Edge Computing Integration for Low-Latency Cache-Based V2V Broadcasting Systems in Urban Environments

Dylan Stilinki and Hubert Klaus

April 20, 2024

Edge Computing Integration for Low-Latency Cache-Based V2V Broadcasting Systems in Urban Environments

Date: 2 Febuary 2024

Authors:

Dylan Stilinski

Bachelor of Science

Department of Computer Science

Uiniversity of Northern Iowa

Hubert Klaus

Bachelor of Science

Department of Computer Science and Engineering

Ladoke Akintola University of Technology

Abstract:

In urban environments, the demand for low-latency and high-reliability communication systems is paramount for ensuring efficient traffic management and enhancing safety. This abstract explores the integration of edge computing with cache-based Vehicle-to-Vehicle (V2V) broadcasting systems as a solution to address latency challenges and optimize communication in urban settings.

The abstract begins by highlighting the inherent latency issues faced by traditional cache-based V2V broadcasting systems, particularly in densely populated urban areas with high vehicular density and network congestion. It underscores the critical importance of reducing latency to facilitate real-time communication and timely dissemination of critical information among vehicles.

Next, the abstract introduces edge computing as a complementary technology that brings computational resources closer to the network edge, minimizing communication delays and improving responsiveness. By deploying edge computing nodes at strategic locations within the urban infrastructure, cache-based V2V broadcasting systems can offload computation-intensive tasks, such as content caching and dissemination, to the network edge.

The abstract discusses how the integration of edge computing enhances the performance of cache-based V2V broadcasting systems by reducing latency and improving scalability. Edge computing enables localized caching and processing of V2V communication tasks, leading to faster response times and more efficient utilization of network resources.

Furthermore, the abstract explores the potential applications and benefits of edge computing integration for cache-based V2V broadcasting in urban environments. It discusses scenarios such as real-time traffic updates, dynamic route optimization, and emergency response coordination, highlighting the transformative impact of low-latency communication on traffic safety and efficiency.

By proposing the integration of edge computing with cache-based V2V broadcasting systems in urban environments, this abstract contributes to the advancement of communication technologies, offering insights into scalable and low-latency solutions for optimizing traffic management and enhancing safety in densely populated areas.
Keywords: Edge Computing, Cache-Based V2V Broadcasting, Low-Latency Communication, Urban Environments, Traffic Management, Real-Time Communication, Network Congestion, Computational Offloading, Edge Computing Nodes, Responsive Communication, Scalability
Content Caching, Dissemination, Traffic Updates, Route Optimization, Emergency Response Coordination, Traffic Safety, Efficiency

I. Introduction

In recent years, there has been a significant rise in the adoption of vehicle-to-vehicle (V2V) communication. V2V communication refers to the exchange of information between vehicles, enabling them to share data and collaborate in real-time. This technology holds great promise for improving road safety, optimizing traffic management, and enhancing entertainment services for passengers.

However, urban environments pose unique challenges for V2V communication, particularly when it comes to content delivery. Two major challenges in urban areas are traffic congestion and network latency. Urban road networks often experience heavy traffic, resulting in increased congestion and limited available bandwidth for communication between vehicles. This congestion can lead to delays in content delivery, making it difficult to achieve real-time interactions and services.

To address these challenges, researchers and engineers have been exploring innovative approaches such as cache-based V2V broadcasting. Cache-based V2V broadcasting leverages the concept of caching, where frequently accessed data or content is stored in nearby caches for quick and efficient retrieval. In the context of V2V communication, this means that vehicles can store and share popular or relevant content in their onboard caches, allowing other vehicles in the vicinity to access the content directly from the caches instead of relying on distant cloud servers.

Cache-based V2V broadcasting offers several benefits for low-latency content delivery in urban environments. Firstly, it reduces dependence on the cloud and minimizes the need for continuous communication with the cloud servers. By relying on nearby caches, vehicles can retrieve content more quickly and efficiently, resulting in reduced latency. This is especially crucial in scenarios where real-time information, such as traffic updates or emergency alerts, needs to be disseminated rapidly among vehicles.

Secondly, cache-based V2V broadcasting can alleviate the strain on the network infrastructure in urban areas. By leveraging local caches, vehicles can offload the content delivery burden from the congested network, leading to improved bandwidth availability for other critical communication needs. This approach enables vehicles to leverage the existing infrastructure more effectively and ensures reliable content delivery even in high-density network environments.

While traditional V2V communication has often relied on a cloud-centric architecture, it has certain limitations in urban environments. Cloud-centric approaches require constant communication with remote cloud servers, which can introduce significant latency due to the round-trip time for data transmission. Moreover, in scenarios with limited network connectivity or high network congestion, reliance on the cloud can lead to service disruptions or delays in content delivery.

To overcome these limitations, there is a growing need for the integration of edge computing in V2V communication. Edge computing brings computational capabilities closer to the network edge, allowing vehicles to perform data processing, caching, and content delivery tasks locally. By leveraging edge computing, vehicles can achieve faster response times, reduce reliance on distant cloud servers, and enhance the overall efficiency and reliability of V2V communication in urban environments.

In summary, the rise of V2V communication in urban environments has brought about specific challenges related to content delivery, including traffic congestion and network latency. Cache-based V2V broadcasting, coupled with edge computing integration, offers a promising solution to address these challenges by enabling low-latency content delivery, reducing dependence on the cloud, and optimizing network resources in urban V2V communication scenarios.

II. Background

A. Cache-Based V2V Broadcasting Systems

Cache-based V2V broadcasting systems are designed to optimize content delivery in V2V communication by leveraging caching mechanisms. These systems utilize the concept of caching, where frequently accessed content is stored closer to the users, enabling faster and more efficient content retrieval.

1. Definition and Core Principles:

Cache-based V2V broadcasting systems involve vehicles caching and sharing content among themselves, reducing the reliance on distant cloud servers. The core principles of these systems include:

a) Content Caching Strategies: Cache-based V2V broadcasting systems employ various content caching strategies to determine which content should be stored in the caches of vehicles. Two commonly used strategies are popularity-based and location-based caching.

i. Popularity-based Caching: In popularity-based caching, vehicles store popular content that is frequently requested by other vehicles. By caching popular content, vehicles can satisfy content requests more quickly and reduce the need for accessing the cloud.

ii. Location-based Caching: Location-based caching focuses on caching content that is relevant to the geographic location of vehicles. For example, vehicles may cache traffic updates, road condition information, or localized advertisements to provide timely and context-aware content to nearby vehicles.

b) Content Delivery Mechanisms: Cache-based V2V broadcasting systems employ various mechanisms to deliver content from the caches of vehicles to requesting vehicles. Two common content delivery mechanisms are:

i. Opportunistic Forwarding: Opportunistic forwarding leverages the intermittent connectivity between vehicles to opportunistically deliver content. When two vehicles come within communication range, content can be transferred directly from the cache of one vehicle to another, without relying on the cloud or traditional infrastructure.

ii. Relaying: Relaying involves using intermediate vehicles as relays to deliver content from the source vehicle's cache to the destination vehicle. This mechanism can be useful when the source and destination vehicles are not in direct communication range but can establish a connection through intermediate vehicles.

B. Urban V2V Communication Challenges

Urban environments present specific challenges for V2V communication, which can impact content delivery performance. Some of the key challenges include:

1. High Network Density and Congestion: Urban areas often experience high network density due to a large number of vehicles and other devices competing for limited wireless resources. This congestion can lead to increased packet loss, higher latency, and reduced available bandwidth, making content delivery more challenging.

2. Dynamic Network Topology due to Vehicle Mobility: Vehicles in urban areas are constantly moving, resulting in a dynamic network topology. This mobility

introduces frequent changes in the connectivity patterns between vehicles, making it difficult to maintain stable and reliable communication links for content delivery.

3. Limited Communication Range of Vehicles: The communication range of vehicles is typically limited, especially in urban environments where tall buildings and other structures can obstruct wireless signals. This limited range requires vehicles to be in close proximity to communicate directly, which can impact the availability and accessibility of cached content.

Addressing these challenges is crucial for efficient and reliable content delivery in urban V2V communication systems. Cache-based V2V broadcasting, with its caching strategies and content delivery mechanisms, offers promising solutions to mitigate the effects of high network density, dynamic topology, and limited communication range, enabling low-latency and efficient content delivery in urban environments.

III. Edge Computing Integration

A. Benefits of Edge Integration

Integrating edge computing into V2V broadcasting systems brings several benefits that address the challenges of content delivery in urban environments:

1. Reduced Content Delivery Latency: By leveraging geographically distributed edge resources, edge computing enables content caching and retrieval closer to the vehicles. This proximity significantly reduces the content delivery latency compared to relying on distant cloud servers. Vehicles can access the cached content quickly, resulting in improved response times and real-time interactions.

2. Improved Network Efficiency: Edge computing offloads content delivery traffic from the core network, reducing congestion and improving network efficiency. Instead of relying on backhaul connections to the cloud, vehicles can retrieve content from nearby edge nodes, minimizing the need for long-distance data transmission. This optimization helps alleviate network congestion and ensures reliable and efficient content delivery, even in dense urban areas.

3. Enhanced Scalability and Reliability: Edge computing provides a scalable and distributed infrastructure for V2V broadcasting. By deploying edge nodes in proximity to vehicles, the system can handle increasing demand and dynamically adapt to changes in network conditions. Additionally, edge nodes can store redundant copies of popular content, improving content availability and reliability. In case of network disruptions or failures, vehicles can still access cached content from nearby edge nodes, ensuring uninterrupted services.

B. Edge Network Architecture for V2V Broadcasting

The edge network architecture for V2V broadcasting involves the deployment of edge nodes with specific roles and functionalities. These edge nodes collaborate to facilitate efficient content caching, retrieval, and forwarding:

1. Caching Edge Nodes: Caching edge nodes are responsible for storing and managing cached content. They monitor content popularity, update cache contents based on caching strategies, and respond to content requests from vehicles. Caching edge nodes are strategically placed in close proximity to vehicles, ensuring quick and reliable access to cached content.

2. Content Retrieval Edge Nodes: Content retrieval edge nodes act as intermediaries between requesting vehicles and caching edge nodes. When a vehicle requests content, the content retrieval edge nodes locate the closest caching edge node that stores the requested content and facilitate its retrieval. They optimize the content delivery path and ensure efficient retrieval and distribution of content to requesting vehicles.

3. Forwarding Edge Nodes: Forwarding edge nodes play a critical role in facilitating content delivery in scenarios where the source and destination vehicles are not in direct communication range. These nodes act as relays, receiving content from the caching edge nodes or other forwarding nodes and forwarding it to the destination vehicles. They establish temporary communication links and coordinate the efficient transfer of content between vehicles.

Inter-edge communication and coordination mechanisms are essential for the seamless operation of the edge network architecture:

i. Edge nodes communicate and exchange information to optimize content delivery. They share cache status, availability of content, and network conditions to make informed decisions on content retrieval and forwarding.

ii. Coordination mechanisms, such as distributed algorithms or protocols, ensure proper coordination among edge nodes. These mechanisms enable efficient content routing, load balancing, and synchronization of cached content to maintain consistency and reliability within the edge network.

By integrating edge computing into V2V broadcasting systems, vehicles can leverage the geographically distributed edge resources, enabling low-latency content delivery, improved network efficiency, and enhanced scalability and reliability for V2V communication in urban environments.

IV. Cache Management Strategies for Edge-Enabled V2V Broadcasting

A. Content Popularity Analysis in Urban Environments

To effectively manage caches in edge-enabled V2V broadcasting systems, it is essential to analyze content popularity in urban environments. Understanding data access patterns and content trends helps optimize cache management strategies. Several factors influence content popularity in urban V2V communication:

1. Location: Content popularity can vary based on the geographic location. For example, in a congested downtown area, traffic updates and navigation information may be more popular, while in a residential neighborhood, localized advertisements or community announcements may be in higher demand. Analyzing location-based content popularity helps allocate caches accordingly.

2. Traffic Density: The density of traffic in different areas can impact content popularity. In areas with heavy traffic or traffic congestion, entertainment content, such as music or video streaming, may be more popular as drivers seek entertainment during their commutes. On the other hand, in areas with smoother traffic flow, real-time traffic updates or safety-related information may have higher demand.

3. Time of Day: Content popularity can also vary based on the time of day. For example, during rush hours, traffic updates and navigation assistance may be more popular, while during off-peak hours, entertainment or social media content may have higher demand. Analyzing temporal patterns helps optimize cache management strategies to ensure the availability of relevant content at the right time.

B. Cache Placement and Replacement Strategies in Edge Networks

Cache placement and replacement strategies play a crucial role in optimizing the performance of edge networks in V2V broadcasting systems. Key considerations include efficient cache allocation across edge nodes and dynamic cache management based on real-time data:

1. Cache Placement: Optimizing cache placement involves strategically allocating caches across edge nodes to ensure efficient content retrieval. This can be achieved by considering factors such as content popularity, vehicle density, and network load. Placing caches in close proximity to areas with high vehicle density or where popular content is likely to be accessed maximizes the chances of quick content delivery.

2. Cache Replacement: As content popularity changes over time, cache replacement strategies are employed to ensure that the most relevant and popular content is cached. Traditional cache replacement policies, such as Least Recently Used (LRU) or Least Frequently Used (LFU), can be extended to incorporate real-time data and adapt to dynamic urban environments. For example, a hybrid policy that combines popularity-based and recency-based metrics can be used to prioritize the caching of frequently accessed and recently requested content.

3. Edge Intelligence: Leveraging edge intelligence and real-time data analysis can enhance cache management strategies. Edge nodes can collect and analyze data on

content popularity, traffic patterns, and user preferences. Machine learning algorithms can be employed to predict content popularity based on historical data and current contextual factors. This enables dynamic cache management by proactively updating cache contents based on the predicted popularity of content, reducing cache misses, and improving overall content delivery efficiency.

By analyzing content popularity in urban environments and employing cache placement and replacement strategies in edge networks, V2V broadcasting systems can optimize cache utilization and ensure the availability of relevant and popular content. Leveraging edge intelligence and real-time data analysis further enhances cache management strategies, enabling dynamic adaptation to changing content demands in urban V2V communication scenarios.

V. Performance Evaluation and Optimization

A. Key Performance Indicators (KPIs) for V2V Broadcasting Systems

To evaluate and optimize the performance of V2V broadcasting systems, several key performance indicators (KPIs) are commonly considered:

1. Content Retrieval Latency: Content retrieval latency measures the time it takes for a vehicle to retrieve requested content. Lower latency indicates faster content delivery and better user experience. By analyzing the latency, system designers can identify bottlenecks and optimize caching, content retrieval, and forwarding mechanisms to reduce latency.

2. Hit Ratio: The hit ratio represents the ratio of content requests that are successfully served from the cache. A higher hit ratio implies efficient content caching and retrieval, reducing the reliance on backhaul connections and improving network efficiency. Monitoring the hit ratio helps assess the effectiveness of caching strategies and optimize cache placement and replacement policies.

3. Network Overhead: Network overhead refers to the additional communication load introduced by V2V broadcasting systems. It includes control messages, coordination overhead, and content dissemination traffic. Lower network overhead indicates more efficient resource utilization and reduced congestion. Optimizing content delivery mechanisms, such as opportunistic forwarding and relay selection, helps minimize network overhead.

4. System Scalability and Robustness: Evaluating system scalability involves assessing how well the V2V broadcasting system performs as the number of vehicles and content requests increase. A scalable system can handle growing demand without significant degradation in performance. Robustness refers to the system's ability to function reliably under various conditions, including high vehicle density, dynamic network topology, and intermittent connectivity.

B. Simulation and Real-World Testing

To evaluate and optimize the performance of V2V broadcasting systems, a combination of simulation and real-world testing approaches is often employed:

1. Simulation: Simulation allows for controlled and repeatable experiments. Mobility models, representing realistic vehicle movements, can be used to generate synthetic traffic scenarios. Simulators enable the evaluation of system performance under various conditions, such as different caching strategies, network densities, and content popularity distributions. Key performance metrics, including latency, hit ratio, and network overhead, can be measured and analyzed to identify areas for improvement.

2. Real-World Testing: Real-world testing involves deploying V2V broadcasting systems in live environments to assess their performance and effectiveness. Field trials enable the evaluation of system behavior under real-world conditions, capturing the complexities and dynamics of urban V2V communication. Real-world testing provides insights into the system's performance in terms of latency, hit ratio, and scalability, considering factors like actual vehicle mobility patterns, road conditions, and interference. It also allows for validating simulation results and uncovering potential issues that may not be captured in simulations.

By combining simulation and real-world testing, system designers can gain a comprehensive understanding of the performance of V2V broadcasting systems. Simulation provides a cost-effective and controlled environment for evaluating various design choices, while real-world testing ensures the system's effectiveness and reliability in practical scenarios. The findings from both approaches can guide optimization efforts to enhance the performance of V2V broadcasting systems in urban environments.

VI. Security and Privacy Considerations

A. Challenges in Secure Content Delivery

Secure content delivery in V2V broadcasting systems involves addressing several challenges to protect user privacy, ensure content integrity, and prevent malicious content dissemination:

1. Data Privacy Concerns: V2V communication collects and exchanges sensitive data, including user locations, driving patterns, and personal preferences. Protecting user privacy is crucial to prevent unauthorized tracking and misuse of personal information. Encryption techniques, anonymization methods, and access control mechanisms are employed to safeguard user privacy in V2V communication.

2. Content Integrity: Ensuring the integrity of content is essential to prevent unauthorized modifications or tampering. Without proper security measures, malicious actors may inject false or malicious content into the system, leading to misinformation or disruption. Techniques such as digital signatures, secure hash functions, and content authentication protocols are used to verify the authenticity and integrity of content.

B. Security Mechanisms for Edge-Enabled V2V Broadcasting

To address security and privacy concerns in edge-enabled V2V broadcasting systems, several security mechanisms can be employed:

1. Secure Content Caching: Secure content caching mechanisms protect the confidentiality and integrity of cached content. Encryption techniques, such as symmetric or asymmetric encryption, can be used to encrypt the content stored in the cache. Access control protocols ensure that only authorized vehicles can access the cached content, preventing unauthorized access or tampering.

2. Access Control Protocols: Access control protocols regulate access to the V2V broadcasting system and its resources. Authentication mechanisms, such as digital certificates or public key infrastructure (PKI), verify the identities of vehicles before granting access to the system. Authorization mechanisms enforce fine-grained access controls, allowing vehicles to access specific content or services based on their privileges.

3. Privacy-Preserving Communication Techniques: Privacy-preserving communication techniques protect user privacy during V2V communication. Techniques such as pseudonymization and anonymization ensure that user identities or sensitive information cannot be directly linked to their communications. Privacy-enhancing technologies, such as differential privacy or secure multi-party computation, can be employed to enable privacy-preserving data analysis while preserving the confidentiality of individual data.

Additionally, secure network protocols, secure software development practices, and intrusion detection systems can be implemented to protect against network attacks, software vulnerabilities, and unauthorized access.

By employing security mechanisms such as secure content caching, access control protocols, and privacy-preserving communication techniques, edge-enabled V2V broadcasting systems can mitigate security risks, protect user privacy, and ensure the integrity of content and communications. It is important to adopt a holistic approach to security and privacy, considering both technical measures and policy frameworks to create a secure and trusted V2V communication environment.

VII. Conclusion and Future Directions

In conclusion, the integration of edge computing in low-latency V2V broadcasting systems offers several advantages for urban environments:

1. Reduced Latency: Edge computing brings computing resources closer to the vehicles, minimizing the latency in content retrieval and delivery. By caching popular content at edge nodes, vehicles can access content with lower delay, enhancing the overall user experience.

2. Improved Network Efficiency: Caching content at edge nodes reduces the reliance on backhaul connections to centralized servers. This reduces network congestion and improves network efficiency, as content can be served from nearby edge caches instead of traversing the entire network.

3. Scalability and Flexibility: Edge computing enables scalable and flexible V2V broadcasting systems. Edge nodes can be dynamically deployed and scaled based on demand, accommodating varying vehicle densities and content popularity patterns. This scalability ensures efficient content delivery in dynamic urban environments.

4. Enhanced Reliability: With edge computing, V2V broadcasting systems become more resilient to network disruptions. Even in scenarios where connectivity to the backhaul network is lost, vehicles can still access locally cached content, ensuring uninterrupted content delivery.

As for future research directions, several areas hold promise for further advancements in low-latency V2V broadcasting:

1. Integration with Intelligent Transportation Systems (ITS): Integrating V2V broadcasting systems with ITS can enhance traffic management, safety, and efficiency. Future research can explore the synergies between V2V broadcasting and ITS, leveraging real-time traffic data, road infrastructure information, and intelligent decision-making algorithms to optimize content dissemination and enable intelligent transportation services.

2. Machine Learning for Content Prediction: Machine learning techniques can be employed to predict content popularity and user preferences in V2V broadcasting systems. By analyzing historical data, contextual factors, and user behavior, machine learning models can anticipate the content that will be in demand, allowing for proactive caching and efficient content delivery. Future research can focus on developing accurate and adaptive machine learning models for content prediction in dynamic urban environments.

3. Security and Privacy Enhancements: Further research is needed to strengthen security and privacy mechanisms in edge-enabled V2V broadcasting systems. This includes exploring advanced encryption techniques, privacy-preserving algorithms,

and anomaly detection methods to protect against emerging threats and ensure user privacy in V2V communication.

4. Energy Efficiency: Energy efficiency is a critical aspect of V2V broadcasting systems. Future research can investigate energy-efficient caching strategies, dynamic resource allocation, and power management techniques to optimize energy consumption in edge nodes and vehicles, extending the operational lifespan of battery-powered devices.

By addressing these research directions, we can unlock the full potential of edge computing integration in low-latency V2V broadcasting systems, enabling efficient and intelligent content delivery in urban environments while ensuring security, privacy, and sustainability.

References:

1) Li, Bing, Jian Xiong, Bo Liu, Lin Gui, Meikang Qiu, and Zhiping Shi. "Cache-Based Popular Services Pushing on High-Speed Train by Using Converged Broadcasting and Cellular Networks." IEEE Transactions on Broadcasting 65, no. 3 (September 2019): 577–88. https://doi.org/10.1109/tbc.2018.2863102.

2) YANDRAPALLI, VINAY, and LAMESSA GARBA DABALO. "CACHE BASED V TO V BROADCASTING THEORY TO OVERCOME THE LEVERAGES THE NETWORK IN METROPOLITAN CITIES."Journal of Jilin University (Engineering and Technology Edition) 42 (12-2023), 8.

3) Li, Chunlin, Mingyang Song, Shaofeng Du, Xiaohai Wang, Min Zhang, and Youlong Luo. "Adaptive Priority-Based Cache Replacement and Prediction-Based Cache Prefetching in Edge Computing Environment." Journal of Network and Computer Applications 165 (September 2020): 102715. https://doi.org/10.1016/j.jnca.2020.102715.

4) XIAO, Xiao. "Multi-Node Wireless Broadcasting Retransmission Scheme Based on Network Coding." Journal of Computer Applications 28, no. 4 (April 20, 2008): 849–52. https://doi.org/10.3724/sp.j.1087.2008.00849.

5) YIN, Yang, Zhen-Jun LIU, and Lu XU. "Cache System Based on Disk Media for Network Storage." Journal of Software 20, no. 10 (November 6, 2009): 2752–65. https://doi.org/10.3724/sp.j.1001.2009.03427.

6) Liang, Kai-Chun, and Hsiang-Fu Yu. "Adjustable Two-Tier Cache for IPTV Based on Segmented Streaming." International Journal of Digital Multimedia Broadcasting 2012 (2012): 1–8. https://doi.org/10.1155/2012/192314.

7) Cardoso, Rodrigo V., and Evert J. Meijers. "Secondary Yet Metropolitan? The Challenges of Metropolitan Integration for Second-Tier Cities." Planning Theory & Practice 18, no. 4 (October 2, 2017): 616–35. https://doi.org/10.1080/14649357.2017.1371789.

8) Sofman, L.B., and B. Krogfoss. "Analytical Model for Hierarchical Cache Optimization in IPTV Network." IEEE Transactions on Broadcasting 55, no. 1 (March 2009): 62–70. https://doi.org/10.1109/tbc.2008.2012018.

9) Ricordel, Pascal. "Economic Component Interactions between Projects in Urban Regeneration Plans: A Network Theory Framework for Plan Quality Evaluation Applied to Three French Metropolitan Cities in Normandy." Cities 120 (January 2022): 103465. https://doi.org/10.1016/j.cities.2021.103465.

10) Justo, Daniela S., Carlos R. Minussi, and Anna Diva P. Lotufo. "Behavioral Similarity of Residential Customers Using a Neural Network Based on Adaptive Resonance Theory." Sustainable Cities and Society 35 (November 2017): 483–93. https://doi.org/10.1016/j.scs.2017.08.029.

11) Qiu, Shuting, Qilin Fan, Xiuhua Li, Xu Zhang, Geyong Min, and Yongqiang Lyu. "OA-Cache: Oracle Approximation-Based Cache Replacement at the Network Edge." IEEE Transactions on Network and Service Management 20, no. 3 (September 2023): 3177–89. https://doi.org/10.1109/tnsm.2023.3239664