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On Blockchain-based Token Usage in Cyber-Physical Production Systems

Über die Verwendung von Blockchain-basierten Tokens in cyber-physischen Produktionssystemen

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Services and devices in a Cyber-Physical Production System (CPPS) can be provided and requested by multiple parties. Therefore, CPPS face challenges such as cross-company interactions, data security, and robustness against failure. Blockchain Technology (BCT) appears to be a suitable solution for these challenges, since it ensures immutable, trust-building, partly automatable, and transparent data handling and storage. In particular, BCT-based tokens enable the digital representation of objects such as products, tools and machinery or values and permissions and offer new possibilities for CPPS. Thus, this contribution focuses on the application of tokens in CPPS. Multiple use cases for tokens such as asset-backed tokens or utility tokens are presented. Based on this, a concept for an asset-backed token, representing material in a CPPS, is developed and demonstrated in a simulation model.

[Keywords: Cyber-Physical Production System (CPPS), Blockchain, Tokenization, Smart Contracts]

Die Dienste und Geräte in einem Cyber-Physischen Produktionssystem (CPPS) können von mehreren Parteien bereitgestellt und nachgefragt werden. Daher stehen CPPS vor Herausforderungen wie unternehmensübergreifenden Interaktionen, Datensicherheit und Robustheit gegenüber Ausfällen. Die Blockchain-Technologie (BCT) scheint eine geeignete Lösung für diese Herausforderungen darzustellen, da sie eine unveränderbare, vertrauensbildende, teilweise automatisierbare und transparente Datenverarbeitung und -speicherung gewährleistet. Insbesondere BCT-basierte Tokens ermöglichen die digitale Darstellung von Objekten wie Produkten, Werkzeugen und Maschinen oder Werten und Berechtigungen und bieten neue Möglichkeiten für CPPS. Daher konzentriert sich dieser Beitrag auf die Anwendung von Tokens in CPPS. Es werden verschiedene Anwendungsfälle für Tokens vorgestellt, wie etwa Asset-Backed Tokens oder Utility Tokens. Darauf aufbauend wird ein Konzept für einen Asset-Backed Token entwickelt, der Material innerhalb eines CPPS repräsentiert, und in einem Simulationsmodell demonstriert wird.

[Schlüsselwörter: Cyber-Physisches Produktionssystem (CPPS), Blockchain, Tokenization, Smart Contracts]

1 INTRODUCTION

As product variety increases, quantities per variant decrease, demand uncertainties grow and new challenges for production systems arise [1, 2]. Simultaneously, manufacturers aim for low machine failure rates [3] and want their production systems to be able to respond quickly to unforeseen events and challenges [4]. To overcome these challenges, Cyber-Physical Production Systems (CPPS) have been developed and gained a lot of attention since [5]. CPPS are embedded systems characterized by a collaboration of digital or virtual and physical entities, enabling communication between humans, machines, and products [5].

As the services and devices in a CPPS can be provided and demanded by multiple parties, challenges such as cross-company interactions, data security, and robustness against failure must be considered [6]. Thus, the system should be tamper-proof, transparent, and decentrally controlled to always guarantee valid and safe transactions between participants, while eliminating the risks of having a single point of failure.

By ensuring immutable, trust-building, partly automatable, and transparent data handling and storage, blockchain technology (BCT) appears to be a suitable solution to face these challenges [7]. Especially the development of blockchain-based tokens, which can represent assets in multiple ways, helps to solve trust issues and risks of transaction manipulation in CPPS. The purpose of tokenization "[…] is always to find a way, such that the asset can easily be traded, transferred and possibly subdivided, while keeping the characteristics of the asset itself" [7]. Furthermore, different types of tokens can be used to facilitate platform governance or to enable the implementation of a wide range of automated services on decentralized platforms such as, for instance, micropayments [8]. Also, tracking and tracing of physical objects, such as in the context of supply chain monitoring, can be achieved with blockchain-based tokens, increasing process transparency [8].

Following this idea to meet the requirements for practical applications of CPPS by employing blockchain-based tokens, this paper deals with possibilities to use BCT and blockchain-based tokens. In addition to a presentation of state-of-the-art use cases, we describe the practical implementation of a CPPS in which the components and parts are digitally represented as tokens. The following section includes explanations and definitions about relevant terms and concepts. Subsequently, use cases for tokens in the manufacturing context are presented, followed by the elaboration, description, and the evaluation of our own implementation of a CPPS using blockchain-based tokens.

2 State of the art in cyber-physical production Systems and blockchain technology

This section lays out the relevant fundamentals concerning CPPS and BCT. The focus is especially set on the combination of CPPS and BCT and the use of blockchain-based tokens.

2.1 Cyber-physical production Systems (CPPS)

The use of embedded software and hardware for the interaction of physical and virtual entities is the defining feature of Cyber-Physical Systems (CPS) [9]. In the manufacturing context, CPPS have emerged as a derivation of CPS and allow for automated, flexible, and self-configuring production [5].

CPPS combine autonomous and cooperative elements in embedded systems and multiple subsystems [5]. These systems enable the interplay of humans, production equipment, and aggregated products through different interfaces used to monitor and control the production processes and for data gathering [10]. The capturing of information and the generation of knowledge is crucial to allow for continuous improvements of the production system and the products emerging from it [10]. Within a CPPS, multiple heterogeneous entities such as manufacturing machinery, mobile robots, and the plant environment interact with one another [11]. Internet of Things (IoT) is a frequently used term for such a network of interconnected agents including machines, vehicles, and other items which are monitored or controlled remotely [12]. These entities communicate and exchange process relevant information on and across different levels including the shopfloor and managerial levels [5]. Consequently, the collection, processing, and interpretation of data are essential success factors [5]. Due to the inherent properties of these systems, they are a key factor in the development of Industry 4.0 applications [5, 10]. Likewise, the importance of human-machine-interactions and the efficient and safe handling of data can easily be derived from this description of CPPS. These issues are also often discussed design elements in industry-related publications regarding Industry 4.0 related research [9]. The collaboration between humans and machines, data and information security, and decentralized decisions are frequently discussed challenges for a successful implementation of Industry 4.0 [13].

2.2 Blockchain Technology (BCT)

BCT is based on a decentralized network maintaining a distributed and virtually immutable database [14, 15]. BCT is a concept originating from the Distributed Ledger Technology (DLT) [14] in which every participant of the network holds a holistic copy of the blockchain [16]. The information on the blockchain is stored in multiple blocks and a consensus mechanism determines which participants may add new information to the blockchain [17]. Besides the consensus mechanism, cryptography and back-referencing blocks ensure validation and integrity of data and transactions [15]. Therefore, characteristic features of BCT are its permanence, immutability, disintermediation, and transparency [18]. These trust-building attributes enable intercompany networks or other types of cooperation of otherwise non-cooperative parties. Since the blockchain ensures the validity and correctness of data and transactions, the participants of the blockchain network do not have to trust each other or a central intermediary [19]. Thus, a number of scholars [20-22] attribute potential to BCT applications in the field of CPPS.

2.3 Blockchain-based tokens

Tokens are digital, quantifiable units, that exist on a blockchain and represent various physical or digital objects [7, 23]. This concept of representation is called tokenization [23, 24]. A multitude of different types of tokens is distinguishable, considering the specific method of tokenization and the type of asset or object the token represents [7]. Besides physical objects and financial assets, tokens can include almost any digitized value, such as rights of ownership, copyrights, voting rights, or participation rights and reputation mechanisms [25]. Furthermore, tokens refer strictly to a specific ecosystem, i.e., to the blockchain network in which they exist [26].

In contrast to this, coins are units of crypto currencies on their respective blockchain [23]. Each blockchain has its own native crypto currency. For Ethereum, for example, this would be Ether (ETH).

A major advantage of tokens over coins is their broader functionality. While coins function strictly as a means of payment, tokens can also fulfill various other functions, as described [25]. In addition, tokens enable faster transactions with a lower volume, compared to coins [27].

2.3.1 Categories of blockchain-based tokens

Depending on their specific functions and purposes, tokens can be classified into different categories. However, these classifications are seldom clear-cut and are not uniformly handled in the relevant literature. Most categories encompass fungible tokens. These can be exchanged, since they are defined by their value rather than a unique property [28].

Security tokens, also known as equity or investment tokens, represent intangible assets. These can be, for example, sharing rights or promises of profits. In this way they are similar to conventional securities [29]. According to [23] asset-backed tokens are seen as part of security tokens. [29] and [30], however, consider them to be separate categories. While asset-backed tokens are very similar to security tokens, they are used to represent real tangible assets or investments, such as real estate [30]. Another category, utility tokens, grant access rights to products or services on a network or access to the network itself. Once the respective access right is granted, it is paid for with tokens [29]. The products or services sold do not have to exist at the time of sale, which enables them to also be used as a project financing tool [23].

In addition to the above mentioned categories, there are the categories of governance and reward tokens. Governance tokens enable a democratic vote on decisions affecting the network [31]. The token owner has a right to vote, the weight of which depends on the amount of tokens held, in relation to the total amount of tokens in circulation. Reward tokens serve as a reward system and can be awarded, for instance, for performing certain tasks [31].

Payment tokens, in contrast, are relatively unambiguously demarcated. They fulfill functions similar to currencies, such as the exchange function, i.e., fulfilling the owner’s willingness to exchange tokens for a good or a service. To do so, the tokens act as an account unit, so that goods can be evaluated in terms of value against the tokens. Unlike some other currencies, payment tokens are subject to much greater value fluctuations, which means that the function of storing value, which traditional currencies possess [29], cannot be fulfilled. However, the situation is different with stablecoins, which are a distinct type of payment token. Their value is hedged by the issuer with less volatile assets, such as commodities or conventional currencies, which allows the price of stablecoins to stabilize around a given value [23].

Beyond these categories of fungible tokens, non-fungible tokens (NFTs) represent non-exchangeable digital assets such as property information [32]. Just like the value behind them, NFTs are individual and distinguishable [23], because they have properties that are unique to every single token. This makes it possible to map ownership rights to NFTs, ensuring that there always is only one owner of a given NFT at a time. This proof of ownership is immutable and it is also not possible to copy or rebuild an NFT [28].

2.3.2 Technical aspects of blockchain-based tokens

The transfer of tokens on a blockchain is based on the use of addresses that are owned by the users through the possession of private keys. For each of these addresses, the respective amount of ownership is stored on the blockchain. Wallets are needed to manage the addresses of the users [23]. There are different types of wallets, which differ in the deposit of the private key and, thus, also in security. Hardware wallets are considered the most secure type, as the keys are only stored on the hardware itself and transactions are verified on it. Software wallets, or desktop wallets, store the keys on the local hard drive of a computer and are therefore considered to be less secure. The most insecure type are online e-wallets, where the keys are stored on one of the e-wallet provider’s servers. As a result, security depends heavily on the provider's implementation. However, e-wallets have the advantage of accessibility from any device and any browser through the internet. [24]

Smart contracts are used to transfer tokens automatically between wallets. These are immutable scripts that are stored on the blockchain and independently carry out transfers if certain conditions are met. The programming language used for smart contracts, in the case of Ethereum, is Solidity, which was developed specifically for this purpose. [23]

2.3.3 Smart contract standards

To implement fungible tokens on the Ethereum network, a standard called Ethereum Request Comments-20 (ERC-20) has been established [23] as shown in figure 1. This standard ensures compatibility with a large number of already existing tokens and smart contracts [33]. For it to be compatible, the implemented token must fulfill certain standard functions and events [24]. These include the name as well as its symbol, its abbreviation, the number of decimals, the amount of tokens to be generated, an account to which the tokens are initially issued as well as various transfer functions and events [27]. *Transfer* functions ensure the transfer of tokens from one account to another and subsequently confirm the success or failure of the transaction. If a successful transaction is reported, the event *Transfer* is triggered. In this context, the

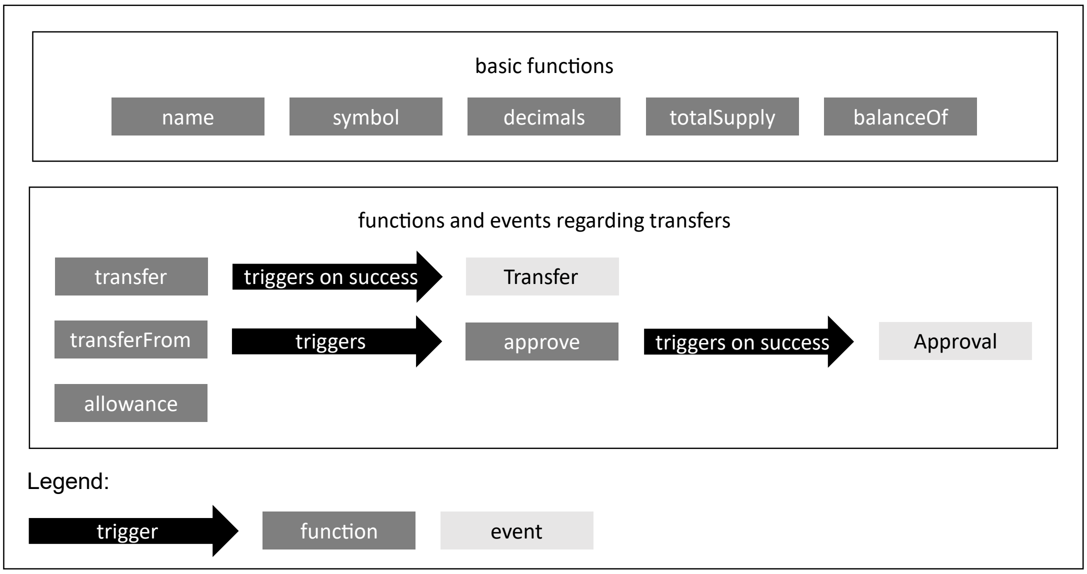

Figure 1.: *Overview of the functions and events of the ERC-20 standard*

transferFrom function offers the possibility of specifying a sender address. Subsequently, the *approve* function issues an approval for the transfer. If the function was executed successfully, the *Approval* event is called. The *allowance* function indicates the number of previously approved units that can still be retrieved. [23, 27]

For non-fungible tokens, another token standard, the ERC-721 standard, exists. Although this standard shares certain characteristics with the ERC-20 standard, it differs primarily in the mechanism through which it identifies tokens, as each token is unique (i.e., tokens are not only counted as part of a sum of tokens, but are individually identifiable). To achieve a representation of uniqueness, each ERC-721 token possesses a unique token ID, which can be used for entities belonging to one class of objects that are to be differentiated and uniquely identified [34, 35].

2.4 APPLICATIONS OF BLOCKCHAIN-BASED TOKENS IN THE CONTEXT OF PRODUCTION AND SUPPLY CHAINS

Aside from the initial use of BCT in the finance sector, CPPS are a field in which BCT in general and tokens in particular can be applied in various different ways [7, 36]. For instance, [37] presents a Cyber-Physical System with components which are holistically represented by a digital twin and are able to communicate with other entities in the IoT and the blockchain network [37]. Payments are processed with the help of tokens through IoT and blockchain interaction [37].

In [38], another an application is shown in this field, aiming at the possibility of implementing cloud manufacturing-as-a-service (CMaaS) platforms using tokens [38]. They demonstrate a way to automate and process secure payments, which are typically required in smart contracts for manufacturing tasks on CMaaS platforms. For this, secure, fungible asset transfer models of the global Ethereum blockchain network are utilized [38]. They examine a process in which an event on the blockchain is triggered when a production step is terminated. The machine that performs a given task is assigned to its owner on the blockchain by being represented as an NFT. This way, payments for the fulfillment of a task by a machine can automatically be transferred to the machine's owner as tested by integrating a CNC mill into the blockchain network. In addition, autonomous negotiation, payment, and refund mechanisms between connected machines in a CPPS as well as performance metrics concerning gas consumption, mining times, and cyclomatic complexity of smart contract codes are investigated concerning their efficiency [38].

In the field of Supply Chain Management, the use of blockchain-based tokens has been investigated in multiple cases [39-41]. For instance, [40] present a monitoring approach for the life cycle of tires by tokenizing their raw materials and tracing them along the supply chain. Thus, providers of raw materials generate tokens as they supply the raw material. These tokens are subsequently transferred together with the supplied material. Therefore, the authenticity of the tires along the supply chain can be verified and guaranteed before each transaction. This allows for the product life cycle to be holistically traceable, ensuring an appropriate recycling or disposal process [40].

Another use case of blockchain-based product life cycle monitoring is the example of spare parts in the aviation industry. To ensure the pristine condition of safety-relevant aircraft parts, a solution for storing transaction, product, material handling, and repair data on a permissioned blockchain is proposed in [41].

Furthermore, use cases for blockchain applications such as self-organized supply chains and production lines

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of machine to machine (M2M) services have been discussed in [7]. In both cases the fast and safe execution of transactions and transfer of data is crucial.

Meanwhile, in [42] blockchain and token applications are investigated in the context of a sharing economy. The authors describe the design of an infrastructure for a decentralized marketplace for production capacities, consisting of two models. The first model, consisting of three layers, describes the interaction of the machine layer, the token layer and the matching layer, while the second model, the flow model, describes the process of capacity exchanges. In this implementation, capacities are represented by ERC-20 tokens with varying supply, which can be traded for stablecoins on a decentralized exchange. The capacity tokens can represent complex combinations of machines, materials, and certifications to allow users to precisely specify their orders [42].

Tokens can also be used to increase the security of the IoT. For this purpose, in [43] a model that handles access control via tokens is proposed. In this case, a special type of token is created using an Ethereum-based smart contract, enabling efficient access while ensuring the privacy of data in an IoT-network [43]. Access tokens and BCT can be applied for authentication in IoT-networks and therefore increase the security of IoT-users [44].

3 USE CASES OF BLOCKCHAIN-BASED TOKENS IN CPPS

As described, blockchain-based tokens are versatile and can, thus, be employed in a plethora of different ways. Therefore, in this section, we present potential use cases of blockchain-based tokens in the context of CPPS as an addition to the examples mentioned in the state of the art section, notably as payment, asset-backed, and utility tokens.

3.1 PAYMENT TOKENS

In most cases, the manufacturing process is ensued by a sales process, in which the manufactured good is put up for sale. Traditionally, the related financial transactions are performed using fiat currency. However, the use of crypto currency can be a valid alternative in this context. To take CPPS as an example, a blockchain could be deployed, for instance, the Ethereum blockchain with ETH as its native crypto currency, which would in turn also be used as a payment method. ETH however, is notorious for its high gas fees [45, 46], representing a major disadvantage of the blockchain. In this case, a blockchain-based token, using the same blockchain, could be used as a valid alternative. Not only could gas fees be reduced, but also transaction speed could be increased.

3.2 UTILITY TOKENS

When it comes to complex systems, in which a multitude of parties are involved but a distinct policy is articulated, the possibility to give certain incentives can be of interest. In the case of distributed CPPS, utility tokens could be handed out to the blockchain participants, which act according to the respective policy of the network community. In the context of a sharing economy, for example, utility tokens, that could be exchanged for currency or other reimbursements, could be used as an incentive for data sharing.

Even beyond policy making, utility tokens could be used as a reputation mechanism in CPPS, either for individual network participants or for agents, which could receive these tokens as a reward for fulfilling tasks. By using such a system, the reliability of agents could be tracked, compared, and analyzed. The gathering of such data could subsequently be used as additional input data for predictive maintenance systems, which in turn would further improve the efficiency of a CPPS.

Additionally, utility tokens could also be used to provide their holders with access to certain parts of a shared CPPS. This could, for instance, be access to machinery, as to reserve the right of usage of said machinery for a given period of time. This would be beneficial to capacity management, preventing bottlenecks and allowing network participants to plan ahead and gain supplementary planning security.

3.3 ASSET-BACKED TOKENS

Additionally, asset-backed tokens could be of great use in CPPS as a system mirroring and representing assets in production. These assets could, for instance, be robots, machinery, workstations, products, or even individual components. Therefore, depending on the granularity with which this concept would be applied and the complexity of the system it would be applied to, different needs and demands could be met. In this sense, this application of asset-backed tokens would permit full transparency for the sourcing of a product's components, by virtue of token transfer between production steps. For instance, if a component were to be represented by an asset-backed token, the acquisition of said token would come with a given price (as part of a smart contract). Based on this, a cost function would be generated, which the agents involved would use to calculate, whether or not they should engage in the acquisition of a given component and perform the task that is attached to its possession. At each processing step, the token would therefore change ownership (for instance, from a robot to a workstation, back to another robot, and so forth) until it would reach its final destination as part of a finished product.

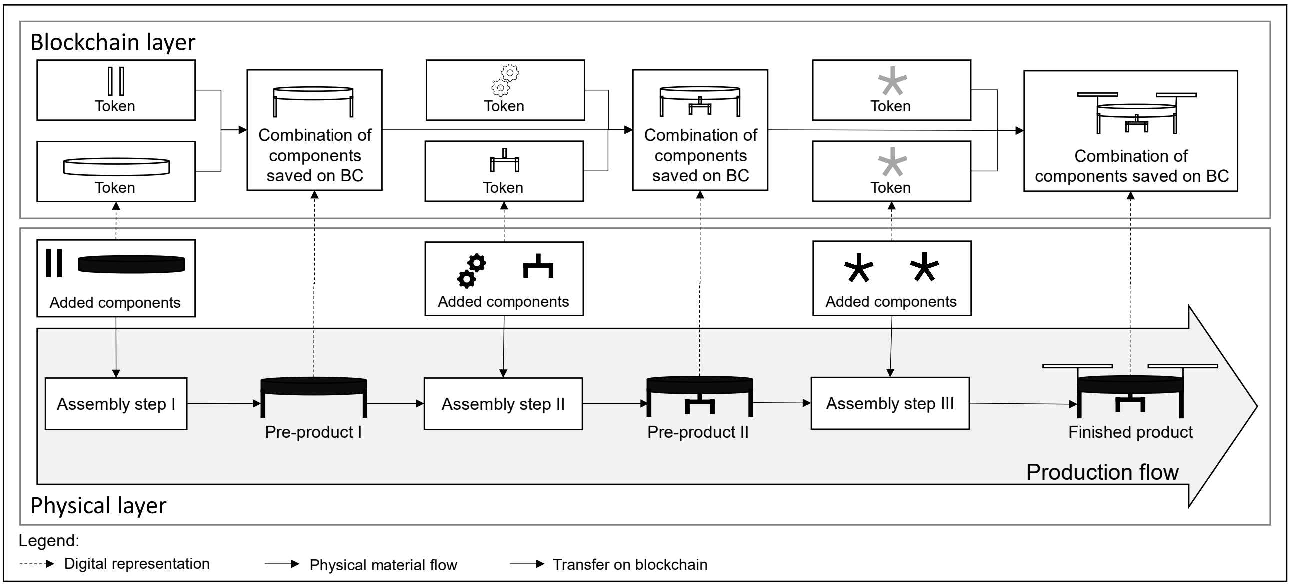

Figure 2.: Concept for the use of asset-backed tokens in a CPPS

4 CONCEPT AND EXEMPLARY IMPLEMENTATION OF ASSET-BACKED TOKENS IN A CPPS

As explained in the preceding sections, tokens can be beneficial for many use cases within a production system and have found plenty of applications so far. However, no application of asset-backed tokens in the context of CPPS, for the purpose of supply chain transparency and traceability, has been encountered during our research. Therefore, in the following, we present our proposed proof-of-concept in this field.

To show an exemplary concept and implementation, we consider the use case of a CPPS as described in [47, 49]. In this use case, individually configurable drones are assembled in a cyber-physical matrix production system. The material is provided in carts which are transported by mobile robots. A market-based approach is used to determine which agents performs which tasks within the production system. For this CPPS, a two-stage market-based task allocation using BCT is designed and implemented in [50] using smart contract functions for the task allocation process and respective payments between agents.

In this use case, asset-backed tokens can be used to represent single components of the drones such as rotor blades or screws. These tokens can store information on suppliers, batch numbers, and also contain certain certificates regarding, for instance, CO2 emission, energy consumption, or sustainable sourcing. Figure 2 displays the concept of token management within the CPPS. Tokens can either be provided by the suppliers or created with the incoming goods. For each assembly step, certain materials are required, which are represented by specific asset-backed tokens. Even though each material is different, material of the same batch such as, for instance, a certain number of screws, is interchangeable and has the same properties. Therefore, we refer to the ERC-20 standard for fungible tokens and design a smart contract accordingly. Figure 3 displays the design of the ERC-20 token and its interplay with the CPPS smart contract functions presented in [50]. To guarantee the secure transfer of the tokens, the token smart contract is embedded in the blockchain-based control of the CPPS. The transfer of the token is triggered on-chain by the CPPS smart contract without any intermediaries. Thus, it can be ensured that the token is transferred correctly and the transfer of ownership is not only documented, but directly linked to the proof in the blockchain that the transfer of ownership was performed as intended.

The transfer of the token is embedded in the CPPS processes. The workstation provides a call for materials in the form of an auction on which carts can bid. To bid on an auction, carts have to be able to provide the required materials in at least the required amount. Proof of the fulfillment of these requirements can be given by the tokens. Thus, if a cart wants to bid on an auction of a workstation, the CPPS smart contract automatically calls on the balance of tokens of the bidder and validates whether the requirements are fulfilled or not. Only then are carts permitted to bid on an auction. To bid, carts have to include offers from robots for transport and then calculate their own offers. A detailed description of the bidding process is presented in [50]. Once the workstation has chosen the most adequate, i.e., most cost efficient, offer, it transfers the required amount of currency for the task to the smart contract and the chosen mobile robot transports the chosen cart to the respective workstation. Once the robot and cart have arrived at the workstation, the smart contract releases the payment for the cart and robot. At this point, the tokens

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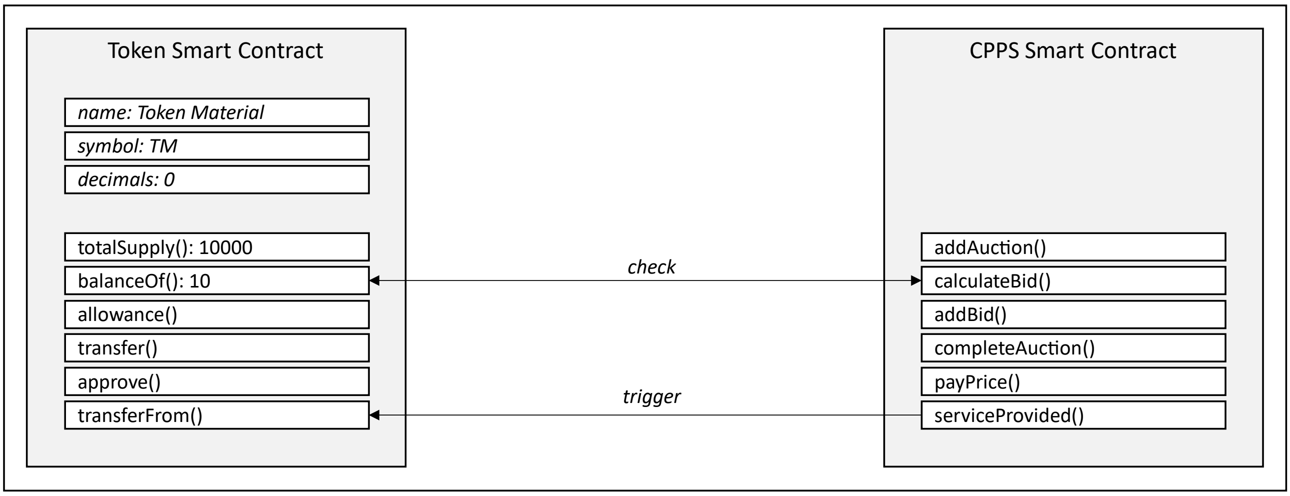

Figure 3.: Interplay of the CPPS smart contract and the prototypical token smart contract

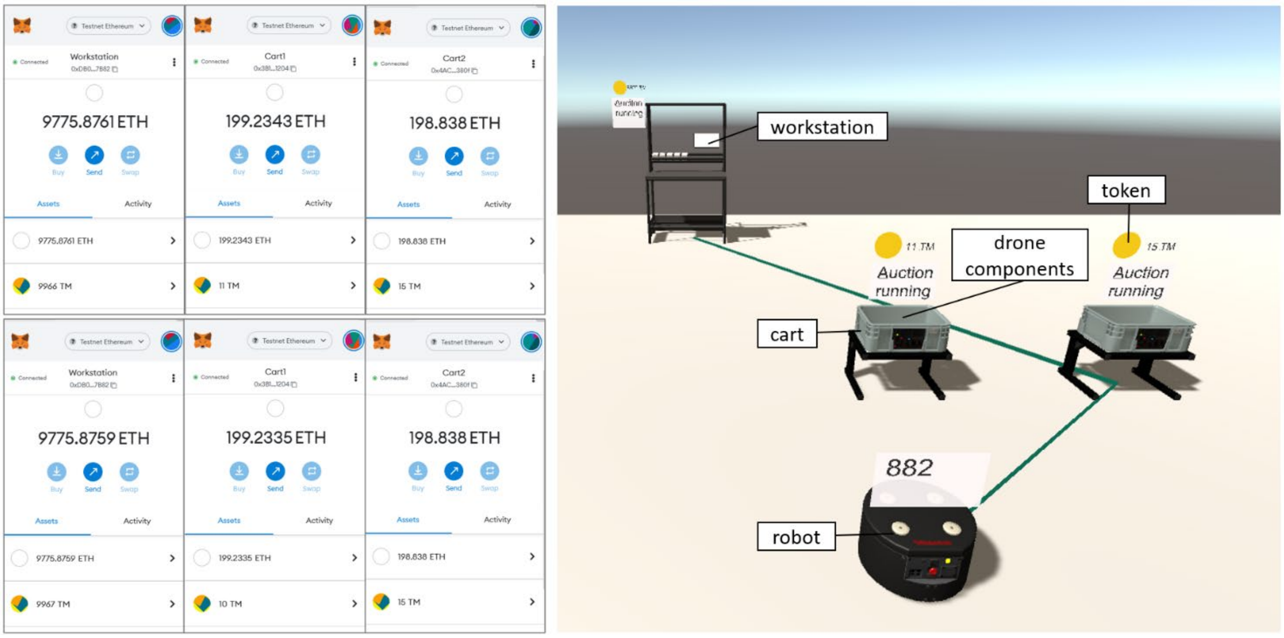

Figure 4.: Tokens TM in MetaMask wallets of three CPPS agents (left-hand side) before (top row) and after (bottom row) token transfer in the Unity model (right-hand side)

of the cart belonging to the required materials are automatically transferred on-chain to the workstation. This means that the workstation now holds tokens for the material that it had been provided with. Once the assembly step at the workstation has been completed and the assembled product, in this example a pre-produced drone, is transported to another workstation, the tokens are transferred along with the workflow. In the end, the finished product can be transferred to the customer together with all collected tokens representing its components. This enables the customer to transparently trace back all assembled components to their suppliers and their original components.

For the implementation of the herein described concept, the prototype presented in [49] and [50] is used. In this prototype, the conjunction of the blockchain framework Ethereum as a testnet, the game engine Unity for visualization, and the interface Nethereum enables a blockchain-based CPPS. While Unity is used for visualization purposes, Remix IDE is used as the backend to create smart contracts in Solidity for Ethereum. The figure 4 displays the wallets of a workstation and two carts before and after a service has been provided and the repective tokens have been transferred (left side). It also shows the visualization of the scenario in the Unity model, including one mobile robot, two carts and one workstation. In the GUI provided to the user, an overview of the state of the CPPS, with tokens attached to their agents, is given. This allows manufacturers to gain insight on the the current status of production and the visual display of tokens increases the overall transparency of the production ystem.

Altogether, a proof-of-concept has been developed, demonstrating the feasibility of the use of asset-backed tokens on the Ethereum blockchain, as a means to increase both transparency and traceability of a CPPS of ownership, which can also be linked to the transfer of money.

5 Outlook

In this contribution, various state-of-the-art applications for different types of tokens were presented. Categories of blockchain-based tokens were presented and evaluated for their use and purpose. It was determined, that the application of asset-backed tokens in the context of CPPS, for the purpose of transparency and traceability increase, has not yet been a subject of research, while being of interest to the broader production and blockchain research community. We therefore proposed a novel approach for tracing materials using blockchain-based tokens, handled by mobile robots inside a CPPS, using the Ethereum blockchain along with the ERC-20 standard. The tokens are created and transferred by a smart contract implemented on the blockchain. This can ensure a secure transfer with direct proof of transfer without the need for an intermediary. In this way, the complete process in the CPPS can be digitally mapped and monitored, from the auction of orders to the finished product with all collected tokens, making it possible to track every step of the process by the customer or manufacturer in retrospect.

Nevertheless, the presented insights and implementation underlie some limitations with regard to the implementation of the specific use case. While several use cases for tokens in production systems have been identified, only one specific use case could be implemented and used to evaluate the functionality of our approach. Besides, the list of identified use cases for tokens in production systems is not to claimed to be holistic and could be further expanded in a more extensive survey. Regarding the implemented token, as of now, the point in time at which the token creation would take place has not yet been defined. An asset-backed token has to be created at some point during in the production process. It can either be transferred from a supplier or could be created with the incoming goods. In either case, it has to be guaranteed that the information stored in the token is trustworthy. Another limitation would be the scenario itself. While the integration in a smart contract and the token transfer are included, the simulation model of the scenario comprises the task allocation process within a production system and does not include the whole production system or the potential transfer between suppliers and producers, or producers and customers.

We plan on addressing these limitations in future research. Especially the proof of generalization, by applying our approach on other use cases, will be of interest. Additionally, the implementation of the herein developed asset-backed tokens will be extended to the whole production system and comprise several different materials. These materials and components could then further be individually distinguished, by using the ERC-721 standard, instead of the ERC-20 that was used for this contribution. Further aspects that remain to be addressed are the implementation of certificates for production and the integration of payment tokens to reduce transaction costs.

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