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BlockTour: A blockchain-based smart tourism platform

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ABSTRACT

The traditional tourism industry is in urgent need of digital technologies for cost reduction and efficiency enhancement. Blockchain, as an emerging technology, is promising to reform the tourism industry because it provides a trustworthy platform to link the tourism company and tourists. However, the existing blockchain-based smart tourism solutions are either conceptual or limited in solving the fundamental tourism challenges. In this paper, we propose BlockTour, a blockchain-based smart tourism platform with dedicated solution to address the challenges and real-world prototype deployment. In particular, we design the overall system architecture of BlockTour to link the tourists and attractions in a trustworthy way. Moreover, an efficient consensus mechanism is designed with incentives for the tourists to explore more attractions. Finally, we implement BlockTour and conduct extensive experiments for performance evaluation. The experimental results indicate that BlockTour is a practical and high-performance smart tourism platform.

1. Introduction

The travel and tourism industry plays an important role in people's daily life and the world economy. According to the economic impact report by the World Travel & Tourism Council,[1] the travel and tourism industry's direct, indirect, and induced impact accounted for 8.9 trillion US dollars (10.3%) of global GDP in 2019. In some countries and regions, such as Macau, Maldives, and Seychelles, the travel and tourism industry contributes more than 50% to the national or regional GDP. Moreover, one in every ten jobs (around 330 million in total) are related to the travel and tourism industry. The statistics have shown strong evidence of the great value of the travel and tourism industry.

Despite the great significance, the traditional tourism industry has been facing serious challenges in the development [1–3]. First, the tourist routes of the visitors are always passively determined, which results in incomplete discovery of the attractions. In particular, some large amusement parks consist of a bunch of events. It is difficult to motivate the tourists to participate in all the events. Second, there is no incentive for the tourists to visit the attractions continuously. The connection between the attractions and the tourists. Finally, new events are difficult to be promoted. The newly established events are less attractive to the tourists compared with the long-standing ones even if they are well designed. During the special period of COVID-19 epidemic, the challenges in the tourism industry become more than severe. The traditional tourism industry needs to be reformed urgently.

The industries and research communities have been developing smart tourism leveraging various information technologies such as Internet of Things (IoT) and big data analytics [4]. The IoT devices disseminated to the tourists and deployed on the attractions can link the tourists and the attractions in a smart way [5–7]. For example, the tourists can be notified of the nearby popular attractions by localization sensors [8,9]. Indeed, IoT is the basis of smart tourism because it provides the fundamental functions of tourism data collection. Big data analytics can be employed for smart tourism using the data collected by IoT devices [10–12]. Travel route recommendation [13], tourist behavior analysis [14], and social media dissemination [15] are the typical applications of big data analytics in smart tourism.

IoT and big data analytics can be used to improve the experiences of the tourists during sightseeing, however, cannot motivate the tourists to be regular customers or try new events. In recent years, the blockchain technology has been attracting extensive attention from both the industries and academia with broad applications in finance [16], education [17], healthcare [18], industrial IoT [19]. Generally, blockchain is a data structure for sequential data storage with immutability and auditability. Smart contract is also implemented in blockchain, which enables automatic execution of programs according to predefined agreements. From the perspective of smart tourism, blockchain is potential to act as a platform to link the tourists and attractions in a trustworthy way [20]. Moreover, rewards can be delivered to the tourists with the help of smart contract as motivation of visits. To summarize, blockchain is a promising complementary solution to IoT, big data, etc. to provide incentives to the tourists.

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In literature blockchain-based smart tourism is emerging. For example, Baralla et al. leverage the blockchain properties of transparency and traceability to ensure the quality of local food so that the tourists can feel assured about the tourism environment [21]. Moreover, Tyan et al. discuss the potential of blockchain technology in smart tourism concerning enhancing tourism experience, rewarding sustainable behaviors, ensuring benefits for local communities, and reducing privacy concerns [22]. To conclude, the existing work about blockchain-based smart tourism are either conceptual [22,23] or not solving the tourism challenges [21]. In particular, there are many challenging issues in blockchain-based smart tourism remaining to be addressed, e.g., design of the overall system architecture, efficient consensus mechanisms, and incentive mechanisms to attract the tourists.

In this paper, we propose BlockTour, a blockchain-based smart tourism platform. In particular, we design the overall system architecture of BlockTour to link the tourists and attractions in a trustworthy way. Moreover, an efficient consensus mechanism is designed with incentives for the tourists to explore more attractions. The main contributions of this paper are as follows:

- We design BlockTour, a practical blockchain-based smart tourism platform to reform the tourism industry. The platform is supported by an efficient consensus mechanism to incentivize the tourists to explore the corresponding attractions.
- We implement BlockTour, deploy a prototype, conduct extensive experiments to evaluate the performance. The experimental results indicate the high performance of BlockTour.
- The future directions of blockchain-based smart tourism are discussed, which may motivate future research.

The rest of this paper is organized as follows. Section 2 presents the existing work and justifies the motivation of this paper. In Section 3, we introduce the preliminary knowledge related to this paper. Section 4 is main technical part, which presents the system architecture and underlying algorithms and mechanisms of BlockTour. In Section 5, BlockTour is implemented, deployed, and evaluated. Finally, Section 6 concludes the paper.

2. Related work

In this section, we introduce the existing work about information technology for smart tourism and blockchain platforms.

2.1. Information technology for smart tourism

There are mainly two perspectives to apply information technologies for smart tourism, i.e., IoT and big data analytics.

From the perspective of IoT for smart tourism, Nitti et al. for the first time analyze the feasibility of using IoT technology and propose a specific architecture for sustainable tourism [5]. The proposed architecture is used to optimize the movement of cruise ship tourists in Cagliari, by taking into consideration factors such as transport information and queue waiting times. In [9], Belka et al. present a bluetooth-based indoor tracking system, which can be used for tourist traffic analysis in smart tourism. Compared to the traditional GPS localization method, the proposed method is more accurate in indoor environments and consumes less energy.

In terms of big data analytics for smart tourism, travel route recommendation is extensively studied in literature. For example, Bin et al. propose to transform the raw tourist behavior sequences into pattern sequences, discover the frequent travel routes based on the pattern sequences, and make recommendation accordingly [13]. Besides travel route recommendation, tourist behavior analysis [14] and social media dissemination [15] are also typical applications.

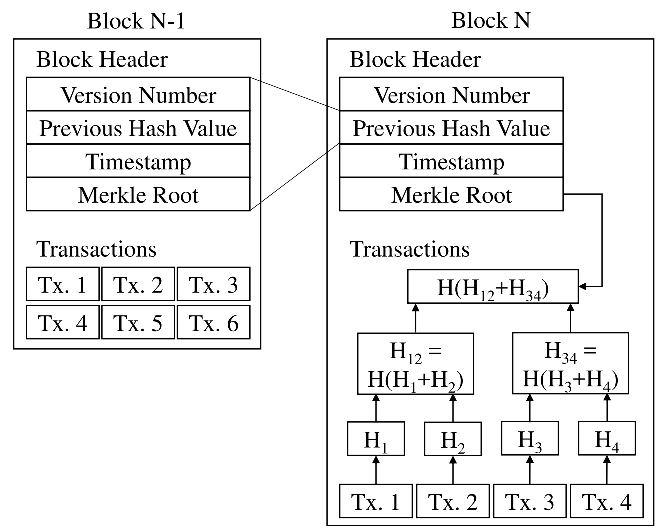

Fig. 1. Structure of a Typical Blockchain.

2.2. Blockchain platforms

The development of blockchain technology has gone through three periods, i.e., blockchain 1.0, blockchain 2.0, and blockchain 3.0. We introduce the three representative platforms, i.e., Bitcoin [24], Ethereum [25], and Hyperledger Fabric [26], in the three periods, respectively.

In 2008, the Bitcoin network was launched and opened the blockchain 1.0 era, in which various cryptocurrencies are developed [24]. Bitcoin can be used as a blockchain platform to develop applications especially the financial ones. However, the tightly-coupled components and low throughput make it difficult to accommodate Bitcoin platform with other applications.

With the successful implementation of smart contract upon blockchain, Ethereum began the blockchain 2.0 era on 2014 [25]. Various decentralized applications are deployed on Ethereum by programming the smart contracts. However, the fair performance and high cost of Ethereum greatly limit the companies to develop highly-customized applications.

Hyperledger is an open-source blockchain project started in December 2015 by the Linux Foundation [26]. Hyperledger consists of a set of blockchain platforms and tools, in which the most popular one is a permissioned blockchain platform named Hyperledger Fabric. Fabric, as a representative platform in Blockchain 3.0 era, provides a highly-modularized architecture with a delineation of roles between the nodes in the infrastructure, execution of smart contracts and configurable consensus and membership services.

3. Preliminaries

In this section, we introduce the preliminary knowledge about blockchain data structure and the underlying consensus mechanism.

3.1. Blockchain data structure

A blockchain is an append-only data structure consisting of a list of blocks linked using cryptographic hashing functions. The structure of blockchain is shown in Fig. 1 described as follows:

- *Version number* indicate the version number of the running consensus protocol. Generally speaking, the version numbers of consecutive blocks should not differ too much.
- *Previous hash value* is hash value of the block header of previous block. The hash values connect the block sequentially. Typically, SHA256 is used as the hash function.

- *Timestamp* is the time generating the block. The timestamp can only reflect the approximate time because it is local time of the node proposing the block.
- *Merkle root* is a cryptographic value to search the transactions in the block. In Fig. 1, the Merkle root of block N is computed using the level-by-level hash results upon the transactions in the block.
- Block header is a collection of the version number, previous hash value, timestamp, Merkle root, etc. Different blockchain may vary the fields in block header. For example, "nonce" and "difficulty target" are added in the block header of Bitcoin to run the underlying Proof of Work (PoW) consensus protocol [24].
- *Transactions* is a list of transactions contained in the block. Note that it is possible that no transaction is contained in a block.

3.2. Consensus mechanisms of blockchain

A blockchain is maintained by a peer-to-peer network. All the nodes in the blockchain network should keep the same copy of the blockchain data. A mechanism is needed to guarantee the consistency of the blockchain data in all the nodes, which is called the consensus mechanism. In literature, there are consensus mechanism designed for various systems and purposes, e.g., PoW [24], Proof of Stake [27], Practical Byzantine Fault Tolerance [28]. Summaries of the existing consensus protocols used in blockchain can be found in [29–31], etc.

4. BlockTour: a blockchain-based smart tourism platform

In this section, we introduce the design of BlockTour, a blockchain-based smart tourism platform. We explain the system architecture of BlockTour in Section 4.1. Moreover, the underlying consensus mechanism is presented in Section 5.1.

4.1. System architecture of blockTour

Fig. 2 depicts the system architecture of BlockTour. There are two kinds of entities in the system, which are the tourists and the companies in charge of the attractions. The companies will host a set of nodes to maintain the blockchain and provides services through the smart tourism interfaces. The nodes hosted by the companies are *static* nodes that are always online. The tourists may use their devices, such as smart phones, to run the *lightweight* node, link with the static nodes through the network communication module, join the blockchain network, and participate in the consensus process.

Each static blockchain node consists of five modules with functionalities explained as follows:

- *Smart tourism interfaces* provide tourism service interfaces to the tourists. The services can be dynamically set by the tourism companies and can be localization, check-in, guidance, ticket, discount, etc.
- *Smart contract module* supports the deployment and execution of smart contracts. The smart contracts should be deployed and defined by the tourism companies. Representative smart contracts include games to promote new events, online check-in, and value transfer.
- *Consensus module* provides consensus mechanism, i.e., proof of participation, which takes a set of unordered tourism transactions as input and output the transactions confirmed by all the nodes in the form of blockchain.
- *Network communication module* provides protocols communicating with other nodes, in which broadcasting, peer-to-peer discovery, etc. are implemented.
- *Data management module* manages the blockchain and application related data and status, e.g., blockchain status, transaction pool, and account status.

The lightweight nodes are simpler compared with the static blockchain nodes. Each lightweight node contain the modules of consensus, network communication, and data management, while no smart tourism interfaces and smart contract module. The data management module does not store the full blockchain data. Instead, only the block headers and Merkle trees are stored for verification, while the transaction data will be fetched from the static nodes if necessary.

The static nodes and lightweight nodes connect with each other, form a peer-to-peer blockchain network, and maintain a blockchain. The nodes are employing proof of participation, which will be introduced in Section 4.2, to generate blocks one by one, in which each block contains a list of transactions. The node to generate block will be rewarded with a certain amount of tokens. Inside the blockchain, there are mainly four kinds of transactions as follows:

- *Attraction information* (Type $= 1, id_T, S, T, \sigma$). When there is a status update of an attraction, there will be a transaction of attraction information published by the tourism company. Each transaction of attraction information has the following four fields:
  - *Attraction ID* (id_T): the unique identifier of the attraction.
  - *Status* (S): the latest status of the attraction, which can be "closed" or "open".
  - *Time* (T): the time of the latest status of the attraction.
  - *Signature* (σ): the signature of the tourism company that can be verified publicly.

  Such a transaction means that at time T, the status of the attraction id_T is updated to be S.
- *Visiting record* (Type $= 2, id_T, id_V, T, \sigma_V, \sigma_T$). When a tourist visits an attraction, there will be a transaction of visiting record published by the tourist. Each transaction of visiting record has the following five fields:
  - *Attraction ID* (id_T): the unique identifier of the visited attraction.
  - *Tourist ID* (id_V): the unique identifier of the tourist.
  - *Time* (T): the visiting time.
  - *Tourist Signature* (σ_V): the signature of the tourist that can be verified publicly.
  - *Tourism Signature* (σ_T): the signature of the tourism company that can be verified publicly.

  Such a transaction means that at time T, the tourist id_V visited the attraction id_T.
- *Sign-in record* (Type $= 3, id_V, T, \sigma_V$). Each tourist may generate a transaction of sign-in record each day. The time interval between two consecutive sign-in records from each tourist should be no less than one day. Each transaction of sign-in record has the following three fields:
  - *Tourist ID* (id_V): the unique identifier of the tourist.
  - *Time* (T): the sign-in time.
  - *Tourist Signature* (σ_V): the signature of the tourist that can be verified publicly.

  Such a transaction means that at time T, the tourist id_V signed in the system.
- *Token transfer* (Type $= 4, id_1, id_2, \upsilon, T, \sigma_1$). The tourists and tourism company may transfer token with each other, which will generate transactions of token transfer. Each transaction of token transfer has the following four fields:
  - *Sender ID* (id_1): the unique identifier of the sender, which can be the tourist or tourism company.
  - *Receiver ID* (id_2): the unique identifier of the receiver, which can be the tourist or tourism company.
  - *Amount* (υ): the amount of transferred tokens.
  - *Time* (T): the time when the transfer action happens.

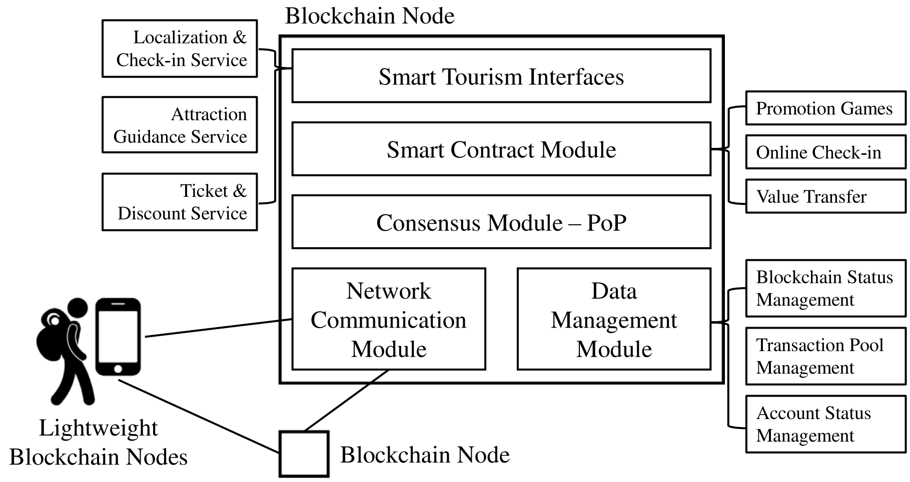

Fig. 2. BlockTour System Architecture.

– *Sender Signature* (σ_1): the signature of the sender that can be verified publicly.

Such a transaction means that at time T, an amount of v tokens are transferred from id_1 to id_2.

4.2. Proof of participation: a new consensus mechanism for smart tourism

We propose proof of participation (PoP), a tourism dedicated consensus mechanism, for BlockTour. The key idea of PoP is to encourage the nodes to confirm the transactions showing more participation activities. PoP runs round by round and a block is confirmed by the blockchain network at the end of each round. Fig. 3 depicts the four sequential phases in each round with explanation as follows:

- *Leader election*: all the blockchain nodes to elect a leader.
- *Transaction packing*: the leader to pack a set of transactions into a block.
- *Block propagation*: the leader to broadcast the generated block to the blockchain network.
- *Status update*: all the blockchain nodes to validate the block generated by the leader and update the blockchain status.

In the phase of leader election, each node can propose a set of valid transactions to be packed into a block. The validity of a set of transactions are judged as follows:

- If there are any transaction whose signature(s) is invalid, then the set is invalid.
- If there are two transactions that are exactly the same, then the set is invalid.
- If there are two transactions of visiting records with the same tourist ID but the time interval between them is less than one day, then the set is invalid.
- If there is any transaction of token transfer that the token balance of the sender is less than the transferred amount, then the set is valid.
- Otherwise, the set is valid.

Each set of transactions will be evaluated according to the participation score using Algo. 1, which takes the transaction set $\mathcal{T}$ as input together with four pre-defined participation coefficients, i.e., α, β, γ, and δ, and outputs the evaluated participation score. Algo. 1 counts the number of unique attraction IDs in type-1 transactions (transactions in whose field of type is 1), the number of type-2 transactions, the number of type-3 transactions, and the total number of transferred tokens in type-4 transactions. Then, these numbers are multiplied by α, β, γ, and

Algorithm 1 Evaluation of participation score

Require: $\mathcal{T} = \{t_1, t_2, \cdots, t_n\}$: a set of transactions; $\alpha, \beta, \gamma, \delta$: participation coefficients of attraction information, visiting records, sign-in records, and transferred tokens, respectively.
Ensure: $\mathcal{S}$: the participation score of $\mathcal{T}$.

$v_1, v_2, v_3 \leftarrow 0$
$\mathcal{A} \leftarrow \emptyset$
for each transaction $t_i \in \mathcal{T}$ **do**
  if $t_i.\text{TYPE} = 1$ **then**
    $\mathcal{A} \leftarrow \mathcal{A} \cup \{t_i.id_T\}$
  else if $t_i.\text{TYPE} = 2$ **then**
    $v_1 \leftarrow v_1 + 1$
  else if $t_i.\text{TYPE} = 3$ **then**
    $v_2 \leftarrow v_2 + 1$
  else if $t_i.\text{TYPE} = 4$ **then**
    $v_3 \leftarrow v_3 + t_i.v$
  end if
end for
$\mathcal{S} \leftarrow \alpha \cdot |\mathcal{A}| + \beta \cdot v_1 + \gamma \cdot v_2 + \delta \cdot v_3$
return $\mathcal{S}$

δ, respectively, and the sum of the products will be output as the final score.

The blockchain nodes will broadcast the final scores of the proposed sets of transactions. The reputation-mixed score of a blockchain node is calculated as the product of the final score and the reputation of the node. In the second phase of transaction packing, the node which proposes the transaction set with the maximum reputation-mixed score will be elected as leader. The leader will prepare the block by packing the transactions, calculating the Merkle tree, and generating the block header. In the third phase of block propagation, the prepared block will be broadcast in the blockchain network.

Afterward, in the fourth phase, all the nodes in the blockchain network will validate the block prepared by the leader and update the blockchain-related data. The validation is divided into two steps. On one hand, the validity of the transactions and block-related data will be checked. On the other hand, all the nodes will check whether the calculated score of the block is the same as the one the leader claimed before. If the block passes the two validation rules, then the block will be confirmed. Otherwise, the block will be rejected.

After validating the block prepared by the leader, all the blockchain nodes will update the confirmed transactions and block. An other important issue will be updating the reputation of the nodes. When the blockchain is newly established or a new node just joins the blockchain,

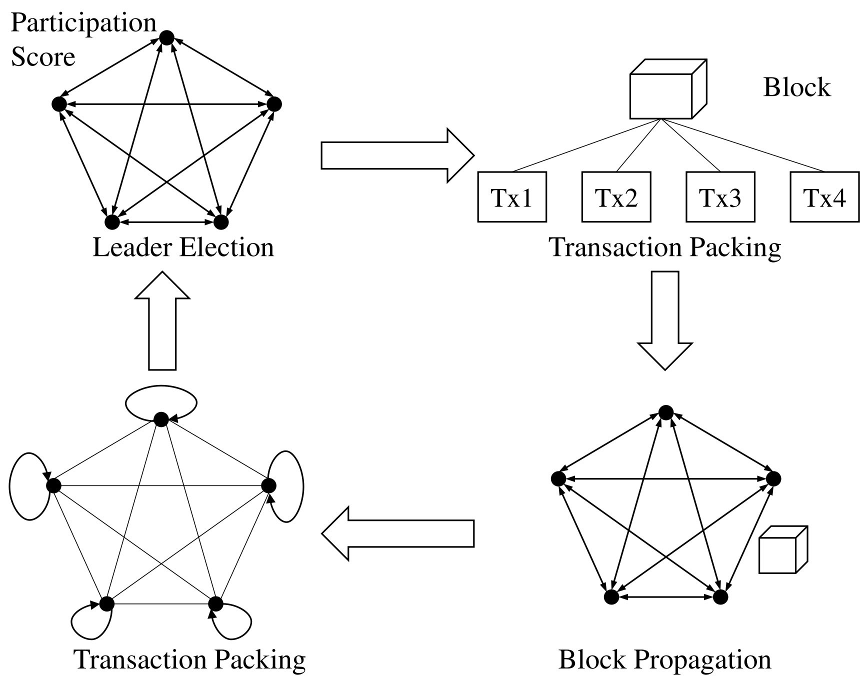

Fig. 3. Four Phases of a Round in PoP.

Algorithm 2 Reputation update of the blockchain nodes

Require: REP: a dictionary storing the reputation of the blockchain nodes; $\mathcal{M}$: a queue of message from the other blockchain nodes; LEADER: elected leader node in the current round.

Ensure: REP: an updated dictionary storing the reputation of the blockchain nodes.

```
S ← UNCERTAIN
while M is not empty do
    m ← Pop the front element out of M
    if m.SENDER is leader then
        if m.BLOCK is valid then
            S ← VALID
            REP(LEADER) ← REP(LEADER) + 0.02
        else
            S ← INVALID
            REP(LEADER) ← REP(LEADER) − 0.04
        end if
    else
        if S = UNCERTAIN then
            Push m at the tail of M
        else if S = VALID and m.REPLY = CONFIRM then
            REP(m.SENDER) ← REP(m.SENDER) + 0.01
        else if S = INVALID and m.REPLY = REJECT then
            REP(m.SENDER) ← REP(m.SENDER) + 0.02
        end if
    end if
    if the phase ends with no message from the leader then
        REP(LEADER) ← REP(LEADER) − 0.04
        break the while-loop
    end if
end while
```

the reputation of the node is initially set as 1. In the fifth phase of a round, the reputation of the nodes will be updated according to Algo. 2. In terms of the leader, if the proposed block is finally confirmed, then the reputation will be increased by 0.02; otherwise, that is, if the block fails to pass any of the validation rules, the reputation will be deducted by 0.04. The reason why the punishment is higher than the reward is that malicious behaviors should be considered seriously. With regards to the other nodes, if a node succeeds to confirm a valid block, then the reputation of the node will be increased by 0.01; if a node succeeds to reject a invalid block, then the reputation will be increased by 0.02; if a node fails to confirm a valid block or reject a invalid block, then the reputation will remain the same. In the design, the normal behaviors of the non-leader nodes are encouraged with reputation increases. Moreover, the failure in confirmation or rejection suffers from no punishment because the failure may result from reasons other than being malicious, e.g., unstable communication channels and device failures. Note that if timeout happens, the reputation of the leader node will be deducted by 0.04 because the round is wasted by the leader node. In Algo. 2, we have also designed mechanism to deal with synchronous message from the leader and non-leader nodes. The method is to delay the message from non-leader nodes if no block is received from the leader node.

5. Implementation & experimental results

In this section, we introduce the implementation, deployment, and performance evaluation of BlockTour.

5.1. System implementation & prototype deployment

We leverage an open-source platform Hyperledger Fabric [26] to implement BlockTour and deploy a prototype. Chain codes in Hyperledger Fabric written in Java are used to deploy the application logic of BlockTour. Moreover, we replace the consensus component in Hyperledger Fabric with an implementation of PoP written in Go. All the blockchain nodes, no matter the static nodes or the lightweight ons, are running on computers with 8GB memory and two i7-6500U CPUs (2.50 GHz and 2.59 GHz) and Ubuntu 20.04 operating system.

Fig. 4 depicts the deployment model of BlockTour showing the components together with their relationship with explanation as follows:

- *P1* and *P2* are the instances of static nodes hosted by the tourism company. In this paper, they are physically installed on computers.

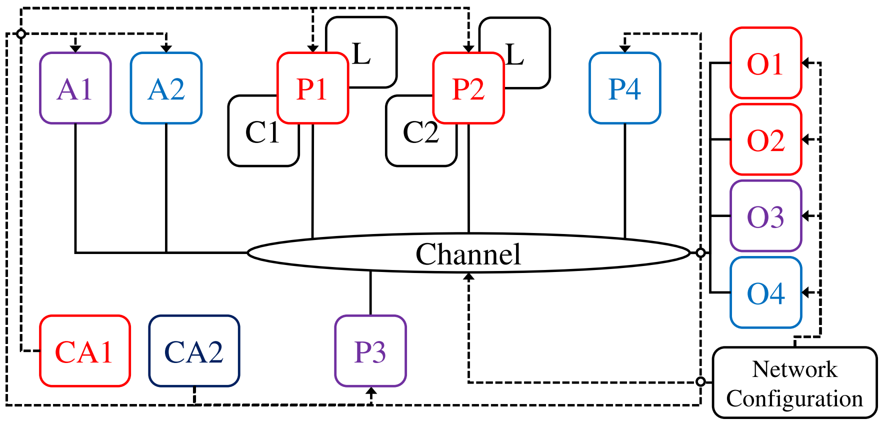

Fig. 4. Deployment Model of BlockTour.

- *A1* and *A2* are the instances of the tourist applications. They can be any devices such as mobile phones and laptops. In this paper, they are hosted by computers.
- *CA1* and *CA2* are the certificate authorities that generate certificates for the nodes. In particular, CA1 is responsible for the certificates of P1 and P2 while CA2 generates and maintains the certificates for A1, A2, P3, and P4.
- *Channel* is a virtual communication panel connecting the components of applications, peers, and orderers.
- *C1* and *C2* are chain codes implementing the application logic and deployed on channel via the peers P1 and P2, respectively.
- *L* is a replica of the blockchain data stored in the peers. As shown in the figure, both P1 and P2 own a copy of the blockchain.
- *O1*, *O2*, *O3*, and *O4* are the orderer components to host the PoP consensus protocol, which takes the transactions from the channels as input and make consensus to output an ordered list of confirmed transactions.
- *Network configuration* is the component that configures and initialize the blockchain network, which includes the orders and components connected to the channel.

In the prototype deployment, we run "A1, P3, and O3", "A3, P4, and O4", "P1 and O1", and "P2 and O2" on four computers, respectively. The four computers connect with each other via local area network and run smooth for over two months, which indicates the system reliability.

5.2. Performance evaluation

We have conducted experiments to evaluate the performance of BlockTour in terms of the system throughput and transaction latency with respect to different request incoming rates. Note that each point of data is recorded as the average number of 100 repeated experimental trials.

Fig. 5 shows how the system throughput of BlockTour is affected by the request incoming rate. When the number of requests per second (RPS) is less than $1400tx/s$, the system throughput increases as RPS increases. The peak system throughput is $1273tx/s$, which is reached when RPS is around $1400tx/s$. When RPS is up to $1400tx/s$, the system throughput will decrease with an increase of RPS. We can conclude Fig. 5 that peak processing power of BlockTour (with four orderers, four peers, and two application components) is approximately $1273tx/s$.

Fig. 6 depicts how the transaction latency is affected by the request incoming rate. When the RPS is less than $1200tx/s$, the transaction latency increases slowly, i.e., fluctuating between $0s$ and $15s$, as RPS increases. When RPS increases from $1200tx/s$ to $2000tx/s$, the transaction latency increases dramatically from no more than $15s$ to up to $135s$. Combined with Fig. 5, the reason is that the peak processing power of BlockTour is around $1273tx/s$. When RPS increases from $1200tx/s$ to $2000tx/s$, RPS exceeds the peak processing power, which leads to an accumulation of transactions in the transaction pool and a dramatic increases of the transaction latency.

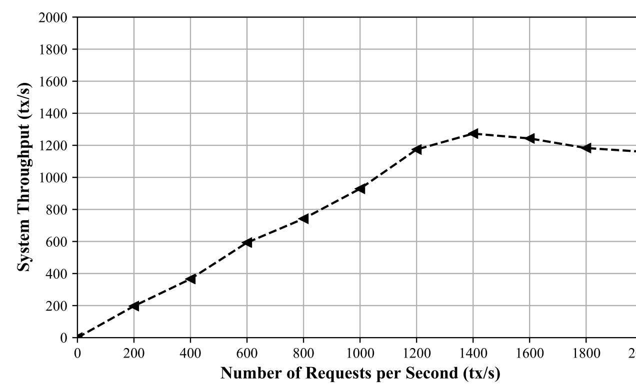

Fig. 5. BlockTour System Throughput.

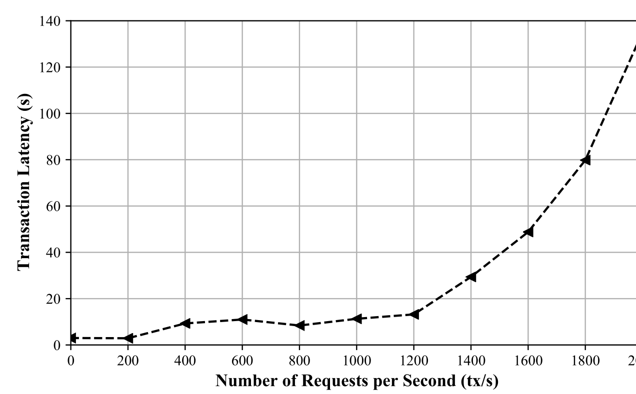

Fig. 6. BlockTour Transaction Latency.

6. Conclusion

In this paper, we propose BlockTour, a blockchain-based platform for smart tourism, which can link the tourism company and tourists to improve the efficiency of the tourism industry. In BlockTour, a layered blockchain system architecture is proposed together with design of the static blockchain nodes and the lightweight ones to reduce the burden from the perspective of the tourists. Moreover, a novel consensus mechanism, i.e., proof of participation, is developed to confirm the transactions of attraction information, visiting records, sign-in records, and token transfer. Finally, a prototype of BlockTour is deployed and extensive experiments are conducted. The real-world deployment and experimental results indicate the practicability and high performance of BlockTour. In the future, practical blockchain-based smart tourism systems are in urgent needs to be developed. Moreover, smart contracts may be developed to enrich the functionalities of BlockTour. Moreover, the interfaces should be improved from the perspectives of the tourists.

CRediT authorship contribution statement

Li Luo: Conceptualization, Resources, Methodology, Validation, Writing - original draft, Writing - review & editing. **Jing Zhou:** Supervision, Project administration, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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