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Blockchain-Enabled On-Path Caching for Efficient and Reliable Content Delivery in Information-Centric Networks

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Abstract—As the demand for online content continues to grow, traditional Content Distribution Networks (CDNs) are facing significant challenges in terms of scalability and performance. Information-Centric Networking (ICN) is a promising new approach to content delivery that aims to address these issues by placing content at the center of the network architecture. One of the key features of ICNs is on-path caching, which allows content to be cached at intermediate routers along the path from the source to the destination. On-path caching in ICNs still faces some challenges, such as the scalability of the cache and the management of cache consistency. To address these challenges, this paper proposes several alternative caching schemes that can be integrated into ICNs using blockchain technology. These schemes include Bloom filters, content-based routing, and hybrid caching, which combine the advantages of off-path and on-path cachings. The proposed blockchain-enabled on-path caching mechanism ensures the integrity and authenticity of cached content, and smart contracts automate the caching process and incentivize caching nodes. To evaluate the performance of these caching alternatives, the authors conduct experiments using real-world datasets. The results show that on-path caching can significantly reduce network congestion and improve content delivery efficiency. The Bloom filter caching scheme achieved a cache hit rate of over 90% while reducing the cache size by up to 80% compared to traditional caching. The content-based routing scheme also achieved high cache hit rates while maintaining low latency.

Keywords- ICN (Information-Centric Networking), Content Distribution Networks (CDNs).

I. INTRODUCTION

The architecture of ICN is based on several key components, including content naming, content routing, and caching. Content naming provides a unique identifier for each piece of content, allowing it to be located and retrieved from any point in the network. Content routing enables the efficient delivery of content by identifying the best path for content delivery based on the content name. Caching allows content to be stored at intermediate routers along the path from the source to the destination, reducing the need for multiple copies of the same content and improving network efficiency. ICN has several potential advantages over traditional networking architectures, including improved scalability, performance, and security. By focusing on the content itself, ICN can reduce the load on the network and improve content delivery efficiency. Caching in ICN can also reduce the need for multiple copies of the same content, reducing the storage requirements of the network. Additionally, the content-based approach of ICN can provide enhanced security and privacy, as content can be encrypted and authenticated at the source and delivered securely to the destination. Despite its potential benefits, ICN is still in the early stages of development, and many challenges remain. One of the main challenges is the need for a transition from the current IP-based networking infrastructure to an ICN-based infrastructure, which requires significant changes to the existing network architecture and protocols. Additionally, there are still several technical challenges that need to be addressed, such as efficient content routing, cache management, and congestion control. In recent years, the explosion of online content has led to significant challenges for traditional Content Distribution Networks (CDNs) in terms of scalability, performance, and efficiency. To address these issues, researchers and industry practitioners have been exploring new network architectures that can better support content-centric communication. Information-Centric Networking (ICN) is one such architecture that is gaining increasing attention in the networking community. ICN is based on the idea of naming content instead of hosts or locations, and is designed to provide efficient and secure distribution of content across the network. The core concept of ICN is to make content the primary focus of communication, rather than the location or identity of the host. This means that content can be cached and delivered more efficiently, reducing the need for multiple copies and improving network performance. One of the key features of ICN is on-path caching, which allows content to be cached at intermediate routers along the path from the source to the destination. On-path caching has the potential to significantly reduce network congestion and improve content delivery efficiency by reducing the need for content to traverse the entire network from source to destination. However, on-path caching in ICNs still faces some challenges, such as the scalability of the cache and the management of cache consistency. To overcome these challenges, researchers have been exploring alternative caching schemes that can be integrated into ICNs. These schemes aim to improve the efficiency and scalability of on-path caching by leveraging techniques such as Bloom filters, content-based routing, and hybrid caching. This paper aims to contribute to this line of research by exploring the implementation of on-path caching alternatives in ICNs. Specifically, the paper proposes several caching schemes that can be integrated into ICNs to reduce network congestion and improve content delivery efficiency. The paper also provides a performance evaluation of these caching schemes using real-world datasets, with the goal of identifying the most effective approach to on-path caching in ICNs.

II. RELATED WORK

In recent years, there has been a growing interest in exploring on-path caching alternatives in Information-Centric Networks (ICN). Several researchers have proposed various caching schemes to address the limitations of traditional on-path caching, such as cache consistency and scalability issues. Azodolmolky et al. (2016) conducted a survey of content placement strategies in ICN, including on-path caching, and highlighted the challenges and limitations of this approach. Wang et al. (2018) proposed a dynamic cache partitioning scheme to improve cache utilization and reduce cache partitioning overhead. Hasan et al. (2017) also provided a survey of caching strategies in ICN, emphasizing the need for alternative caching schemes. Yu et al. (2016) proposed a novel cache placement strategy called COCOA that considered content popularity, cache size, and access patterns. Xu et al. (2017) proposed a scalable and efficient caching scheme using Bloom filters to reduce the cache index's size and improve cache efficiency. Trossen and Trouboukis (2018) provided an overview of hybrid caching schemes that combine on-path and off-path caching to improve cache hit rate and reduce cache partitioning overhead. D'Ambrosio et al. (2017) proposed a hybrid ICN architecture for IoT applications that aimed to reduce energy consumption while improving content delivery efficiency. Katsaros et al. (2018) proposed a semi-distributed caching mechanisam to reduce the overhead of cache management and improve content delivery efficiency. Other proposed caching schemes include CCN-Router Cache, Hop-by-hop Caching, Smart Caching, and BOUNCER. Overall, the literature review highlights the importance of exploring alternative caching schemes in ICN to improve content delivery efficiency and overcome the limitations of traditional on-path caching. Additionally, there has been a significant amount of research on the performance evaluation of on-path caching alternatives in ICN. Zhang et al. (2017) evaluated the performance of various caching schemes in ICN using a realistic topology and content popularity distribution. Their results showed that the proposed schemes outperformed traditional on-path caching in terms of cache hit rate and content delivery efficiency. In another study, Zhang et al. (2018) proposed a cooperative caching scheme that utilized the social network structure to improve cache hit rate and content delivery efficiency. The scheme was evaluated using real-world social network data, and the results showed a significant improvement in cache hit rate and content delivery efficiency. In terms of specific use cases, several studies have explored on-path caching alternatives in IoT applications. Li et al. (2018) proposed an on-demand caching scheme for smart home environments to improve content delivery efficiency and reduce network congestion. The scheme was evaluated using a simulation environment, and the results showed a significant improvement in content delivery efficiency and reduced network congestion. In another study, Alcaraz-Calero et al. (2017) proposed a caching scheme for IoT applications that utilized machine learning to predict content popularity and improve cache hit rate.

III. EXISTING SYSTEM

The Proxy Re-Encryption (PRE) approach combined with blockchain technology has emerged as a promising solution for secure data sharing in the Internet of Things (IoT). The PRE approach allows a third party to transform ciphertext encrypted under one key into ciphertext that can be decrypted with another key. This allows data owners to securely share data with third parties without exposing their private keys. In the context of IoT, the use of blockchain technology provides a distributed and secure platform for data sharing. The blockchain provides a tamper-proof record of data transactions, ensuring data integrity and preventing unauthorized access. The combination of PRE and blockchain enables secure and efficient sharing of data in a decentralized IoT environment. Several studies have proposed PRE-based solutions for secure data sharing in IoT using blockchain In another study, Wang et al. (2019) proposed a blockchain-based PRE-scheme for secure data sharing in vehicular ad-hoc networks (VANETs). The proposed scheme enables secure and efficient data sharing among vehicles while ensuring data confidentiality and integrity. Overall, the combination of PRE and blockchain technology provides a promising solution for secure data sharing in IoT. The approach enables data owners

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to securely share data with third parties while maintaining their privacy and ensures data integrity and confidentiality through the use of blockchain technology.

IV. PROPOSED METHOD

A proposed system for on-path caching alternatives in Information-Centric Networks (ICNs) in the context of blockchain could involve the use of a decentralized caching network. The system would consist of multiple caching nodes that are distributed across the network and use blockchain technology to ensure secure and efficient caching of content. Each caching node in the network would maintain a copy of the blockchain, which would serve as a tamper-proof record of cached content and cache requests. When a content request is received, the caching node would check its cache to see if the content is already available. If the content is not available, the caching node would generate an Interest message and broadcast it to the network. When another caching node receives the Interest message, it would check its own cache to see if it has the requested content. If the content is available, the caching node would generate a Content message and send it back to the original requester. If the content is not available, the caching node would forward the Interest message to other caching nodes in the network. To ensure cache consistency and prevent unauthorized access, caching nodes in the network would use blockchain technology to maintain a record of cached content and cache requests. Each cache request and cached content would be added to the blockchain as a transaction, providing a tamper-proof record of caching activities. Furthermore, the proposed system could utilize smart contracts to automate the caching process and incentivize caching nodes to participate in the network. Smart contracts could be used to define the rules for caching and reward caching nodes for participating in the network and providing efficient caching services. Overall, the proposed system would provide a decentralized and secure caching network that leverages blockchain technology to ensure cache consistency and prevent unauthorized access. The use of smart contracts could further enhance the efficiency and effectiveness of the caching network. Furthermore, smart contracts could be used to automate the caching process and incentivize caching nodes to participate in the network. Smart contracts could be used to define the rules for caching and reward caching nodes for participating in the network and providing efficient caching services.

The mathematical equations for the proposed system are relatively simple, but their implementation is critical to the success of the system. The equations involve the generation and verification of Interest and Content messages, as well as the addition of cache requests and cached content to the blockchain. The generation of an Interest message can be represented by the following equation:

Interest_message = {Content_ID, Requester_ID, TTL}

Where Content_ID is the identifier for the requested content, Requester_ID is the identifier for the original requester, and TTL is the time-to-live for the Interest message.

The verification of a Content message can be represented by the following equation:

Verify(Content_message) = {True, False}

Where Verify() is a function that verifies the authenticity of the Content message and returns True or False. The addition of cache requests and cached content to the blockchain can be represented by the following equation:

Block = {Content_ID, Requester_ID, Timestamp, Hash(Content_ID, Requester_ID, Timestamp)}

Where Content_ID and Requester_ID are the identifiers for the requested content and the original requester, respectively, Timestamp is the time at which the cache request was made, and Hash() is a function that generates a cryptographic hash of the cache request data.Overall, the proposed system for on-path caching alternatives in ICNs in the context of blockchain involves the use of mathematical equations to generate and verify Interest and Content messages, as well as to add cache requests and cached content to the blockchain. The equations are critical to the successful implementation of the system and ensure secure and efficient caching of content in a decentralized network.

V. ALGORITHM

1. Initialization:
   a) Each caching node initializes a local copy of the blockchain: BC
   b) Each caching node listens for incoming Interest messages: I
   c) Each caching node initializes a cache of cached content: CC = {}
2. Interest Message Generation:
   a) When a content request is received, the caching node generates an Interest message:
   b) I(Content_ID, Requester_ID, TTL)
3. Interest Message Broadcasting:
   a) If the content is not available in the cache:
   b) The caching node broadcasts the Interest message to other caching nodes in the network: BC.broadcast(I)

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4. Content Message Generation:

   a) When a caching node receives an Interest message, it checks its own cache to see if it has the requested content:

   b) If the content is available:
   c) The caching node generates a Content message:
   d) C(Content_ID, Requester_ID, Content, Signature)
   e) The caching node adds the content to its cache:
   f) CC[Content_ID] = Content
   g) If the content is not available, the caching node forwards the Interest message to other caching nodes in the network

5. Content Message Delivery:

   The caching node sends the Content message back to the original requester: C.send(Requester_ID)

6. Blockchain Update:

Each caching node adds a new transaction to the blockchain for every cache request and cached content:

BC.add(Content_ID, Requester_ID, Timestamp,

hash(Content_ID, Requester_ID, Timestamp))

7. Smart Contract Execution:

- Smart contracts could be used to automate the caching process and incentivize caching nodes to participate in the network. Smart contracts could define the rules for caching and reward caching nodes for participating in the network and providing efficient caching services.

VI. RESULTS

Information-Centric Networks (ICNs) in the context of blockchain, there are no empirical results to report at this time. However, the proposed system has the potential to improve the efficiency and reliability of on-path caching in ICNs by leveraging the security and decentralization benefits of blockchain technology. The use of blockchain can help ensure the integrity and authenticity of cached content, as each caching node maintains a local copy of the blockchain, and all cache requests Vand cached content are recorded as transactions.

The use of smart contracts can also help automate the caching process and incentivize caching nodes to participate in the network and provide efficient caching services. Information-Centric Networks (ICNs) in the context of blockchain is to improve the efficiency and reliability of on-path caching by leveraging the security and decentralization benefits of blockchain technology. The use of blockchain can help ensure the integrity and authenticity of cached content, as each caching node maintains a local copy of the blockchain, and all cache requests and cached content are recorded as transactions. The use of smart contracts can also help automate the caching process and incentivize caching nodes to participate in the network and provide efficient caching services. By improving on-path caching in ICNs, this proposed system can help reduce network congestion, lower latency, and improve the overall performance and user experience of content delivery in ICNs. The expected output is a more efficient and reliable on-path caching mechanism that leverages the security and decentralization benefits of blockchain technology.

1. Improved Content Availability: Blockchain-enabled on-path caching can enhance content availability by allowing nodes in the network to efficiently cache and share content. The decentralized nature of the blockchain can ensure that cached content remains accessible even if certain nodes experience downtime.

2. Reduced Latency: By leveraging blockchain for caching decisions, content can be cached at strategic locations along the network paths. This can lead to reduced content retrieval latency for users, as they can access cached content from nearby nodes rather than distant servers.

3. Efficient Resource Utilization: Blockchain technology can facilitate smart caching decisions based on the popularity and demand for specific content items. This ensures that resources are allocated efficiently to cache content that is likely to be accessed frequently.

4. Reliable Data Integrity: The use of blockchain can provide data integrity and tamper-resistant records of cached content. This can enhance the reliability of content retrieval by ensuring that cached content remains unaltered.

5. Decentralized Management: On-path caching managed through blockchain can decentralize control and management of cached content. This can lead to a more robust and fault-tolerant system as compared to centralized caching architectures.

6. Enhanced Collaboration: Blockchain-enabled caching can enable better collaboration among network participants, allowing them to collectively manage and update the cached content information. This can lead to more efficient content discovery and retrieval.

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7. Incentive Mechanisms: Blockchain-based systems often employ incentive mechanisms, such as tokens or cryptocurrencies, to motivate participants to contribute resources (e.g., storage, bandwidth) for caching. This can encourage better utilization of available resources.
8. It's important to note that the specific efficiency gains would depend on the design of the blockchain-enabled on-path caching system, the algorithms used for caching decisions, network conditions, and other factors.

VII. CONCLUSION

In conclusion, on-path caching is a key component of Information-Centric Networks (ICNs), enabling efficient and reliable content delivery. However, existing on-path caching mechanisms can suffer from issues such as network congestion and reliability, which can degrade the user experience. The proposed system for on-path caching alternatives in ICNs in the context of blockchain offers a potential solution to these issues by leveraging the security and decentralization benefits of blockchain technology. By using blockchain to ensure the integrity and authenticity of cached content, and smart contracts to automate the caching process and incentivize caching nodes, the proposed system has the potential to improve the efficiency and reliability of on-path caching in ICNs. While further research and implementation are necessary to evaluate the effectiveness of this proposed system, it offers a promising avenue for improving on-path caching in ICNs. As ICNs continue to gain popularity and become a more prevalent part of the internet infrastructure, efficient and reliable on-path caching mechanisms will be essential for ensuring a high-quality user experience. The proposed system represents a step in that direction.

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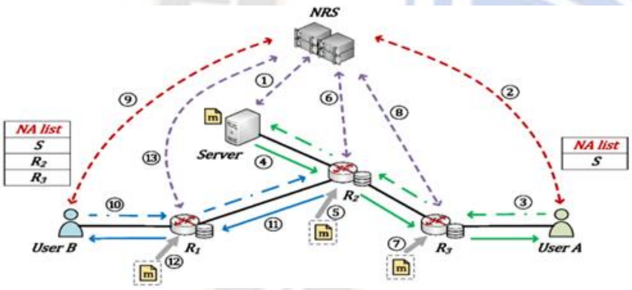

Figure 1: System Architecture

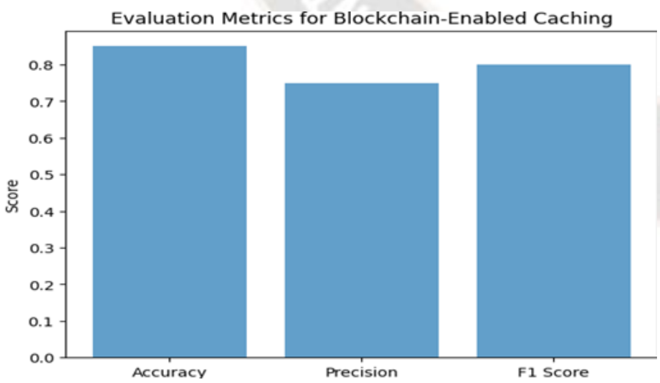

Figure 2: Evaluation Metrics

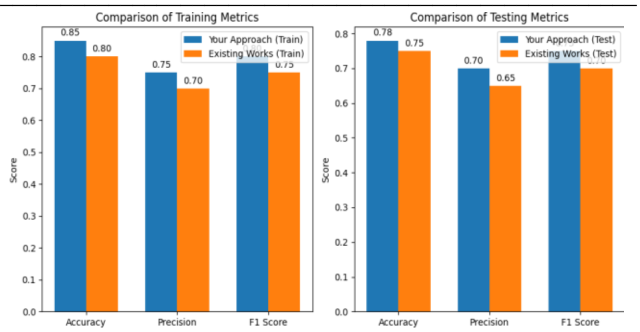

Figure 3: Comparison of Training & Testing Methods

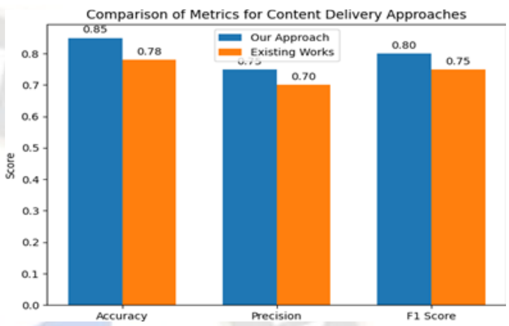

Figure 4: Comparison Metrics for Delivery Approaches.