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Application of distributed and decentralized technologies in the management of intelligent transport systems

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Abstract
Shifting focus from the field of distributed and decentralized technologies in the management of intelligent transportation systems (ITS), we now delve into the specific application of blockchain in transportation management. Blockchain is a fundamental component of distributed and decentralized technologies. The research paper discusses the utilization of blockchain technology in managing transportation systems through multi-agent systems. Specifically, the use of blockchain technology is examined in the context of the quick road system (QRS) in ITS to provide a service for obtaining a special fare status. This service aims to establish a decentralized network that facilitates real-time road lane sharing. The study indicates that depending on traffic situations, drivers can share their lane space with other vehicles traveling on the same route by exchanging incentives via blockchain with other private car owners, thereby allowing for faster travel for individuals in a hurry or those requiring priority access to fast lanes. The paper also addresses the increasing number of connected devices in ITS due to the development of the internet of things (IoT) technology. It highlights the importance of efficiently utilizing large datasets and identifies the internet of vehicles (IoV) as a crucial area of integration for existing IoT technologies to address smart traffic within multi-agent systems.

Keywords: Traffic, blockchain, intelligent transport systems, Internet of Things, smart contracting, end-to-end technologies, digitalization

1. INTRODUCTION

Intelligent transportation systems (ITS) have become increasingly important in recent years as they provide a range of services aimed at improving the efficiency, safety, and sustainability of transportation networks. However, traditional ITS solutions often suffer from several limitations, such as security vulnerabilities, data silos, and inefficiencies in data exchange and processing. To address these challenges, blockchain technology has emerged as a promising solution for the transportation industry.

Blockchain technology is characterized by its decentralized, secure, and immutable nature, which makes it ideal for creating secure and transparent platforms for exchanging data between different stakeholders in a transportation network, such as vehicles, roadside devices, and traffic management systems. In addition, blockchain technology can be used to create decentralized platforms for managing various transportation processes, such as payment for transportation services, vehicle identity management, and supply chain management.

Before delving into the subject, let us examine the characteristics of distributed decentralized technologies. The ITS and the Vehicular Ad Hoc Network (VANET) are closely related since VANET is a specific type of ITS that uses wireless communication technology to allow vehicles to interact with each other and with the infrastructure around them.

In an ITS, various technologies are employed to gather and analyze data from different sources, such as sensors and cameras, to provide real-time information to drivers, traffic managers, and other stakeholders. This information is used to optimize traffic flow, enhance safety, and minimize congestion. Additionally, ITS can facilitate communication between vehicles and the surrounding infrastructure, such as traffic lights and road signs, to provide additional information to drivers and improve traffic management.

VANET is an essential technology used in ITS that enables communication between vehicles and infrastructure through wireless networks. VANET allows vehicles to exchange information on traffic conditions, road hazards, and other crucial data. This information enables vehicles to make informed decisions about their routes and speed, leading to enhanced traffic flow and safety.

Overall, ITS and VANET work together to create a smarter and more connected transportation system. By integrating wireless communication technology into the infrastructure and vehicles, ITS can provide real-time information and communication that can improve traffic flow, reduce accidents, and enhance the overall driving experience.

Task offloading in VANET refers to the allocation of computational tasks between vehicles and roadside infrastructure[1]. Vehicles may have limited processing power and storage capacity, while roadside infrastructure can provide additional computational resources. One solution to this issue is a privacy-aware multi-agent deep reinforcement learning approach for task offloading in VANET. This approach involves a deep reinforcement learning algorithm to learn the optimal task offloading strategy, a multi-agent system to coordinate the task offloading process between the vehicles and roadside infrastructure, and a privacy-aware mechanism to ensure that the privacy of agents is preserved during the task offloading process.

Although the proposed approach has the potential to improve the efficiency of task offloading in VANET and preserve the privacy of the agents involved, it has its limitations. The approach involves multiple components, which may add complexity to the task offloading process. Furthermore, the use of deep reinforcement learning may require significant computational resources, which may limit the feasibility of the approach in real-world VANET systems with limited resources. Additionally, there is always a risk that sensitive data could be leaked or exposed during the task offloading process, even with the privacy-aware mechanism in place.

In recent years, cloud-assisted VANETs and internet of things (IoT) applications have become increasingly popular. However, these systems have also raised concerns about privacy, energy efficiency, and resource allocation. Two recent research papers, "PPVF: privacy-preserving protocol for vehicle feedback in cloud-assisted VANET"[2] and "AFED-EF: An energy-efficient virtual machine (VM) allocation algorithm for IoT applications in a cloud data center"[3], propose solutions to these challenges.

The PPVF protocol presented in the first paper aims to enable privacy-preserving feedback collection in cloud-assisted VANET systems. The protocol utilizes a group signature scheme for anonymous authentication of the vehicle, a zero-knowledge proof for proving the correctness of the feedback without revealing the actual data, and a homomorphic encryption scheme for computation on encrypted data. While the PPVF protocol has the potential to improve privacy, it may also introduce complexity, computational requirements, communication overhead, and security risks. Therefore, careful consideration is necessary before implementing the protocol in practical applications.

The algorithm AFED-EF is designed for energy-efficient VM allocation in cloud data centers that host IoT applications. The algorithm is based on the Ant Colony Optimization (ACO) algorithm and includes energy-saving techniques such as dynamic voltage and frequency scaling (DVFS) and VM consolidation on physical servers. AFED-EF considers the workload characteristics of IoT applications and the energy efficiency of the physical servers in the cloud data center. The algorithm offers several advantages, including improved energy efficiency, reduced operational costs, and improved performance for IoT applications. However, the algorithm may have limitations and require further testing and refinement in practical applications.

Overall, both papers present promising solutions to challenges in cloud-assisted VANETs and IoT applications. However, as with any research paper, further testing and refinement is necessary before implementing the proposed solutions in practical applications. These papers demonstrate the importance of considering privacy, energy efficiency, and resource allocation in designing and implementing cloud-assisted VANETs and IoT applications.

The integration of blockchain technology in ITS has the potential to revolutionize the transportation industry by addressing key challenges faced by traditional ITS solutions. By providing secure and decentralized platforms for exchanging data, managing transportation processes, and facilitating payment systems, blockchain technology can help to create more efficient, secure, and transparent transportation networks. In this paper, we provide a comprehensive review of the current state of the art in the use of blockchain technology in ITS, with a focus on its applications in secure data exchange, decentralized platforms, and payment systems.

The potential of blockchain technology in managing transport systems lies in its ability to create decentralized ITS[4]. However, to fully realize this potential, there are several key issues that must be addressed. The objective of this study was to explore the use of blockchain technology in managing transport systems within multi-agent systems that account for the independence and limited view of the participants of the system and its decentralized nature.

The study focused on utilizing the decentralized features of blockchain technology and IoT technologies in the transport system. The rapid growth of connected devices in the IoT is expected to continue, creating significant opportunities for enhancing transport management[5].

The optimal utilization of large amounts of data has become a significant research area in multiple fields. The internet of vehicles (IoV) is a key area of focus for integrating existing IoT technologies to address the issue of intelligent traffic. The prevention of road incidents is crucial, and regulations are more effective than quick reactions. ITS indirectly improve traffic safety and reduce accidents. While significant effort has been invested in creating ITS, safety issues must be addressed. Blockchain technology can solve potential safety problems associated with traditional centralized security systems[6].

Data protection has two critical aspects: trust and privacy. The decentralization of a blockchain system ensures a reliable level of security. Personal data can be shared only with users, leading to an intelligent transport system monitoring system. The trust and privacy of blockchain align with the concept that personal rating of system participants is closely linked to their behavior on the road. Therefore, a safer driver will have a reputation as a trustworthy driver.

To coordinate real-time traffic monitoring and control, individual user ratings can be connected to road behavior to incentivize safe driving. While a single traffic regulation cannot solely improve the road environment, efforts should be made by the community and social environment. By monitoring and managing intelligent traffic, precise action can be taken against dangerous drivers, ultimately improving the traffic situation during rush hours[7].

A credit token, a type of blockchain, could be used to record traffic violations and exchange big data between agencies, preventing the isolation of intelligent transport systems. A credit token transaction system based on blockchain technology could be created and integrated within the road platform. The credit token represents personal reputation and works only within the road platform. To reduce accidents and create a better urban transport environment, the token payment process is linked to the correct lane change and the current selection of a safe speed limit[8].

2. BLOCKCHAIN TECHNOLOGY AS A PLATFORM ITS

2.1. Parallel transport management

Let us outline the main research questions and potential ideas.

2.2.1. Decentralized autonomous transportation systems

Decentralized autonomous transportation systems leverage the core features of blockchain technology. Peer-to-peer (P2P) networks, based on distributed consensus and economic incentives, provide a natural approach to modeling complex transportation systems. Each computing node (such as IoT devices, vehicles, or other objects with computing power) can function as an autonomous agent in this system[9].

A multitude of such nodes can be linked to a shared network and interact with each other through diverse block-based decentralized applications (Dapps), leading to the creation of decentralized autonomous organizations (DAOs) geared towards specific requirements and tasks. Moving to the macro-level, this can result in the development of a decentralized autonomous system and even a community of systems (DAS)[10].

2.1.2. Creating incentives for crowdsourcing

The process of distributed consensus in blockchain-based systems can be seen as a crowdsourcing task performed by a large number of nodes that contribute their computing power to verify the blockchain data[11]. Since these nodes act as independent agents, any crowdsourcing mechanisms and incentives must ensure that the individual behavior of each node, motivated to maximize its income, is aligned with the overall goal of maintaining system reliability and security. The block technology has the potential to bring together all available computing resources in ITS to tackle hitherto unsolvable problems, such as more precise real-time transportation management and control. However, further research is needed to design effective incentives for crowdsourcing in decentralized ITS.

2.1.3. Development of software for establishing trust within ITS

The trust that stems from blockchain technology plays a critical role in creating decentralized ITS and enabling its application to tasks such as P2P commerce, payment, and communication[12]. This trust is secured by the code and the validation of the majority of the process participants. The technology has the potential to simplify structurally complex systems, thereby reducing social issues. It will allow for the transfer of currency and assets between legal entities and individuals without hindrance. For example, P2P trust could enable cars to be resold and registered directly through blockchain applications rather than centralized bodies or platforms.

Further research is needed to address the fundamental principles underlying trust and trust management in this domain.

2.1.4. Intelligent contracts for intelligent transport systems

Smart contracts act as a catalyst for blockchain by utilizing various algorithms (such as machine learning and big data analysis) and high-level logic programs to construct an ITS software ecosystem and enhance its application intelligence[13]. These self-executing contracts significantly reduce social complexity by minimizing the importance of human involvement, serving as software agents acting on behalf of their creators or even themselves. Therefore, there is a pressing need to explore the development and implementation of specific smart contracts and their management and control of ITS.

2.1.5. Data security and privacy protection

While blockchain has demonstrated high reliability and security, the encryption structure must be further strengthened in ITS with numerous devices to safeguard against attacks.

Several researchers[14] have proposed the concept of PTMS (Parallel Transportation Management and Control System), which optimizes the real transport system by simultaneously interacting with its artificial or virtual counterparts. Blockchain is considered one of the most secure and reliable architectures for PTMS, making it an important step toward the realization of this concept. Figure 1 below illustrates one of the possible applications of blockchain technology in PTMS.

A PTMS, based on blockchain, will encompass all physical objects, such as IoT devices, vehicles, and assets, which can be easily digitized through the "blockchain of things" and registered in the blockchain online. The transmission of large data in cyberspace can also be integrated into the blockchain. Furthermore, using the Ethereum platform and its programmable scripts to support complex modeling and computation[15], one or more artificial transport systems can be created in the code space of smart contracts.

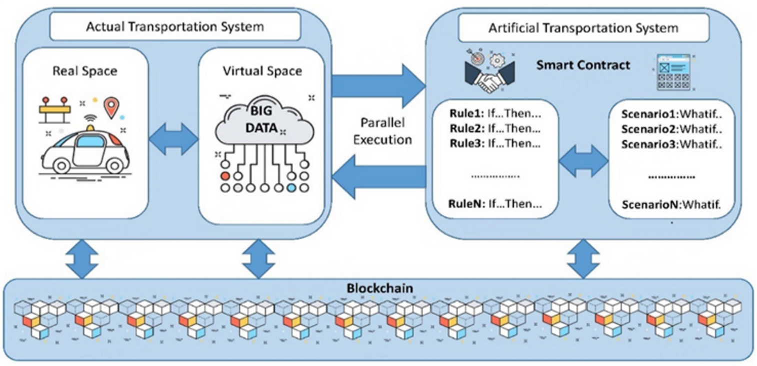

Figure 1. Parallel transport management[4].

Using these jointly developed real and artificial transport systems, multi-directional computational experiments can be designed and conducted to assess and validate specific behavior, mechanisms, and strategies in ITS (e.g., to evaluate traffic conditions). These experiments can be designed as "What If" scenarios and modeling based on predefined "If Then" rules. The optimal solution will be developed through a large number of computational experiments and returned to real transport systems. This process will be repeated indefinitely until the actual transport system approaches its optimal artificial counterparts[16].

2.2. Quick road system

One possible scenario for utilizing blockchain in intelligent transport systems is to create a service that provides a way for drivers to obtain unimpeded passage, referred to as quick road system (QRS)[4]. This service aims to establish a decentralized network of road lane sharing in real time. If a driver is in a rush or desires priority in utilizing the speed lane, they can designate a special status and share their place in the lane with other vehicles traveling the same route by exchanging incentives through the blockchain with other private car owners.

To function as one of the QRS computing nodes, a special application can be installed on the smartphone of a driver or integrated into the vehicle software, referred to as "Road miners". Real-time data is verified and stored on a P2P network supported by the community. All lane and payment sharing behavior is coordinated and performed through this network, with the road miners connected to the P2P network without any central authority.

One possible solution for incentivizing road miners to contribute to the QRS is to introduce an innovative consensus algorithm called "proof of traffic". This algorithm encourages road miners to use the QRS application while driving and share their traffic data, thereby building a local network of lane social use. As a reward, QRS generates new tokens called "QRS" for road miners, which can be used to pay for travel and other transport services. The more road miners drive in slow lanes and contribute to the community, the more QRS tokens they earn. Additionally, drivers who use fast lanes will have to pay for the service from their own funds or from previously accumulated QRS tokens [as shown in Figure 2].

In addition to the proof of traffic algorithm, various decision-making algorithms will also be developed to automate specific processes in QRS. For example, these algorithms can determine whether QRS can be used in a particular location or activate a service in an area where the number of active users exceeds a "critical

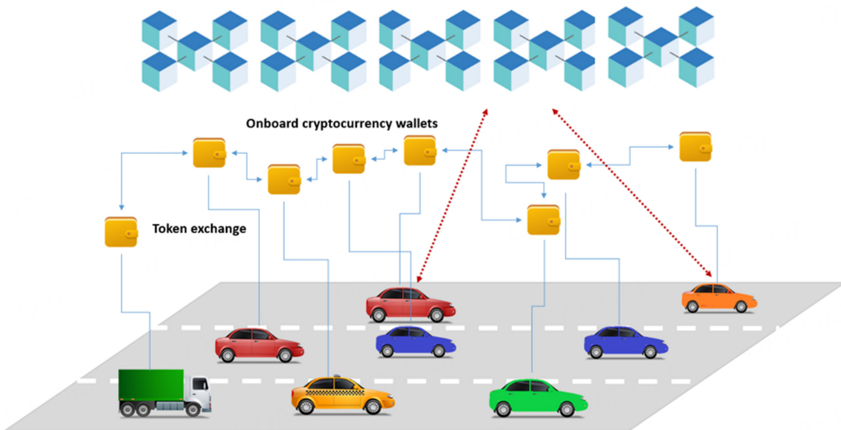

Figure 2. The service of getting a free passage[4].

mass". By automating these processes, QRS can function more efficiently without requiring human involvement.

The QRS could be a pioneer in the trend of decentralized, self-directed systems or DAOs. Alongside similar services, it may alter the sharing economy of urban transport and become a leading model for social transport in the future[17-20].

Another potential use case for blockchain technology is a distributed transport service that operates using proprietary cryptocurrencies. This network would be constructed on the Bitcoin blockchain and adopt a new concept called "proof of motion" to mine coins.

The transport network is open to everyone, and becoming a miner is as easy as downloading the app on your smartphone and turning on the GPS when traveling at a speed of over 20 km/h. Alternatively, users can buy coins by contributing to the software or design of the app or by inviting others to join the network. This approach allows early adopters to establish the foundation for the network, with rewards paid in proprietary cryptocurrencies issued through mechanisms such as Mastercoin, Counterparty, or similar protocols[21]. As the number of participants grows, the entire system can run autonomously. This concept opens up new possibilities for the future of transportation and creates a decentralized ecosystem for mobility services.

However, in the pursuit of profit, various sources may generate false information about a particular service request, making it difficult to identify reliable information from multiple sources in a reliable QRS platform. To address these issues, we propose the use of QRR-chain (Quick Road Reputation chain), a reputation-based blockchain platform for crowdsourcing. The QRR-chain uses advanced blockchain platforms such as Cosmos, Polkadot, and Avalanche, which are decentralized, transparent, and irreversible, to manage crowdsourcing activities. Each crowdsourced exchange is recorded as a blockchain transaction governed by predefined criteria specified in a smart contract that ensures a secure trading environment and prevents malicious user behavior. Furthermore, the QRR-chain incorporates a reputation model created using the smart contract, which improves the quality of crowdsourcing services. This model evaluates the level of trust of both service providers and consumers based on their actions, including the quality of missions and payment fulfillment. A quantitative reputation score helps users select potential service providers and allows providers to choose appropriate missions. Each reputation score of a service provider is updated and recorded on the blockchain after each crowdsourced transaction, with a warning issued for any provider with a negative reputation. QRR-chain is the first solution to combine blockchain-based crowdsourcing management with reputation evaluation, and it addresses the aforementioned issues while offering a secure and efficient platform for VCS scenarios.

In the future, there are plans to develop a reputation-based blockchain crowdsourcing system called the QRR-chain to address the issues mentioned above. The QRR-chain will record each traffic lane seat purchase as a transaction on the blockchain, which will prevent malicious behavior and ensure the security of the trading environment. Furthermore, there are plans to establish a reputation model using smart contracts to evaluate the trustworthiness of QRS users based on their activities, such as mission quality and payment transactions. Quantifying reputation can help consumers choose potential vendors and vendors select missions. The QRR-chain will merge the traffic flow seat selling and reputation evaluation components. Queuing theory will be utilized to optimize the configuration and performance of the QRR-chain.

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The QRR-chain is a new blockchain-based platform that aims to enhance trust in the crowdsourcing system. Its smart contracts will define all trading rules, and every seat purchase in the traffic flow will be registered as a QRR-chain transaction.

To elevate the quality of crowdsourcing services, the QRR-chain will integrate a novel reputation model. This model will thwart malicious or irresponsible behavior by diminishing the reputation of unscrupulous service providers or consumers. Additionally, the model will leverage mission-based reputation scores to detect untrustworthy service providers, helping consumers find high-quality ones.

To optimize the performance of the QRR-chain platform, an efficient configuration scheme will be developed using queuing theory. The effectiveness of the proposed scheme will be evaluated based on key performance indicators such as transaction confirmation time and throughput.

The convergence of two game-changing ideas, decentralized transport and cryptocurrencies, is inevitable. Our aim is to leverage the technology behind cryptocurrencies to achieve the necessary critical mass of users and create a truly decentralized transport system in cities[22,23]. The proceeds from the coin sales will be used to enhance and refine the transport system, and the coins will be redeemable for rides once the network is operational.

3. RESULTS

Blockchain is a revolutionary technology that enables the transfer of value between peers without requiring a central intermediary. It achieves this through the use of cryptographic hashing functions, consensus protocols, and decentralized data storage to guarantee secure, decentralized trust, immutability, and transparency of transactions. By pairing blockchain technology with smart contracts, businesses can automate rules and processes in a reliable, efficient, and trustworthy manner. A smart contract is a self-executing code that runs on a blockchain network. It translates predefined rules between participating organizations into functions that establish trust between them.

Let us explore the main opportunities and potential ideas for blockchain technology in the transport sector.

3.1. Decentralized autonomous transport systems

Decentralized autonomous transport systems embody the core elements of blockchain. P2P networks, which rely on a consensus of distributed coordination and economic incentives, are a natural way to model the complex transport system. In this system, each computational node, such as IoT devices, vehicles, or other objects with computational power, can act as an autonomous agent[4].

These nodes can be linked to a common network and interact with each other through various types of blockchain-based Dapps, resulting in a DAO that is subject to specific requirements and tasks. Eventually, this can lead to the creation of a decentralized autonomous system and even a DAS[24].

To advance in this area, it is important to investigate both the micro-level of individual behaviors and interactions among autonomous system agents and the macro-level of modeling, self-organization, self-improvement, and self-adjustment of systems.

3.2. Create an incentivization framework for crowdsourcing

In blockchain-based systems, distributed consensus competition can already be viewed as a crowdsourcing task where numerous nodes contribute their computing power to validate blockchain data[8]. Since these nodes are individual agents, the incentivization and crowdsourcing mechanisms must ensure that individual actions of a node in the pursuit of profit maximization align with the system-wide objective of safeguarding the protection and dependability of the system. The blockchain technology applied can aggregate all available computational resources in an ITS to improve ITS services and enhance decision-making speed.

3.3. Implementation of software-defined trust in ITS systems

Trust is a crucial aspect of creating a decentralized ITS using blockchain technology, which can facilitate services such as commercial transportation, public transport, and electronic payments in transport[9]. This type of trust is established through code and the verification of the majority of process participants, potentially reducing structural complexity and addressing social problems. For instance, P2P trust can enable the direct sale and registration of used cars through blockchain applications without relying on centralized authorities or platforms. Further research is needed to explore the underlying rationale for trust and fiduciary formation in this direction.

3.4. Leveraging smart contracts for intelligent transport systems

Smart contracts act as a catalyst for blockchain technology by enabling the dynamic execution of processes based on pre-set rules and conditions. Through various algorithms such as machine learning and big data analysis, smart contracts can enhance the intelligence of ITS and its applications, resulting in a more efficient and effective transport ecosystem. They also decrease social complexity by minimizing the involvement of humans in executing the contracts. Thus, it is important to study the creation and deployment of smart contracts in ITS and the management and monitoring of the system built upon them.

3.5. Ensuring data security and privacy protection

Despite its high reliability and security, blockchain needs to have a stronger encryption framework when used in an ITS that involves a large number of devices to safeguard against attacks.

Researchers have proposed the concept of PTMS[24], which optimizes the real transportation system by enabling parallel interactions with artificial or virtual counterparts. Blockchain is a secure and reliable architecture for PTMS and can be considered an important step toward its implementation.

A blockchain-based PTMS can include all physical objects, such as IoT devices, vehicles, and assets, which can be easily digitized and registered online in a "blockchain of things." The transmission of big data in cyberspace can also be integrated into blockchain. It is also possible to create one or more virtual transport systems in the code space of smart contracts using the Ethereum platform, which provides programmable scripts to support modeling and computation. Therefore, it is crucial to ensure the security and privacy of data in such systems to maintain the trust of the participants of the system[25].

The co-development of real and virtual transport systems enables the design and execution of computational experiments to evaluate and verify specific behaviors, scenarios, and strategies in ITS. These experiments can take the form of 'What If' scenarios and simulation output based on predefined 'If Then' rules. The optimal solution is derived from a large number of computational experiments, which are then applied to the actual transport systems. This cyclic process is repeated until the actual transport system approximates its optimal virtual counterparts. This approach offers an efficient means of evaluating traffic conditions and improving the overall performance of ITS[26].

4. DISCUSSION

In order to use blockchain as a reliable ledger for transactional data, a user needs to be able to verify on the blockchain whether a transaction has been made to their address or electronic wallet, where cryptocurrencies are stored. If this information was stored on a single computer or server, the availability of the data would be dependent on that particular device. In the event that the device goes down or fails, the data becomes inaccessible. However, this is where blockchain technology proves useful. The current state of the blockchain is downloaded, synchronized, and made available to a large number of computers around the world, known as nodes. These nodes operate in a P2P network, working together to keep the blockchain secure and up-to-date. Each node stores a complete and updated version of the blockchain, and when a new block is added, all nodes update their respective blockchains.

Using a P2P network to store the blockchain has several advantages over relying on a single node. First, information is available at any time because there are multiple nodes.

Second, it makes the blockchain highly secure because the data is distributed across many computers. In order to change the data, all the nodes must be updated simultaneously, which is practically impossible. This makes the data tamper-proof and immutable.

Third, the decentralized nature of the blockchain means that an attacker would need to gain control of thousands of nodes at the same time to manipulate the data. This would require an enormous amount of processing power, making such an attack highly unlikely.

Finally, once data is stored on the blockchain, it cannot be edited or deleted, ensuring the integrity and authenticity of the recorded transactions.

The consensus mechanism is a critical component of a P2P network, which is responsible for validating transactions and blocks. When a new block is added to the blockchain, it must be accepted by all nodes in the network to be considered valid.

In contrast, in centralized systems, a single administrator controls the database and makes decisions on which files to keep and how to update them. Each transaction is approved, edited, or deleted by a single person or computer, and other users in the system do not have real-time visibility into the changes being made. This lack of transparency makes the system vulnerable to fraud, misuse, and errors.

Decentralized public resources, such as blockchain, do not have administrators. No single node can approve, edit, or delete any transaction without the consensus of all blockchain nodes. This presents a challenge for achieving real-time consensus and updating the state of the public ledger. The solution is found in mining, which is a mechanism that checks and updates transactions in real-time to maintain consensus among all nodes.

In conclusion, implementing information technologies is generally cheaper and easier than building infrastructure. Several available technologies, such as GPS and intelligent vehicles, can be utilized to improve performance[18,19].

The adoption of information technology can enhance facility performance by reducing transaction delays, improving productivity, and minimizing check processing time. It can also increase transit speed and decrease operational costs, thereby improving the overall capabilities of ITS. As the development of artificial intelligence and 5G wireless connectivity continues to progress, intelligent traffic is expected to become a comprehensive solution that involves numerous IoT devices that connect and communicate with one another. This will enable the prediction of traffic conditions and the anticipation of optimal solutions. Moreover, due to significant advancements in intelligent software development, a more sophisticated system has been implemented.

Integrating ITS with blockchain technology is expected to make the system even more powerful and efficient. This integration can help to mitigate the influence of human factors and external malicious attacks, allowing vehicles to communicate and self-organize based on traffic conditions through an intelligent contract in a blockchain.

In the coming years, there is an expectation of developing machine learning algorithms for predicting traffic conditions and determining traffic intensity. Moreover, a consensus block algorithm is being developed to improve tolerance and transaction rates in the real-time system.

The integration of machine learning systems in the process of data retrieval, loading, and conversion is not just about creating a more efficient system, but it also has the potential to create a self-improving and self-managing service that is capable of continuous learning. The results of sensory data and extensive data analysis of road modules will be processed and added to the knowledge base, leading to subsequent quantitative analysis that is more accurate than the previous one. This implies that road modules, which are primarily responsible for accumulating large data streams, can adapt their data collection strategies according to the results of statistical analysis.

The impact of blockchain technology is extending beyond its initial use in cryptocurrency and is poised to revolutionize a wide range of industries. Among these is the logistics sector, where blockchain holds the potential to enhance the efficiency of business operations and enable the development of new services and business models.

In conclusion, the integration of blockchain technology in ITS within multi-agent systems holds great promise for revolutionizing the transportation industry by addressing key challenges faced by traditional ITS solutions. By providing secure and decentralized platforms for exchanging data, managing transportation processes, and facilitating payment systems, blockchain technology has the potential to create more efficient, secure, and transparent transportation networks. Further research is needed to fully realize the potential of blockchain technology in ITS within multi-agent systems and to explore new applications and use cases in this field.

5. CONCLUSIONS

In conclusion, integrating blockchain technology into the transport sector has the potential to revolutionize the industry by addressing key challenges and unlocking new opportunities. Decentralized autonomous systems of blockchain can model complex transport networks, while incentivization frameworks can enhance crowdsourcing efforts. Software-defined trust and smart contracts offer secure and efficient transactions, minimizing reliance on centralized authorities. Data security and privacy protection are crucial considerations, especially in parallel transportation management systems. By integrating real and virtual transport systems, computational experiments can optimize traffic conditions and improve overall performance. The adoption of blockchain technology can enhance efficiency, security, and transparency in transportation networks. Further research is needed to fully explore and exploit the potential of blockchain in multi-agent systems within the transport sector, unlocking its full benefits and discovering new applications.

DECLARATIONS

Authors' contributions

Contributed significantly to the development of the concept of blockchain integration with ITS: Eremina L, Mamoiko A, Aohua G
Working out the Quick Road System (QRS): Eremina L, Mamoiko A, Aohua G
Developed the concept of performance measurement indicators and provided technical support: Eremina L, Mamoiko A, Aohua G

Availability of data and materials

Not applicable.

Financial support and sponsorship

None.

Conflicts of interest

All authors declared that there are no conflicts of interest.

Ethical approval and consent to participate

Not applicable.

Consent for publication
Not applicable.

REFERENCES
1. Wei D, Zhang J, Shojafar M, Kumari S, Xi N, Ma J. Privacy-aware multiagent deep reinforcement learning for task offloading in VANET. *IEEE Trans Intell Transport Syst* 2022:1-15. DOI
2. Cheng H, Shojafar M, Alazab M, Tafazolli R, Liu Y. PPVF: privacy-preserving protocol for vehicle feedback in cloud-assisted VANET. *IEEE Trans Intell Transport Syst* 2022;23:9391-403. DOI
3. Zhou Z, Shojafar M, Alazab M, Abawajy J, Li F. AFED-EF: an energy-efficient VM allocation algorithm for IoT applications in a cloud data center. *IEEE Trans on Green Commun Netw* 2021;5:658-69. DOI
4. Eremina L, Mamoiko A, Bingzhang L, Kudriavtcev S, Murgul V. Use of blockchain technology in planning and management of transport systems. *E3S Web Conf* 2020;157:04014. DOI
5. Zhang J, Wang F, Wang K, Lin W, Xu X, Chen C. Data-driven intelligent transportation systems: a survey. *IEEE Trans Intell Transport Syst* 2011;12:1624-39. DOI
6. Wang F. Parallel control and management for intelligent transportation systems: concepts, architectures, and applications. *IEEE Trans Intell Transport Syst* 2010;11:630-8. DOI
7. Li L, Li X, Li Z, Zeng DD, Scherer WT. A bibliographic analysis of the IEEE transactions on intelligent transportation systems literature. *IEEE Trans Intell Transport Syst* 2010;11:251-5. DOI
8. Swan M. Blockchain: blueprint for a new economy. O'Reilly Media; Inc., 2015.
9. Antonopoulos AM. Mastering bitcoin. O'Reilly Media; Inc., 2014.
10. Yuan Y, Wang FY. Blockchain: the state of the art and future trends. *cta Automatica Sinica* 2016;42:481-94. DOI
11. Kong Q, Li L, Yan B, Lin S, Zhu F, Xiong G. Developing parallel control and management for urban traffic systems. *IEEE Intell Syst* 2013;28:66-9. DOI
12. Wang FY. Parallel system methods for management and control of complex systems. Control and Decision 2004;19:485-9. (in Chinese). DOI
13. Wang FY, Dai RW, Zhang SY, et al. A complex system approach for studying sustainable and integrated development of metropolitan transportation, logistics and ecosystems. *Complex Systems and Complexity Science* 2004;1:60-9. Available from: http://en.cnki.com.cn/Article_en/CJFDTOTAL-FZXT200402008.htm [Last accessed on 23 May 2023].
14. S. Nakamoto. Bitcoin: a peer-to-peer electronic cash system. Available from: http://bitcoin.org/bitcoin.pdf [Last accessed on 23 May 2023].
15. Ferrag MA, Ferrag M, Mukherjee M, et al. Blockchain technologies for the internet of things: research issues and challenges. *IEEE Internet of Things Journal* 2019;6:2188-204. DOI
16. Lakshman TV, Agrawala AK. Efficient decentralized consensus protocols. *IIEEE Trans Software Eng* 1986;SE-12:600-7. DOI
17. Kitahara F, Kera K, Bekki K. Autonomous decentralized traffic management system. In: Proceedings of International Workshop on Autonomous Decentralized Systems, 2000 Sep 87-91. DOI
18. Mori K. Autonomous decentralized systems technologies and their application to a train transport operation system. In: Winter VL, Bhattacharya S, editors. High integrity software. Boston: Springer US; 2001. pp. 89-111. DOI
19. Wen D, Yuan Y, Li X. Artificial societies, computational experiments, and parallel systems: an investigation on a computational theory for complex socioeconomic systems. *IEEE Trans Serv Comput* 2013;6:177-85. DOI
20. Lv YS, OU Y, Tang SM, Zhu FH, Zhao HX. Computational experiements of evaluating road network traffic conditions based on artificial transportation systems. *Journal of Jilin University* 2000;39:87-90. Available from: http://qikan.cqvip.com/Qikan/Article/Detail?id=1003866541 [Last accessed on 23 May 2023] (in chinese).
21. Kim HM, Laskowski M. Toward an ontology-driven blockchain design for supply-chain provenance. *Intell Syst Account Financ Manag* 2018;25:18-27. DOI
22. Crosby M, Pattanayak P, Verma S, Kalyanaraman V. Blockchain technology: beyond bitcoin. *Appl Innov* 2016;2:6-10. Available from: https://scet.berkeley.edu/wp-content/uploads/AIR-2016-Blockchain.pdf [Last accessed on 31 May 2023].
23. Morley HR. Industry skeptical of pace of logistics tech sdoption. JOC: New York, NY, USA, 2017.Available from: https://www.joc.com/article/industry-skeptical-pace-logistics-tech-adoption_20170620.html [Last accessed on 31 May 2023]
24. Lehmacher W. Why blockchain should be global trade's next port of call. World Economic Forum: Geneva, Switzerland, 2017.Available from: https://www.weforum.org/agenda/2017/05/blockchain-ports-global-trades/ [Last accessed on 31 May 2023]
25. Yang C, Lirn T. Revisiting the resource-based view on logistics performance in the shipping industry. *IJPDLM* 2017;47:884-905. DOI
26. Sun L, Yang Q, Chen X, Chen Z. RC-chain: reputation-based crowdsourcing blockchain for vehicular networks. *J Netw Comput Appl* 2021;176:102956. DOI