Journal of Traffic and Transportation Management
Volume 3, No. 1 (2020) pp. 33-41

The convergence of Internet of Things, Blockchain and Connected Vehicles: Conceptual Advantages and Disadvantages of a new Cooperative Intelligent Transportation System

Vittorio Astarita[a]*, Vincenzo Pasquale Giofrè[a], Giuseppe Guido[a], Alessandro Vitale[a]

[a] *Department of Civil Engineering, University of Calabria, Arcavacata di Rende (CS) 87036, Italy*

Abstract

This paper intends to explore the convergence of some technological innovations that could lead to new cooperative Intelligent Transportation Systems (ITS). The technologies that might soon converge and lead to some new developments are: the Blockchain Technology (BT) concept, Internet of Things (IoT) and Connected and Automated Vehicles (CAV). Advantages and disadvantages of the new concepts founding a new ITS system are discussed in this conceptual paper. Blockchain technology has been recently introduced and many research ideas have been presented for application in the transportation sector. In this paper, we discuss a system that is based on a dedicated blockchain, able to involve both drivers and city administrations in the adoption of promising and innovative technologies that will create cooperation among connected vehicles. The proposed blockchain-based system can allow city administrators to reward drivers when they are willing to share travel data. The system manages in a special way the creation of rewards which are assigned to drivers and institutions participating actively in the system. Moreover, the system allows keeping a complete track of all transactions and interactions between drivers and city management on a completely open and shared platform. The main idea is to combine connected vehicles with BT to promote Cooperative ITS use, a better use of infrastructures and a more sustainable eco-system of cryptocurrencies. A short description of BT is introduced to evidence energy problems of sustainability in the implementation of Proof of Work (PoW) that is adopted by many blockchains.

Keywords: *Intelligent Transportation Systems (ITS), Floating Car Data (FCD), Blockchain Technology (BT), traffic management, connected and autonomous vehicles.*

1. Introduction

Two innovations in vehicle technology are universally acclaimed as the future of road traffic management: connected and autonomous vehicles (CAV).

Connected vehicles are also part of another innovative trend which is called the Internet of Things (IoT) and that possibly will include also traffic signal and other road infrastructures.

Classic road traffic engineering practice was founded on efforts to allocate demand on transit systems [1] and on better road traffic control by adopting tools such as: traffic simulation [2–7] dynamic network loading equilibrium and dynamic models [8–11] and the implementation of efforts to influence user route choice [12–16]. CAV may help to manage and control road traffic in many new different ways.

Road traffic management systems could potentially use CAV information providing driving directions to reduce congestion. In addition, other traffic control strategies could be implemented such as adaptive traffic signal control based on the use of Floating Car Data (FCD)[17]. Adaptive traffic signals are presently based on traffic flow measures obtained with magnetic loops embedded in road pavement. This is a fixed infrastructure which is very expensive. Connected vehicles that would communicate their position to a central server could make it possible to regulate traffic signals according to the real vehicle positions on the transportation network in a more sustainable way. These systems which have been defined as Floating Car Data Adaptive Traffic Lights FCDATL or FCDATS in [18] have, in fact, the two following advantages: no need for costly infrastructures and the adaptive traffic signal control algorithms could profit of an augmented data set, offering better control results than traditional adaptive traffic signal systems.

In some research works the penetration rate of connected vehicles to obtain good results for traffic information systems was established: in [19] it is asserted that just 5% of the connected vehicles would be sufficient to estimate the journey times on a motorway network with an accuracy of 95%, Ferman et al. in [20] showed that an information system on real-time traffic based on probe vehicles is feasible and should

* Corresponding author. Tel.: + 39 3473770256
E-mail: vittorio.astarita@unical.it

DOI: 10.5383/JTTM.03.01.005

work for motorways with penetrations above 3%, while other roads would require more than 5%. Other works have been a real implementation in the field of combined Global Navigation Satellite System (GNSS) and data transmission [21],[22],[23]. The idea of using radio receivers to estimate traffic conditions was foreseen in the patent Astarita [24] and received real field implementations in 2008 when the Bluetooth protocol was used to detect radio signals from Bluetooth cellular phones with an external Bluetooth device. The results of the first implementation of Bluetooth monitoring were presented starting from June 2008 in [25] and [26], followed after 2010 by [27],[28] and [29].

All the research and inventions described above show the great advantage of involving drivers to share their position with the administrations that deal with road infrastructure management and traffic control.

This advantage, however, is not well perceived by users as a personal utility and the problem with all the described systems is always that of encouraging drivers to share their travel information with the administrations and with the other drivers.

Navigation systems based on dedicated devices or smart-phones have been successful in involving drivers to connect to the mobile internet and share their positional data. Relying on mobile devices that can be temporarily positioned on vehicles can be a possible solution but it is important to note that drivers that share the position for navigation purpose (also to receive updated traffic information) are willing to share this data to obtain a service which is operated by private companies. In this scheme both users and the private company obtain a benefit: the users receive real time traffic information and map guidance while the company can build loyalty, retain users and obtain data which are also sold on the market.

The kinds of data which can be useful for traffic management are different. As an example: vehicle identification is important in city traffic management as proved by the introduction of the vehicle plates. Other important data might be information connected with pollutant emissions fuel consumption and the category of the vehicles (vehicle type). City management, in fact, has a duty to keep traffic flows in the city sustainable and avoid extremely high levels of pollution. Moreover the city management may want to involve all new connected vehicles and not rely simply on some sporadic user of mobile devices.

While all these innovations such as CAV and IoT are shaping the future of the transportation sector another universally claimed innovation in informatics has been acclaimed having many applications in traffic operations: the blockchain: a distributed ledger technology. This technology originated from the efforts of anonymous developers in creating a secure digital currency. Digital currencies that are based on a blockchain are defined cryptocurrencies since they are based on cryptographic mathematical tools. The first cryptocurrency that was developed was Bitcoin originated from a paper anonymously published in 2008 on the cryptography mailing list at metzdowd.com [30].

Since 2008 a great development of initial concepts has brought to the creation of many distributed and active blockchains. The blockchain concept involves different knowledge and many researchers anticipate many applications of this innovative concept especially in the logistics sector and in the CAV networks [31],[32],[33][34],[35].

The paper presents advantages and disadvantages of a potential application of the blockchain-based technology in traffic operations to promote cooperation among vehicles.

2. Blockchain technology.

In this section we will introduce Blockchain technology, potential applications to traffic management and the main motivations for the proposed system.

2.1. What is a Blockchain?

The first research published Blockchain Technology (BT) was the work: "Bitcoin: A Peer-to-Peer Electronic Cash System"[30]. This paper describes the technical details that originated a digital currency called "Bitcoin". The author of the paper also wrote the code that was implemented and used in January 2009 in the first (and thus the oldest) blockchain that was ever started. Information on how a blockchain works can be found on web sites, papers and reports [36]. The first digital currency code was released open source and, since the origin, many developers have been actively applying modification to the code of the system maintaining the original founding concepts exposed in [30]. For readability, and also since we want to present a better explanation of what could be the advantages of the proposed system, we will introduce shortly in this section the principal details on how a blockchain works.

The BT is based on a Distributed Ledger Technology (DLT), which is a distributed database, since it is hosted on many servers positioned around the globe, all implementing the same code, with some specific characteristics. In the original version of [30] the ledger mainly holds data on currency transactions between different parties. In a general blockchain, different information can be stored on "distributed" computers which run the same code replicating the ledger information and any other type of information that can be useful to store on such "distributed" database. Each computer that is running the founding software and holding the distributed database is called a ‘node’ of the blockchain network. The database in a blockchain is structured in blocks which have a linear chain structure: blocks start from block 1, which is the origin of the chain, and are created one after the other. Each block is linked and univocally connected to its predecessor creating a "chain" structure. Blocks are added one by one at the open end of the chain at regular interval of time. Each server holds a complete copy of all the chain of blocks that have ever been created. When a lucky server completes some specific task (Proof of Work or PoW) it has the right to add a new block that will be then copied by all the other servers.

We have been using the term "lucky" since, in many working blockchains, the server that completes this PoW task is rewarded with the issuance of coins of the blockchain digital currency (for some blockchains this has been compared to win a lottery).

The connection in the chain of blocks between blocks is strengthened with a cryptographic signature system based on a consensus mechanism that guarantees certain conditions. A consensus mechanism is a mechanism that offers resistance to mistakes in transmitting or copying data and is used in blockchain systems to obtain an agreement on data values and the state of the blockchain in this kind of distributed networks. The more used consensus mechanism in BT is based on PoW. PoW consists in performing computationally complex operations before each block is added. The complexity required in executing this computational task guarantees that it is not possible to falsify the blockchain data since adding an altered block at some point of the chain would be difficult since it would also require to add all subsequent blocks and that is computationally unfeasible

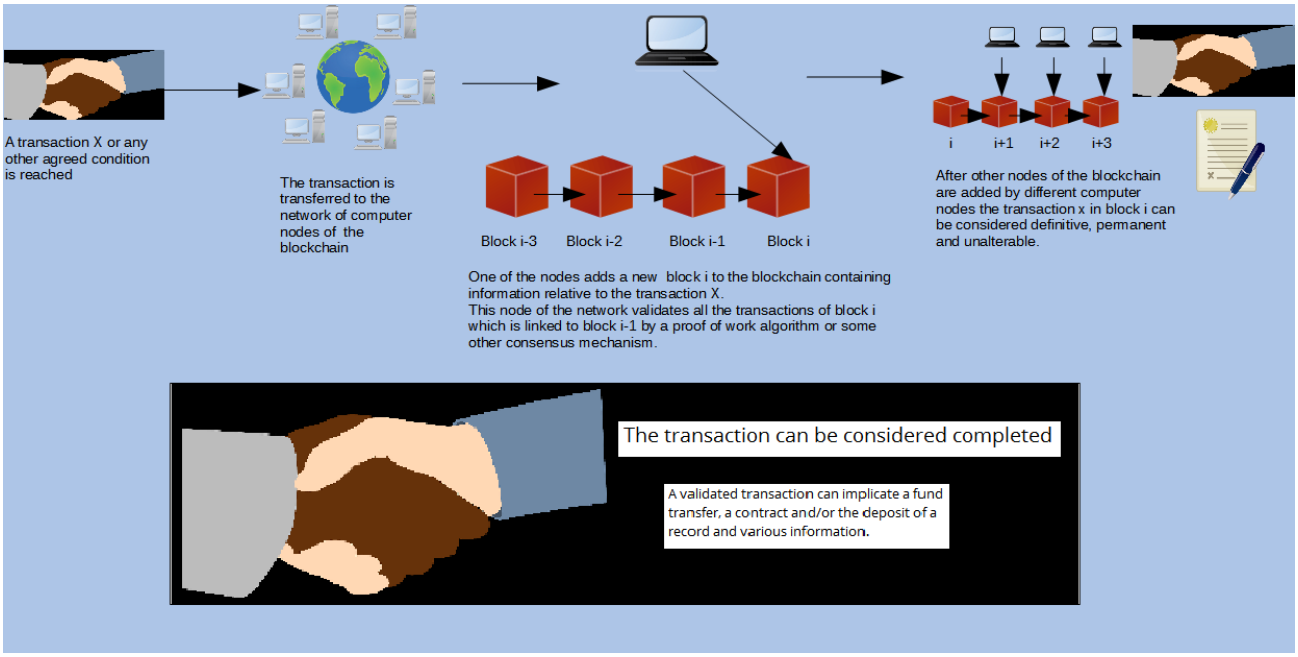

Fig. 1. The blockchain technology in a simple image (see also [35]).

PoW requires a considerable calculation effort before a server (BT network node) is allowed to add a block in the chain and this also avoids the problem that different blocks n+1 could be added in different servers. Two blocks added at the position n+1 would constitute a "fork" of the blockchain and this is avoided in some instances of blockchain technology by a preliminary agreement that only the longest sequence of blocks (blockchain) prevails and the blocks added to other side chains are discarded. The mechanism is such that it is in the interests of every node to add new blocks to the main chain and to replicate the other blocks which are added to the main chain. Side chains are abandoned and forgot by users. The only exception is when a considerable number of users decide to create such a "fork" applying some change to the software. In this case the network servers have to decide what version of the software to implement and which chain data propagate. An example of this kind of "forks" is the fork which originated Bitcoin Cash[37].

The use of PoW as consensus mechanism in cryptocurrencies has been criticized since it requires an enormous calculation power which turns into an enormous electricity power [38]. The data that are stored in a blockchain are generally currency transactions but every data could in theory be inserted in a block, such as: information about an event, logistic information regarding freight handling and even automatic transactions which can be confirmed only when a given event happens, such as, for example, the delivering of some merchandise in a specific place (smart contracts [39]). This is one of the main features that make blockchain useful for many different applications in the transport sector.

2.2. What are the potential applications in transportation?

Many scientists and research experts expect many applications of BT especially in the logistics sector [31],[32],[33],[40] some authors have defined BT a "disruptive" technology for the transportation sector [41].

The Blockchain data system is considered immutable and resistant to any attack having a distributed structure. The consequence of this specific structure is that of some specific features: decentralization, immutability and irreversibility and BT can also be transparent and based on some form of consensus.

The information saved in a blockchain becomes public and immutable. Data which is contained in a block cannot be modified or counterfeited once it is added to the BT database since the algorithm which is applied to bond succeeding blocks guarantees that any modification is unachievable. Every block of the blockchain is also associated with a time stamp. A blockchain can be a useful tool to confirm and endorse information among a network of different stakeholders also when the different organizations are far away and have no contact and especially in the situation where the organizations do not trust each other. BT has been advocated to allow transactions between peers without a central organization acting as intermediary. For this, BT is believed to be capable to generate confidence and better cooperation between prospective partners that are not located close to each other..

The concept of a distributed database [42] is not something new. Distributed databases without BT are centrally managed. The innovation of BT is to allow users to share a decentralized database among competing organizations were each computer node competes with the others and at the same time cooperates to keep the blockchain system active.

Blockchain databases can perform a great deal of services that are useful in the transportation sector such as: history and proof of ownership of a physical (consignment) or documental asset (data and Intellectual Property), immutability, consensus and agreement on the validity of data, a single version of truth since the database is replicated in all nodes of the network, data transparency can be customized allowing restricted data access according to who is reading the data, (who is able to read what data) and decentralization.

Despite all the great expectations on BT in transportation and other sectors, despite the great number of research papers and proposed blockchain systems ([41],[35]), the majority of the blockchain systems that are currently working are mainly based on the initial concepts of digital currency.

On CoinMarketCap (https://coinmarketcap.com/coins/) more than 1000 different blockchains are listed that are all connected with the emission of a specific digital currency. Very few are the stable and currently used blockchains that are not based on the emission of a digital currency.
The reason for this is that the incentive, in most blockchain systems, for server owners (to keep up the service of running a network node) is only that potential reward that is issued for the generation and addition of one block in the chain of blocks. Without this reward the motivations to run a decentralized node are not clear.
The reward could be paid by stakeholders in the system which could find some agreement to split the running costs of the blockchain. The costs of running a blockchain can be extremely high as shown in the next section.
For this reason the paying scheme of blockchain systems that has revealed the greater success is the creation of new cryptocurrencies (digital currencies). Many White Papers (they are a declaration of intent and an explanation of the purposes of the blockchain) of different blockchain systems declare some specific primary functions for the blockchain and then make use of the emission of a some new digital currency to reward the server owners and to engage the users.
With the above statements we do not intend to minimize the potential for BT technology in the transportation sector, which we believe are great. We only intend to point out that at the moment the success of BT seems inextricably tied with the emission of a digital currency as reward. The idea of this paper as described in the following is to partially use this reward to engage drivers and users of the transportation system to cooperate for a more sustainable transportation system while at the same time the majority of currently operating blockchains are not sustainable in terms of energy consumption.

2.2. The sustainability of BT based on PoW.

The use of PoW as a mechanism of consensus has been criticized for its carbon foot print[43][44]. The inventor of BT was trying to create a digital currency which would become "digital gold". The algorithm of the first blockchain was conceived so that a finite amount of digital currency would be generated, ever. This number is 21 Million of Bitcoin. The consensus mechanism based on PoW that was introduced had to mimic the scarcity of gold on earth. The creation of a new block in a PoW based blockchain was called "mining" with respect to this similarity.
The "miners" (servers of the blockchain network) that have to perform PoW for Bitcoin have to solve a complicated calculation problem which requires enormous calculation resources.
This "mining" process has many similarities with the real gold mining. The "miners" compete for a scarce resource and have to use calculation resources that resemble the use of gold extraction resources. The blockchain is programmed to add regularly a new block every 10 minutes. This is obtained by regulating the difficulty of the calculation problem: the more powerful and numerous "miners" are (hash-rate) the more the calculation problem to solve becomes complicated.
Moreover, the reward that is issued to "miners" has been programmed to become half approximately every 4 years, it started at 50 Bitcoin (BTC) per block in 2009 and after three halving it is now 6.25 BTC (Fig. 2).
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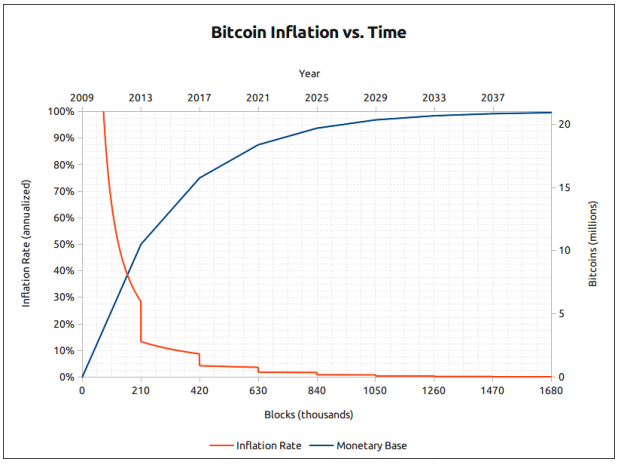

Fig. 2. Bitcoin reward for mining a block (inflation rate) and the total number of BTC in circulation (source https://www.bitcoinblockhalf.com/).

The efforts to obtain the reward in terms of digital currency are not virtual at all, they are real work efforts. The energy consumption of the Bitcoin network is comparable to the electricity consumed by a country the size of Chile (see Fig. 3).
The Bitcoin price has shown a growing trend in the past and with the increase in price so does the energy consumption (see Fig 4).
At the same time the world is facing an economical crisis and this energy which is necessary to power up all BT would be better directed toward other more social activities. For this reason in BT other consensus mechanism have been proposed such as Proof of Stake (PoS). Not many implementations of PoS have yet been deployed and most active BT is still based on PoW.
A more sustainable PoW could receive more social acceptance and a better reallocation of resources.
The proposed system has been designed to both solve this PoW problem of sustainability and also to reward transportation users for more sustainable behaviors. The idea is that to reward drivers that use a dedicated on-board device (a smart-phone also could be used but some problems of certification would need to be addressed). drivers using this device would agree to transform the driven vehicle into a "connected" vehicle and in exchange for this would receive some of the "mining" reward that would be issued to city administrations that would embrace such BT.
The system is described in more details in the next section

Fig. 3. Countries that consume more or less electricity than bitcoin mining in late 2018 (source: powercompare.co.uk/bitcoin-mining-electricity-map/)

Fig. 4. Bitcoin PoW Energy consumption and Bitcoin price (Source: Coinmetrics and Cambridge Bitcoin Electricity Consumption Index).

3. A system to promote cooperation among drivers

The proposed system has the final scope to reward and motivate drivers (or owners of vehicles) to share vehicle position (obtained from satellite localization) in real time with road traffic management organizations, this would allow institutions who are responsible for traffic control and traffic management to gather an enormous quantity of FCD.

The concept of combining Blockchain Technology (BT) with connected vehicles is not new [45–50], already paper [45] discusses the idea of influencing transportation users on the base of "tradable mobility permit".

In this work, we merely propose the founding concepts that can stimulate a useful scientific discussion that eventually could lead to a more accurate specification for an actual system to develop in the future.

In detail, in this paper, we introduce the idea of developing a new specific cryptocurrency inspired by Bitcoin and yet different in the way it performs the PoW. In our proposed system the PoW, for the servers that are operated by traffic management organizations, becomes the completion and certification of an established number of travelled kilometres certified by the on-board devices. The motivational force for the users to adopt and promote this system is thus the generation of a "traffic coin" as a reward for using a connected vehicle and for sharing trip information.

It should be noted that this traffic coin is imagined as an "Altcoin": a complete new cryptocurrency (not a token). The difference between Altcoins and Tokens is explained in Fig. 5.

The system blockchain takes care of storing data and at the same time rewards anyone who is creating and sharing data. This "traffic coin" is generated similarly to the Bitcoin system, on the base of a PoW, with the difference that the Bitcoin classical PoW is modified in the system by mixing the hash calculations with a PoW based on the vehicles trajectories. Dedicated servers that are operated by the traffic management organizations will be some of the node of the blockchain system.

Independent servers such as those in other BT will just sign transitions and receive a reduced reward for mining compared to that obtained by the city administration entities.

The system is able thus to reward "cooperating" drivers with the emission (creation) of a dedicated cryptocurrency. Cooperating drivers would be drivers who carry on the effort to activate, while travelling, some on-board device and to share positions with the community in real time. The on-board device would be a sealed device that could certify travelled/kilometres. A certification using smart-phones could also be possible once technical problem are addressed. The use of a dedicated device would make much simpler to certificate travelled/kilometres.

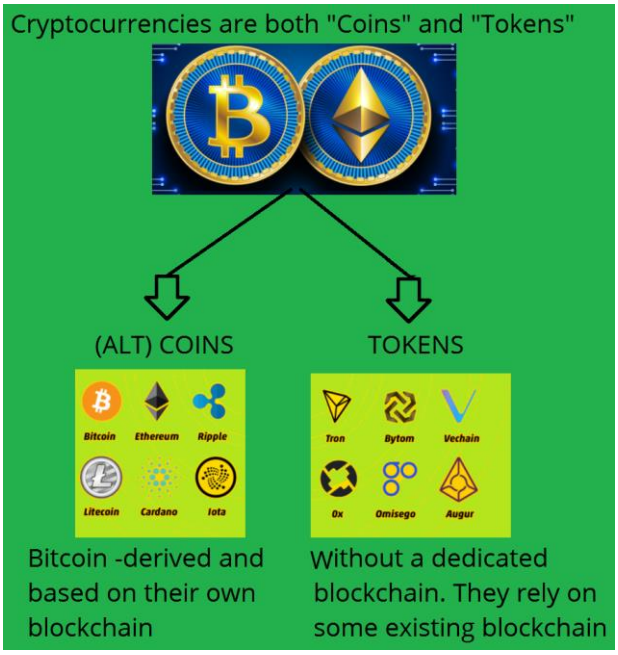

Fig. 5. "Coins" and "Tokens". The proposed system is based on its own "coin" with its own blockchain.

In detail, the architecture of the system is presented in Fig. 6 and consists of a group of devices connected on the internet network. It is made up by: connected vehicles (1), computing servers of road management organizations (2) and common blockchain servers for common currency transactions (3) for verification, signing and monetary transaction insertion in the blockchain. Vehicles (1) can be normal vehicles with an on-board mobile device such as a smartphone or new "connected" vehicles can participate in the system). Servers (3) are similar to normal Bitcoin network servers (nodes). Technically servers (3) are optional and the system could also work without them, leaving the task of monetary transaction entry in the system to the servers of road management organizations (2 in Fig. 6). The reason for having them in the system is to help keep it decentralized.

The system here described is able to reach the above-described final scope by working in the following way: on-board devices should have an electronic card with a microprocessor, a circuit for wireless phone data connection, a memory chip for local data storage, a backup battery in case the electrical supply from the vehicle fails, a satellite receiver for geographic localization of the device and last, but not least, (since this is the characterizing and innovative element) a private key for signing electronic documents and specifically for signing monetary transactions. The private key coupled with on board device would be analogous to private keys that are used in cryptocurrency blockchains to verify and sign crypto currency transactions. For each vehicle, this private key corresponds to a public address that is also the address for the vehicle owner to receive system payments. The on-board devices on vehicles can: establish, through the GNSS satellite receiver, the vehicle

positions in time, take a record of position data, validate position data with electronic signature and send signed position data to the road traffic management organization server that is responsible for the travelled local road network.
Road traffic management organization servers (2 in Fig. 6) work with two different functions: to generate and propagate the blockchain of the cryptocurrency and manage vehicle positional data received from on-board devices.

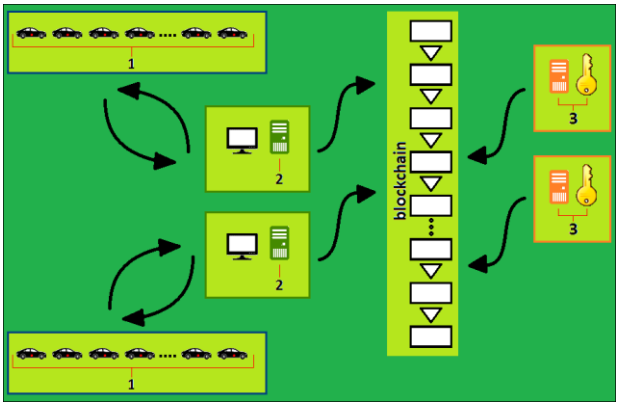

Fig. 6. The proposed system.

The generated cryptocurrency and the corresponding blockchain are structured in a specific and different way with respect to Bitcoin and other similar cryptocurrencies. In a cryptocurrency system the blockchain contains all the history of the monetary transaction transfers. In the system presented here the blockchain stores not only all the monetary transfers of the cryptocurrency ("traffic coin") but also data relative to positions in time (trajectories) of on board devices.

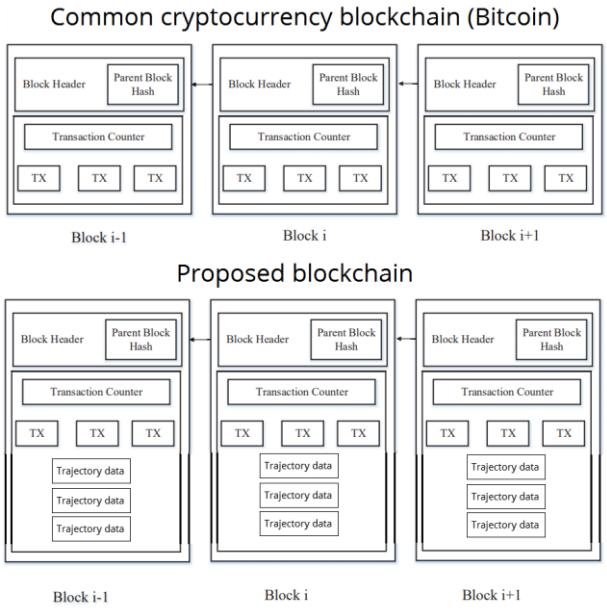

Fig. 7. The proposed system blockchain structure.

In practical terms, drivers (or owners of vehicles) by using the on-board devices send in real time trajectories data validated by electronic signature. Road traffic management organizations servers verify the signature and insert the trajectories data into the blockchain. In other wordsv the blockchain stores not only data of the monetary transactions, but also data relative to travels that have been completed by the on-board system devices.
In the proposed blockchain the generation of "traffic coin" is carried out by substituting Bitcoin hash calculation with a physical proof of work: the completed and shared vehicles trajectories. In practical terms the proof of work, for the servers that are operated by the traffic management organizations, becomes the completion and certification of the travelled distance of the on board devices.
As an example, a possible implementation of the above-introduced proof of work concept (but not the only one), is that of allowing the administrations to generate some "special" blocks of the blockchain, containing positional data of vehicles, without any onerous hash computation. The reward for generating such a block can then be divided among the administration, the drivers and the server that creates the next block of the blockchain. In this way the system would guarantee an immediate insertion of "special" blocks with positional data in the blockchain when the established number of travelled kilometres is reached by one of the administration servers.
The system would bring obvious advantages both for drivers and for public administrations since it would allow public administration to use the data in real time, received from on-board devices, applying vehicle traffic control strategies useful for the community to increase transport sustainability. The system would spread among drivers once the road users accept the validity of this system and of the related generated cryptocurrency and the public administrations adopt this industrial invention using the data received from on-board devices by applying vehicle traffic control strategies. Many control strategies can be applied from the generated data that can be useful for the community to increase transport sustainability such as: traffic signals real time regulation, car sharing, and better management of transit systems.

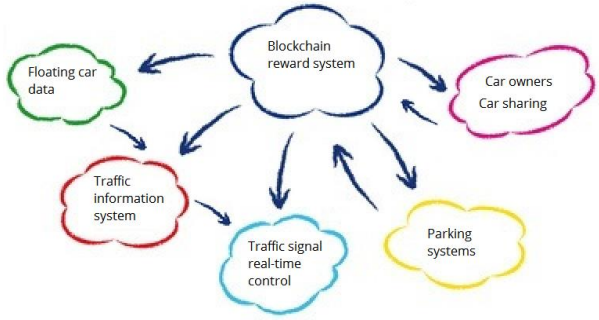

Fig. 8. Some potential applications of the blockchain rewards.

Among the possible strategies to incentivize the use of the system, administrations could reimburse the costs of on-board devices by accepting the cryptocurrency issued to drivers in exchange for city services such as parking, access to restricted traffic areas etc. The Floating Car Data obtained could also allow informing the drivers on the network in real time. This information can be provided in different ways and create other advantages for drivers such as: the ability to see the evolution of traffic on the road on the Internet in real time. The drivers could decide to use transit or postpone trips in cases of traffic over-saturation. The benefit of this system is therefore also the information service to users based on the data sharing among users themselves. These data can be the source of traffic forecasts and better traffic planning (see Fig. 8).
Moreover, if the cryptocurrency were to increase in value the same administrations would obtain a capital gain from just

adopting the system even if there were no traffic management improvements.

4. Conclusion

Mobile devices and "connected" vehicles as a means of information collection and transmission enables a revolution that can be fully exploited in systems where the same administrations and citizens become involved in the process of gathering and sharing of information. This paper presents a system which aims to involve both drivers and city administrations in the use of promising and innovative technologies for a better traffic system management based on floating car data. The introduction of incentives to drivers who are willing to share travel data would be possible with a Blockchain that would allow keeping a complete track of all transactions and interactions between drivers and city management. The use of both mobile technologies and BT would promote Cooperative ITS use and a better use of infrastructures.

This paper introduces just some basic concepts which could lead to further scientific discussions. Many issues need to be further investigated before an actual implementation can be carried on such as:

-the real-time implementation of the proposed system could put a heavy load on the computing system. This issue evidences the need for a proper investigation of practical solutions to make the system feasible in large-scale situations;

-the details regarding the practical implementation of a mixed PoW that is based on both hash calculations and data coming from vehicles trajectories.

-the details regarding the dedicated on-board sealed device (we obtained a patent for such device but many alternative implementations might be also successful).

This work presents some ideas that could help to develop an ITS system that could contribute to more sustainable cities.

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