Privacy-Preserving Smart Parking System Using Blockchain and Private Information Retrieval

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Abstract—Searching for available parking spaces is a major problem for drivers in big cities, causing traffic congestion and air pollution, and wasting drivers’ time. Smart parking systems enable drivers to solicit real-time parking information and book parking slots. However, current smart parking systems require drivers to disclose their sensitive information, such as their desired destinations. Moreover, existing schemes are centralized which makes them vulnerable to bottlenecks and single point of failure problems and privacy breaches by service providers. In this paper, we propose a privacy-preserving smart parking system using blockchain and private information retrieval. First, a consortium blockchain is created by different parking lot owners to ensure security, transparency, and availability of the parking offers. Then, to preserve the drivers’ location privacy, we adopt private information retrieval technique to privately retrieve parking offers from blockchain nodes. In addition, a short randomizable signature is used to allow drivers to authenticate for reserving available parking slots from parking owners anonymously. Our evaluations demonstrate that our proposed scheme preserves drivers’ privacy with low communication and computation overheads.

Index Terms—Smart parking, blockchain, security and privacy preservation, and private information retrieval.

I. INTRODUCTION

With the fast-growing number of vehicles over the past few years, finding a vacant parking space has become a major problem for drivers in big cities. According to [1], searching for a vacant parking space leads to an average of 30 percent of traffic congestion. In addition, 47,000 gallons of gasoline are consumed which produces 728 tons of carbon dioxide on average per year in Los Angeles area alone [2]. Consequently, technology should be used to help drivers find and book vacant parking slots to avoid traffic congestion [3], air pollution, and wasting drivers’ times [4].

Due to the advancement in wireless communications and Internet of Things (IoT) devices, smart parking system has been emerging as an efficient solution to finding a parking slot. In smart parking system, an IoT device is installed in each parking spot and uses an ultrasonic sensor to detect whether a certain parking spot is available or not. Hence, it provides occupancy status of parking spaces to a service provider. The service provider enables drivers to check the available parking spaces and make online reservations, which facilitates finding vacant parking spaces.

Despite the aforementioned benefits of smart parking systems, they impose several challenges that need to be addressed before widely deploying them. One major concern is the privacy of drivers’ information. The current systems require the drivers to disclose sensitive information, such as real identities, destinations, and reservation times to the service provider. Thus, the service provider can infer drivers’ daily activities and life patterns such as home/work address, health condition, income level, etc. By analyzing the data it receives along with background information [5]. Moreover, the existing smart parking systems are usually centralized which suffer from several limitations [6]–[8]. First, they are prone to an inherent single point of failure problem. Second, they are vulnerable to distributed denial of service (DDoS) attacks and remote hijacking attacks, which could make the parking services unavailable. Third, and more importantly, driver’s sensitive information (e.g., name, email address and phone number) and daily parking information are stored in the database of smart parking systems, which has the risk of privacy breach and data loss.

In contrast to existing centralized solutions, a promising blockchain technology with advantages of decentralization, security, and trust has been utilized for different applications. A blockchain is a distributed, transparent and immutable public ledger organized as a chain of blocks and managed by a set of validators/miners [9], [10].

Motivated by this technology, in this paper, we propose a decentralized and privacy-preserving smart parking system using consortium blockchain. To the best of our knowledge, this is the first work to leverage blockchain technology to provide decentralized smart parking services.

In our scheme, consortium blockchain created by different parking lot owners is introduced. Each parking owner sends his/her parking offers to the blockchain network, which records the parking offers in a distributed shared ledger. To preserve drivers’ location privacy, we use private information retrieval (PIR) technique to allow drivers to privately retrieve parking offers from the blockchain nodes without revealing any information to the nodes about the requested parking offers [11]. Short randomizable signature is used for authentication to allow drivers to make parking reservations with parking owners in an anonymous manner [12]. We run experiments to evaluate the communication overhead and computational overhead.

The remainder of this paper is organized as follows. The network and threat models are described in Section II. Section...
III presents preliminaries. The proposed scheme is presented in Section IV. Security and Privacy analysis are discussed in Section V. Performance evaluations are conducted in Section VI. The related works are presented in Section VII. Finally, a conclusions are drawn in Section VIII.

II. System and Threat Models

In this section, we presents the system and threat models.

A. System Model

As illustrated in Fig. 1, the considered system model has the following entities.

- **Offline Trusted Authority (TA).** The TA is responsible for initializing the whole system including registering drivers, generating cryptography public parameters, distributing keys, and generating public keys certificates for parking lot owners, so that they can get permissions to write on the blockchain. In practice, the TA is a governmental agency that is interested in the security of the parking system, such as Department of Motor Vehicles (DMV).

- **Consortium Blockchain Network.** The consortium blockchain network is the core of our proposed scheme. It provides decentralized parking services. The consortium blockchain network is made of authorized nodes, (i.e., parking lot owners). Specifically, it processes and records all parking offers (transactions) on the shared ledger using a pre-defined consensus algorithm.

- **Parking Lot Owners (POs).** POs are owners of parking lots. Each lot includes IoT devices that collect available parking information. POs then can publish their offers to the blockchain network. The POs can be public or private, e.g., residential parking or employees parking.

- **Drivers.** Drivers can use their smartphones to interact with the system to find available parking spaces and make online parking reservations.

B. Threat Model

We consider that the TA is fully trusted. Also, we follow the standard blockchain threat model in [13]. Blockchain in our proposed scheme is maintained by a set of validators/miners, and trusted for execution correctness, but not for privacy. The consortium blockchain is made of a group of parking lot owners. In this model, we assume that at most \( t \) nodes may collude during the private data retrieval process to infer information about drivers parking locations. Also, at most \( b \) nodes may return erroneous responses, which we refer to them as Byzantine nodes. In addition, some drivers can be malicious. For example, they may reserve multiple parking spaces for the same time to prevent others from booking parking slots. Finally, an external attacker can eavesdrop the communications in the system to infer drivers’ sensitive information.

III. Preliminaries

A. Short Randomizable Signatures

The short randomizable signature scheme has been proposed in [12] to provide efficient anonymous authentication. It allows a user to sign a message and randomize the signature several times so that no entity can link that the received signatures is generated by the same user. The scheme provides efficiency and avoids the linear-size drawback of the traditional signature schemes. We refer to [12] for the detailed construction.

B. Private Information Retrieval (PIR)

The PIR technique enables a user to retrieve or download a specific data from a storage system without revealing any information about the data being requested. This fits our model as every driver (user in PIR) needs to query the blockchain (distributed databases in PIR) for parking offers within certain geographical area (cell) without revealing the driver’s interest in a specific parking offer.

In this work, we adopt the PIR scheme in [11]. This scheme is an information-theoretic PIR scheme for retrieving data from MDS-coded, colluding, unresponsive, and Byzantine databases. The reason we use this scheme instead of the capacity achieving scheme in [14] is to avoid the exponential file size (in the number of parking offers), which is needed to realize the scheme in [11]. Furthermore, as the number of parking offers become sufficiently large, the retrieval rate of [11] converges to the capacity expression of [14].

By using the PIR technique, a driver privately retrieves parking offers by sending queries to the blockchain, where each blockchain node sends a response to the driver. The driver reconstructs the desired parking offers by computing a deterministic function from the received responses.

IV. Proposed Scheme

Our proposed scheme consists of five phases: system initialization, submitting parking offers, parking offers retrieval, parking reservation, and parking and payment.
A. System Initialization

In the system initialization phase, the TA generates the public key certificates for parking lot owners and anonymous credentials for drivers. The TA runs the initialization for short randomizable signatures as follows.

Consider $e : G_1 \times G_2 \rightarrow G_T$ a cryptographic bilinear map with generators $g_1 \in G_1$ and $g_2 \in G_2$, where $G_1$ and $G_2$ are cyclic groups of prime order $p$. Firstly, the TA generates the public parameters $(g_1, g_2, p, G_1, G_2, e, H)$. Then, it selects randomly $(x, y) \in Z_p^2$ as group secret key, where $Z_p$ is a finite field of order $p$. After that, the TA computes $(\tilde{X}, \tilde{Y}) \leftarrow (g_2^x, g_2^y)$, and sets the group public key as $(g_2, \tilde{X}, \tilde{Y})$.

A driver $D$ can register at the TA to obtain her credentials as follows. She generates a secret key by randomly selecting $a_1 \in Z_p$ and computes a public key $A = g_1^{a_1}$. The driver randomly selects $a_2 \in Z_p$, computes the pair $(\gamma, \tilde{\gamma}) \leftarrow (g_2^{a_2}, Y^{a_2})$ and a signature $\eta \leftarrow Stg_{a_1}(\gamma)$. She sends to the TA $(\gamma, \tilde{\gamma})$ and $\eta$. The TA verifies the signature $\eta$ by checking $e(\gamma, \tilde{\gamma}) \overset{?}{=} e(g_1, \tilde{\gamma})$. Then, the driver invokes an interactive zero knowledge proof of $a_2$. After verification, the TA randomly selects $k \in Z_p$ to compute

$$$(\sigma_D^{[1]}, \sigma_D^{[2]}, \sigma_D^{[3]}) \leftarrow \left( g_1^k, (g_1^k \gamma)^k, (g_2^k, \tilde{Y}) \right) \tag{1} $$$$

The TA stores $(ID, \gamma, \eta, \tilde{\gamma})$ in its tracking list and returns $(\sigma_D^{[1]}, \sigma_D^{[2]}, \sigma_D^{[3]})$ to the driver. The driver sets her group secret key as

$$gsk_D = (a_2, \sigma_D^{[1]}, \sigma_D^{[2]}, \sigma_D^{[3]}) \tag{2}$$

B. Submitting Parking Offers

In this phase, each parking lot owner $PO$ submits its parking offers to the blockchain nodes. First, we assume the area $A$ (e.g., a city) where the smart parking is deployed, is divided into small geographical areas, cells, as shown in Fig. 2. Then, a $PO_j$ wishes to offer its parking spaces, it constructs a blockchain transaction that includes the following information: number of available spaces $N$, cell identifier $C^{[m]}$, public key $PK_{PO_j}$, location $loc$, charging station availability in the parking lot $CS$, price $pr$, and availability times $t_{av}$.

$$Offer = \{ N, C^{[m]}, PK_{PO_j}, loc, CS, pr, t_{av} \} \tag{3}$$

Note that submitting offers can be done routinely every specific period of time (e.g., 10 min). Then, each transaction offer is signed with the secret key of the $PO_j$ and is broadcasted on the blockchain network. Before storing the transaction on the ledger, the validators of the blockchain network should verify that the received parking offers are coming from an authorized $PO_j$. Then, the blockchain nodes add the offers on the ledger based on the cell identifier $C^{[m]}$, where $m \in \{1, \ldots, M\}$, as shown in Fig. 3. Specifically, for the PIR technique to work efficiently, the parking offers in each cell is represented in the form of $L \times 1$ matrix on the ledger. Note that the same ledger is stored in $n$ blockchain nodes.

After submitting the offers, the transactions stored on the blockchain should be validated by the blockchain validators, and a secure consensus protocol should run by all participants to agree on the content of the ledger. Specifically, the nodes run the Raft consensus algorithm, which is used in quorum blockchain of JPMorgan bank system. The Raft is a leader-based algorithm, where the consensus is achieved via a leader election. The leader is responsible for offers replication to the followers. The Raft provides fast consensus time for the blockchain nodes. Therefore, it is desirable for the realization of our scheme [15].

C. Parking Offers Retrieval

In this phase, a driver $D$ wants to retrieve the parking offers in the $d^{th}$ cell, $C^{[d]} = \{ C_1^{[d]}, \ldots, C_L^{[d]} \}$ from the $n$ blockchain nodes without leaking any information (in information-theoretic sense) about the identifier of the requested cell $d$. In this model, we protect the privacy of the users from any group of $t$ colluding nodes even if there exist $b$ Byzantine nodes that respond with erroneous answer strings and $r$ unresponsive nodes.

To that end, we assume that the size of the parking offers is $L = n - t - 2b - r$ without loss of generality. To retrieve the offers in $C^{[d]}$, the driver $D$ chooses i.i.d. and uniformly codewords from a query code $C_q$, which is an $[n, t]$ Reed-Solomon code. The purpose of this randomness is to hide the identity of the desired parking offers from any $t$ colluding nodes. The codewords can be represented as evaluations of a polynomial $f^{[m]}(z)$, where $\ell \in \{1, \ldots, L\}$, and $m \in \{1, \ldots, M\}$. The
query polynomial, $Q^m_\ell(z)$ can be written as:

$$Q^m_\ell(z) = \begin{cases} \beta^m_\ell(z) + z^{n-2b-r-\ell} & m = d \\ \beta^m_\ell(z) & m \neq d \end{cases}$$

(4)

Now, the driver $D$ prepares the query to the $j$th blockchain node by evaluating these polynomials at $z = \alpha_j$, where $\alpha_j \in \mathbb{F}$ a finite field with sufficiently large alphabet (to realize the Reed-Solomon codes). Hence, the query vector to the $j$th node $Q_j$ is given by:

$$Q_j = (Q^1_1(\alpha_j), \ldots, Q^L_1(\alpha_j), \ldots, Q^M_1(\alpha_j), \ldots, Q^H_1(\alpha_j))$$

(5)

When the blockchain node receives the query, it uses it as a combining vector to its content, i.e., the $j$th blockchain node performs an inner product between $Q_j$ and the vector of content (the parking offers) $Y_j = (C^1_1, \ldots, C^L_1, \ldots, C^M_1, \ldots, C^H_1)$. Hence, the response of the $j$th node is:

$$R_j = Q^T_jY_j$$

(6)

$$R_j = \sum_{m=1}^M \sum_{\ell=1}^L Q^m_\ell(\alpha_j)C^{[m]}_\ell$$

(7)

$$R_j = \sum_{m=1}^M \sum_{\ell=1}^L \beta^m_\ell(\alpha_j)C^{[m]}_\ell + \sum_{\ell=1}^L a^2_j \alpha_j^{n-2b-r-\ell}C^{[d]}_\ell$$

(8)

Eq.(8) can be written as an evaluation of the polynomial $\mathcal{R}(z)$ as,

$$\mathcal{R}(z) = \sum_{m=1}^M \sum_{\ell=1}^L \beta^m_\ell(z)C^{[m]}_\ell + \sum_{\ell=1}^L z^{n-2b-r-\ell}C^{[d]}_\ell$$

(9)

To show the decodability, we note that the degree of $\mathcal{R}(z)$ is $n - 2b - r - 1$, hence, the responses of the $n$ databases are codewords from an $[n, n - (2b + r)]$ Reed-Solomon code. An $[n, n - (2b + r)]$ Reed-Solomon code is capable of correcting $b$ errors (which results from $b$ Byzantine nodes) and $r$ erasures (which results from $r$ unresponsive nodes). Therefore, with applying Reed-Solomon decoding techniques, the driver $D$ can decode the parking offers $C^{[d]}$ correctly.

To prove the privacy, we note that the query code $C_q$ used to confuse the blockchain nodes is an $[n, t]$ MDS code, and hence, the distribution of any $t$ queries is uniform and independent from $d$ in the same manner of Shamir’s secret sharing [16]. Hence, the scheme is private.

For the retrieval rate, the driver can retrieve $L$ symbols from $n - r$ responsive nodes, consequently, the retrieval rate is given by:

$$R = \frac{L}{n - r} = \frac{n - t - 2b - r}{n - r}$$

(10)

D. Parking Reservation phase

In this phase, once the driver retrieves all the parking offers within a specific cell, she starts the parking reservation phase as follows.

First, the driver $D$ generates a $fresh$ public-private key pair $(PK_D, SK_D)$ and sends a reservation request to the selected $PO_j$. The parking request includes all necessary information for the $PO_j$, such as driver temporary public key $PK_D$, parking start time $t^s_p$, and parking period time $t^P_p$. Then, she computes

$$C^p_D = Enc_{PK_{PO_j}}(PK_D, t^s_p, t^P_p)$$

(11)

where $Enc$ is an asymmetric public key encryption algorithm, e.g., using Elliptic curve. Then, she uses the short algorithmic signature scheme to generate a signature on $C^p_D$ as follows. First, she randomizes $(\sigma_D^{[1]}, \sigma_D^{[2]}, \sigma_D^{[3]})$ by selecting $r_1, r_2 \in Z^*_q$ and computes the following values

$$C^p_D = \sigma_D^{[1]} \cdot \sigma_D^{[2]} \cdot \sigma_D^{[3]}$$

(12)

$$c_D = H(\sigma_D^{[1]}, \sigma_D^{[2]}, \sigma_D^{[3]}, C^p_D)$$

(13)

$$s = r_2 + c_D \cdot a_2$$

(14)

where $a_2$ is the secret used by the driver to generate the $gsk_D$ in the system initialization phase. Then, the tuple $(\sigma_D^{[1]}, \sigma_D^{[2]}, c_D, s)$ represents the driver signature on $C^p_D$, denoted as $Sig_D(C^p_D)$. Then, she sends both $C^p_D$ along with $Sig_D(C^p_D)$ to the $PO_j$. Once the $PO_j$ receives the request, it verifies the signature $Sig_D(C^p_D)$ to ensure that the request is from a legitimate driver. The $PO_j$ computes

$$V = e \left( \sigma_D^{[1]}, X \right) \cdot e \left( \sigma_D^{[2]}, g_2 \right) \cdot e \left( \sigma_D^{[3]}, Y \right)$$

(15)

Then, it verifies the signature by checking the following:

$$c_D = \sigma_D^{[1]} \cdot V \cdot C^p_D$$

(16)

If it does not hold, the $PO_j$ discards the request. Otherwise, it decrypts $C^p_D$ and proceeds to check the availability of the selected parking. If the selected parking is available, it sends an acknowledgement $ACK$ message to the driver, i.e., the parking space is still available and has not been reserved. Otherwise, the $PO_j$ sends $NACK$ message if another driver has reserved the parking slot. Then, after the driver receives the response, she should send a down payment to confirm reservation using existing cryptocurrency systems that preserve privacy (e.g., bitcoin [17]). Using debit or credit card payment may reveal sensitive information about drivers parking times and locations. Note that the down payment discourages malicious drivers to make multiple reservations at the same time.

E. Parking Phase

In this phase, the driver $D$ arrives at the parking lot and the payment for the parking is done. When she arrives at the $PO_j$, the $PO_j$ should first authenticate that the driver was the one who has made the parking reservation. This authentication is done as follows.

First, the $PO_j$ sends a challenge message $\Gamma$ to the driver $D$. Then, $D$ uses the temporary secret key $SK_D$ corresponding to the $PK_D$ that was sent in the reservation request to generate a signature $\sigma_{SK_D}(\Gamma)$ and sends it to the $PO_j$. After that, the $PO_j$ verifies the signature. If it is valid, the $PO_j$ allows the driver to park in its lot. At the end of the parking phase, the payment is also done by using an existing cryptocurrency system. Note that the down payment is a part of the payment.
V. EVALUATIONS

A. Communication and Computation Overhead

To evaluate communication and computation overheads of our scheme, we implemented the required cryptographic operations using Python charm cryptographic library [18] running on Raspberry Pi 3 devices with 1.2 GHz Processor and 1 GB RAM. We used supersingular elliptic curve with the asymmetric Type 3 pairing of size 160 bits (MNT159 curve) for bilinear pairing, and SHA – 2 hash function.

1) Communication Overhead: The communication overhead is measured by the size of transmitted messages in bytes between (i) a driver and the blockchain nodes (Parking lot Retrieval phase), and (ii) a driver and a parking lot owner (Reservation phase).

For the communication overhead in the retrieval phase, the total downloaded data is calculated using the Eq. (17)

\[
Total\ Downloaded\ Data = \frac{n - t - 2b - r}{R} \tag{17}
\]

Where \(n\) is the number of blockchain nodes, \(t\) colluding nodes, \(b\) byzantine nodes, \(r\) unresponsive nodes, and the retrieval rate \(R\) is given in Eq. (10). Note that the upload cost for the queries sent by the driver to blockchain nodes to retrieve parking offers is ignored according to [11]. Note also that unlike public blockchain where the number of nodes is very large, we use consortium blockchain where the number of blockchain nodes is small.

For the simulation, we considered \(t = b = r = 1\), also each parking offer by \(PO_j\) contains the number of available parking slots \(N\) (2 byte), cell number \(C[m]\) (2 byte), a public key \(PK_{PO_j}\) (20 byte), location coordinates \(loc\) (6 byte), a charging station existence index \(CS\) (1 byte), a price \(pr\) (1 byte), a time availability \(t_{av}\) (8 byte). So, the total size of a parking offer is 40 bytes. Fig. 4 shows the total downloaded data at the driver side with 44 blockchain nodes. In Fig. 4, as the number of parking offers increase in a cell, the total amount of downloaded data increases. However, the size of total downloaded data is acceptable for smartphones where it is less than 5 kbytes when the number of parking offers is 100 in each cell. As per Fig. 5, as the number of blockchain nodes increases at fixed number of offers, the total downloaded data decreases, i.e., the data retrieval rate \(R\) is more efficient. This is because the effect of Byzantine node is reduced, where we considered that we have a fixed number of Byzantine blockchain nodes \((b = 1)\).

In the parking reservation phase, the driver reservation request contains: a ciphertext \(C_{D'}\), and a signature \((\sigma_{D'}, \sigma_{D''}, c_D, s)\). The communication overhead is: \(2 \times 20 + 4 \times 20 + 2 \times 32 = 184\) bytes.

2) Computation Overhead: The computation overhead is measured by the time of cryptographic operations needed in parking reservation phases. In the parking reservation phase, the driver has to compute \(1 Enc\) which requires \(2 Mul\), and \(1 Add\), in addition to a short randomizable signature that requires \(3 Exp, 1 Mul, 1 Add\), and \(1 Hash\) to generate a parking reservation request. Therefore, the overall computation overhead equals to \(3 \times 0.333714 + 3 \times 0.000269 + 2 \times 0.000227 + 1 \times 0.000227 = 1.003\) ms

B. Storage Overhead Discussion

In this section, we discuss the storage cost overhead (i.e., size of parking offers) on the blockchain nodes. We suppose that the size of block header and tailer is 80 byte, the size of each parking offer is 40 bytes, each cell contains 50 offers, number of cells is 39, and blocks are generated frequently every 10 minutes. Then, the size of the ledger after one year would be \((40 \times 40 \times 34) \times 6 \times 24 \times 365 = 3.6\) GB. For these parameters, we assume that the POs free up their storage on annual basis to reduce the storage overhead. Note that the data content of the blocks needs to be backed up and POs storage should be released periodically.

C. Security/Privacy Analysis

Our scheme can achieve the following the security/privacy preservation features.

1) Secure system without a trusted third party. Parking lot owners can offer their parking spaces without reliance on
a trusted third party. Blockchain network is responsible for managing parking offers made by untrusted parking lot owners that make the system robust and scalable.

2) **Location privacy.** The location privacy of drivers is protected from blockchain nodes by using the PIR technique during parking offers retrieval phase. In the parking reservation phase, the drivers’ identities are preserved by using short randomizable signature.

3) **Reservation requests unlinkability.** Given different parking reservation requests from one driver at different times, no one can learn whether these requests are sent from the same driver or not. This is due to the use of short randomizable signature to generate anonymous signatures. In other words, a driver can use different random numbers $r_1$ while randomizing the signature $(\sigma^{(1)}, \sigma^{(2)})$ on different reservation requests. Moreover, the drivers’ privacy is protected by replacing their real identities by temporary public-secret key pairs during parking offers retrieval. Each key pair expires once the driver sends a parking offer retrieval request to the blockchain.

4) **Authentication.** The anonymous authentication security is based on the unforgeability of the short randomizable signature $(\sigma^{(1)}, \sigma^{(2)})$, which is proved under LRSW assumption 1 in [12].

### VI. RELATED WORK

In the literature, different works have been proposed for smart parking systems.

The schemes [6], [7] proposed a centralized privacy-preserving parking reservation services. These schemes preserve the privacy of drivers’ real identities using anonymity. Also, they use location obfuscation techniques (e.g., geoid-indistinguishability and cloaking) to protect the drivers’ desired destinations. However, the location obfuscation techniques reduce the accuracy of selecting nearest parking during the reservation process. They also disclose information on the requested area for parking.

Ni et al. [8] presented a smart parking navigation where users are guided by a cloud server and road side units (RSUs) to available parking lots in their destination. The scheme mainly preserves drivers’ privacy by using anonymous credentials. However, hiding drivers’ real identities is not enough because the cloud server can identify the drivers from their parking locations. Moreover, the drivers reveal sensitive information, such as current locations, destinations, and arrival times, to the cloud server. This enables cloud servers to track drivers easily.

Different from existing schemes, we leverage blockchain in this work to provide a decentralized parking management services. Also, our scheme guarantees availability where there is no single point of failure since it is managed by many peers. In addition, the information-theoretic PIR scheme provides absolute privacy guarantees in comparison with computational guarantees [6], [7]. The used PIR scheme can mitigate $b$ byzantine blockchain nodes and $r$ unresponsive nodes without leaking any information about the requested offers to any set of $t$ colluding nodes.

### VII. CONCLUSION

In this paper, we proposed a privacy-preserving smart parking system using blockchain and private information retrieval. A consortium blockchain is created by different parking lot owners to store the parking offers on a shared ledger to ensure security, transparency, and availability. To preserve the drivers’ location privacy, we used private information retrieval that allows drivers to privately retrieve parking offers from the blockchain nodes. To preserve the privacy of drivers’ identities, we used short randomizable signature to allow drivers to reserve available parking slots anonymously and efficiently. Our performance evaluations demonstrated that the proposed scheme preserves drivers’ privacy with low communication and computation overhead.

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