Blockchain for Smart Mobility

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The concept of a smart city aims to help cities to address these challenges by adapting modern information and communication technology. Smart mobility and transportation form one important aspect of smart cities. Inefficient mobility in cities can lead to problems such as traffic congestion, which results in frustration for residents and a decrease in the quality of life. In the context of smart mobility, blockchain can be used for transactions relating to ridesharing and electric charging, handling of interactions of platoon members, or serving as a foundation for communication between vehicles.

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1. Blockchain

The concept of blockchain was first described in the whitepaper introducing Bitcoin [1]. The blockchain is a new combination of technologies that already existed before, for example, digital signatures and public-key cryptography [2] and hash functions [3][4]. The idea of Bitcoin was to establish a decentralized payment system in which all participants store a copy of the same ledger, including past transactions and ownerships of particular assets [5]. In a blockchain system, transactions can be processed quickly and without a trusted third party [6]. Transactions made in the blockchain system are stored in blocks which are then validated and added to the prior blocks. The validation process is fully distributed without a controlling authority [1][7]. One important characteristic of blockchain systems is their resistance to data modification. Due to the connection of the blocks, transactions in the blockchain that have been validated once can't be altered, changed, or manipulated anymore [8].

Nowadays, the blockchain cannot be seen as one single, uniform technology. Instead, there are thousands of different blockchain projects in development [9]. Therefore, [9] refer to "blockchains" or "blockchain technologies" instead of speaking about one single blockchain technology. Blockchains can differ in the ways in which the consensus in the network is achieved, what kind of currency is used, and how security and privacy are achieved [9]. Two criteria that are also often used to classify blockchains are access to transactions and access to the validation of transactions [10][11]. In public permissionless blockchains, all participants can read, submit, and validate transactions.

In contrast, hybrid blockchains allow the reading and submitting of transactions for all network nodes. However, only authorized nodes can validate the new transactions. Lastly, private blockchains are the most restricted systems and allow only authorized nodes to read, submit, and validate transactions. **Table 1** gives an overview of the resulting three types of blockchain systems.

Table 1. Classification of Blockchain Systems (based on [10][11]).

		Access to Transaction Validation	
		Permissioned	**Permissionless**
Access to transactions	Public	All nodes can read and submit transactions. Only authorized nodes can validate transactions.	Every node in the network can both read, submit, and validate transactions
	Private	Only authorized nodes can read, submit, and validate transactions	Not possible

Since the blockchain first emerged, its potential has been investigated for many different domains and use-cases. Examples include, but are not limited to, healthcare [12], the improvement of supply chains [13][14], direct democracy [15], and e-commerce [16]. Next to use-cases for specific industries and applications, there is an increasing convergence of blockchain with other technologies; for instance, the blockchain is used in combination with the internet of things [17], artificial intelligence (AI) [18], and big data [19].

Smart contracts are another term often used in direct connection with the blockchain. Smart contracts, first proposed by Nick Szabo, are computerized protocols that automatically enforce contractual clauses when certain conditions are met [6][20]. Smart contracts allow payments and the transfer of currencies or other assets to be executed and automated. An example of an application is a payment to a supplier as soon as a shipment is delivered. Similarly, a company could use a blockchain with smart contracts to signal that a particular item has been received. If the product has GPS functionality, the evaluation of the location could also automatically trigger a payment [21]. The utilization of smart contracts is investigated for a number of different applications, like the sharing economy [22], IoT [23], or the public sector [24][25].

Despite its advantages and many potential use-cases, there are also disadvantages related to blockchain. One dark side of cryptocurrencies, especially the bitcoin, is that it is often used for criminal purposes and money laundering. Cryptocurrencies are attractive to criminals for a variety of reasons: The anonymity, the ease of use, and the fact that cryptocurrencies' use is independent of borders or legislation make it suitable for criminal purposes [26][27][28]. Another problem often mentioned in relation to bitcoin is its high level of energy consumption. In PoW networks, the so-called miners must find a specific hash value that meets specific requirements. The amount of energy consumed for that purpose has reached an immense scale [29], comparable to the consumption of countries like Belgium, Kazakhstan, or the Netherlands. Although this disadvantage relates to blockchain networks based on PoW, like bitcoin, it does not apply to all forms of blockchain systems in general [5]. For instance, in systems using the proof of stake (PoS) or delegated proof of stake (DPoS) consensus algorithms, energy consumption is greatly reduced. Furthermore, other blockchain implementations exist that do not require a mining process at all [29].

2. Smart City and Smart Mobility

The globe is witnessing a paradigm change to 'smartness' in cities, management, and sustainability, leading to the widespread popularity of the notion of smart cities [30]. Over the last several years, the term 'smart city' has gained popularity [31]. Smart cities as a concept have their roots in the 1980s, when ideas appeared that focused on cities' efficiency and competitiveness and the ways in which cities can be managed easily [31][32]. The authors of [33] published a well-known approach to the structure dimensions of smart city initiatives in six main parts. According to these dimensions, the fundamental smart city components are smart economy, smart people, smart governance, smart environment, smart living, and smart mobility. Comprehensive surveys, for example [34] or [35], give a holistic overview of different topics like research goals, definitions, application domains, technologies, and architectures. Other topics investigated in the context of smart cities are, for instance, software architectures [36], trace analysis [37], business models [38], and entrepreneurship [39]. Despite being around for at least three decades, the smart city concept consists of blurred definitions which are not consistent and appear in many different ways [40]. Given the multifaceted character of smart cities, we follow [41] and stick to the definition of [42], since it has gained widespread use and covers all aspects of a smart city that are relevant for this article's results: "[…] a city [is] smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance" [42].

One of the major targets of smart city initiatives is alleviating the existing congestion conditions in most metropolitan regions. The solutions vary from self-driving cars that eliminate automobile ownership to sensor deployment in vital urban infrastructure [43]. One of the dimensions of a smart city is referred to as smart mobility. According to [44], smart mobility is a buzzword for combining different technologies and approaches. The overarching goal of smart mobility is to make the transportation of people and goods more sustainable and efficient [45][44][46]. Intelligent transportation systems (ITS) have emerged with the goal to apply several advantages to mobility, like improving travel security and increasing the performance of transportation systems [47]. In addition, ITS enables smart vehicles to communicate with each other and access the internet [48]. Smart mobility is also a critical component of the urban environment's functioning. However, transportation presents several significant issues and negative consequences for citizens' quality of life, such as pollution or longer travelling times. Smart mobility aims to assist cities in reducing traffic, accident rates, and urban footprint. Furthermore, smart mobility concepts can help to improve air quality and thus assist cities in achieving sustainable growth [49], since mobility and transportation are major drivers of climate change [46].

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