the unknown object and the history of the voting based on the blockchain analysis.

5. Discussion and conclusion

The technique takes into account the energy-efficiency of the swarm and includes the following components:

- data propagation mechanism, which bases on the randomized rumor spreading adapted to the RS with constraints of data transmission diameter;
- the weighted voting.

The information propagation algorithm, which is used in classical cryptocurrency systems, has been adapted to decrease the energy consumption in conditions of data transmission constraint existence. This adaptation hardly affects the upper time bounds for the rumor spreading algorithm, as the latter usually is computed for the switched networks with varying structure. So, it is expedient to propagate the information only to those neighbors, which are reachable without routing procedure.

The weighted voting proposed includes two key ratio components: the ratio of distance between the voter and the presupposed obstacle and the ratio of authority, which can be proportional to the “proper” voting through the mission history written in blockchain.

So, those ARs, which are nearer to the obstacle, and voted with the majority in previous voting rounds, will have more weighty votes.

Obviously, the technique proposed is not stable in conditions of byzantine AR behavior, yet this problem might be solved partially by cryptography algorithms usage (public and private keys).

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