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Time Segmentation-Based Hybrid Caching in 5G-ICN Bearer Network

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Abstract: The fifth-generation communication technology (5G) and information-centric networks (ICNs) are acquiring more and more attention. Cache plays a significant part in the 5G-ICN architecture that the industry has suggested. 5G mobile terminals switch between different base stations quickly, creating a significant amount of traffic and a significant amount of network latency. This brings great challenges to 5G-ICN mobile cache. It appears urgent to improve the cache placement strategy. This paper suggests a hybrid caching strategy called time segmentation-based hybrid caching (TSBC) strategy, based on the 5G-ICN bearer network infrastructure. A base station's access frequency can change throughout the course of the day due to the "tidal phenomena" of mobile networks. To distinguish the access frequency, we split each day into periods of high and low liquidity. To maintain the diversity of cache copies during periods of high liquidity, we replace the path's least-used cache copy. We determine the cache value of each node in the path and make caching decisions during periods of low liquidity to make sure users can access the content they are most interested in quickly. The simulation results demonstrate that the proposed strategy has a positive impact on both latency and the cache hit ratio.

Keywords: 5G-ICN; mobility; hybrid caching; time segment

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1. Introduction

Up untill now, fifth-generation communication technology (5G) has been used by more than 200 operators in more than 58 countries to build commercial networks. In terms of speed, bandwidth, dependability, and delay, 5G networks outperform the 4th Generation mobile communication technology (4G). Future application requirements from users and sectors, including virtual reality, ultra-high definition video, smart manufacturing, and autonomous driving, can be met by it. The improvement of 5G terminals and the improvement of the industrial convergence application ecology are both results of the rapid growth of 5G networks. Vertical industry convergence applications are in high demand due to the rise in 5G enabled vertical industries, which in turn encourages the advancement and development of 5G network technology. The current 5G is driven by three key factors: support for new service categories; support for extremely high throughput; and support for high-density Internet of Things devices and services with very rigorous end-to-end requirements. Augmented Reality and Virtual Reality Panorama, new movies, the Internet of Things, and vertical sectors, are examples of novel scenarios that pose problems for 5G networks in terms of continuous low-latency service response and the efficient distribution of massive amounts of data.

The indicators of communication networks have undergone a significant change as we enter the 5G era. It is impossible to upgrade the wireless interface component alone to satisfy this need. The network faces new difficulties because the entire end-to-end network design, including the bearer network (BN), must be altered. The uncertainty of traffic and services is the first problem. We all know that the operator's current IP network uses the "best effort" and "nearest forwarding" mechanisms. The network's development has resulted in an enormous increase in network traffic. The variety of corporate and enterprise applications (APPs) will still be cloud-based in the future. Operators are unable to satisfy criteria for differentiated service networks and dynamic network configuration based on user needs. The second challenge is the difficulty of ensuring a user's experience. Higher network latency requirements are needed for autonomous driving, cloud virtual reality, telemedicine, and remote learning. As 5G empowers to business (2B) sectors, its remote control and drone services are improved. Due to the wide band-width, higher new demands will be made. The complexity of network operation and maintenance (O&M) is the third challenge. Operators' network O&M has huge problems in terms of network provisioning frequency, dependability, and service diversity, in the context of 5G, when network complexity grows by a factor of 10.

Information-centric networks (ICNs) have developed into one of the research themes of future network architecture as the result of the expansion of mass content and mobile users [1,2]. ICN is thus a potential network architecture for achieving 5G objectives. Intranet caching, which uses content naming as the foundation for supplying built-in caches to speed up content delivery, provides high-speed access and high network utilization as its key feature. The achievement and optimization of 5G goals benefit greatly from this. To address the requirement, the industry suggests a 5G-ICN network design [3]. ICN can be integrated into a BN or data network (DN) in a 5G-ICN network. The current ICN caching technique, which is based on 5G, is unable to handle the huge requests and low latency demands of numerous mobile users. The objective of this work is to improve the ICN cache strategy on this new architecture.

Tidal phenomena occur in mobile networks [4], and a base station's access frequency varies during the day. A single caching technique is insufficient to accommodate fluctuating user counts and mobile access. The time segmentation-based hybrid caching strategy (TSBC), described in this research, divides a day into two types of periods based on the mobility access frequency of users. It is used in the 5G-ICN BN. In TSBC, various time periods utilize various improved caching strategies. This strategy somewhat enhances user experience and network performance. The main contributions of this paper are as follows:

- This paper proposes a caching scheme of time segmentation in 5G-ICN BN. A time cycle is divided into two kinds of periods based on "tidal phenomenon". One is the high liquidity period and the other is the low liquidity period.
- Different caching strategies are used during different periods. We employ the name resolution system (NRS) to determine whether the content has been cached during the high liquidity period. The least hot copy on the path will be replaced by un-cached content. The variety of cached copies is ensured by this strategy. We calculate the cache value based on the popularity, freshness, and hop during the low liquidity period to determine which nodes will cache independently.
- We test the cache strategy's viability and performance by putting it to use in real network topologies. The results show that our caching strategy works better in various network topologies.

The rest of the paper is organized as follows. Section 2 reviews the relevant research on 5G-based ICN cache schemes. Section 3 introduces our proposed scheme TSBC. In Section 4, we carry out simulation experiments and analyze the results and performance of our scheme. Finally, we summarized the scheme and simulation results.

2. Related Work

2.1. 5G-ICN Network

ICN is an emerging paradigm in which data or content is assigned a name. Unlike IP-based networks, ICN networks retrieve data/content without knowing the physical location of the content provider. Several ICN architectures have been proposed, such as DONA [5], NDN [6], PURSUIT [7], and NetInf [8]. For research on the integration of ICN and 5G, in addition to the 5G-ICN architecture proposed in paper [1], paper [9] presents an extension of the 5G core (5GC) control and user planes to support protocol data unit (PDU) sessions from endpoints in ICN. The paper [10] proposes that the fusion of the ICN paradigm and MEC brings new opportunities and challenges for realizing the 5G vision and beyond the 5G system. The paper [11] proposes the great potential of ICN for 5G mobile edge computing (MEC), software-defined networking (SDN), and network function virtualization (NFV). Among other things, it summarizes content naming schemes and content caching schemes. The paper [12] points out that the current content caching strategy (CCS) in ICN is not suitable for the 5G-ICN architecture and proposes an improved optimization scheme.

In the 5G-ICN research, the Internet Research Task Force (IRTF) [3] pointed out the new data-centric architecture of the ICN network and its network capabilities, such as in-network caching and multicast. These capabilities are an effective solution to the needs of 5G. In this architecture, PDU coexists in the dual-stack mode of ICN and IP and is combined according to the ICN and IP protocol of PDU and network facilities. IRTF pointed out that the current network architecture can adopt different deployment implementations such as IPoIP, ICNoIP, IPoICN, and ICNoICN. Table 1 summarizes how these four deployments work and the pros and cons of each.

Table 1. 5G-ICN deployment method.

Deployment Method	Work Method	Advantage	Disadvantage
IPoIP	Existing traditional methods	Use the existing framework system	Uncertainty of business and traffic; difficult to guarantee user experience; more complicated network operation and maintenance
ICNoIP	The business system newly adopts the ICN method, which can inherit the existing infrastructure	Effectively improve performance in terms of bandwidth, delay, synchronization, and reliability; strong practicability	Different network connections need to be solved by specific gateways
IPoICN	The business system follows the existing IP protocol system and builds a new ICN infrastructure	High compatibility of business systems	High cost; weak practicability
ICNoICN	Both business systems and infrastructure are ICN protocol systems	High efficiency; completely solve the limitations of traditional IP networks	High cost; poor compatibility; weak practicability

Table 1 shows that the ICNoIP deployment method is the most suitable for the current principles of minimum cost and optimal effect. For improving the deployment method of ICNoIP, the ICN network that solves the 5G requirements can be sunk under the user plane function. [13,14] both try to use ICN-enabled forwarding equipment between the base station (gNB) and the core network, while [15,16] enable ICN and adopt device-to-device (D2D) communication in 5G. However, due to the limited resources of mobile devices, edge caching also needs to be considered to balance the load on mobile devices.

In the converged architecture proposed by IRTF above, the working group considered three possible 5G-ICN deployment scenarios, all of which were discussed with reference to the Long Term Evolution (LTE) architecture. The first is the coverage model. On the premise of retaining the basic IP settings, ICN serves as an upper-layer overlay service. The second integration model has an explicit control management plane, which acts as a relay of PDUs using 5G as the carrier from the UE to the gateway that carries the ICN. The advantage of this model is that it can use the signaling and control layer infrastructure of the original LTE, and the cache is distributed in the core infrastructure closer to the UE. The third flat model integrates 5G-ICN into the network and can accommodate control functions such as the mobile management entity (MME), home subscriber service (HSS), and policy and charging rule functions (PCRFs) by enabling ICN functions at the network layer. In the three scenarios, the communication packets between the DN and the external network use the connected ICN gateway (ICN-GW) for protocol conversion, as is it between the 5G-IP BN and the DN. In this way, even if the ICN network is not used in the external network, information communication can be carried out smoothly, as shown in Figure 1 [12]. Based on the flat model, this paper considers the user plane function (UPF) sinking scenario.

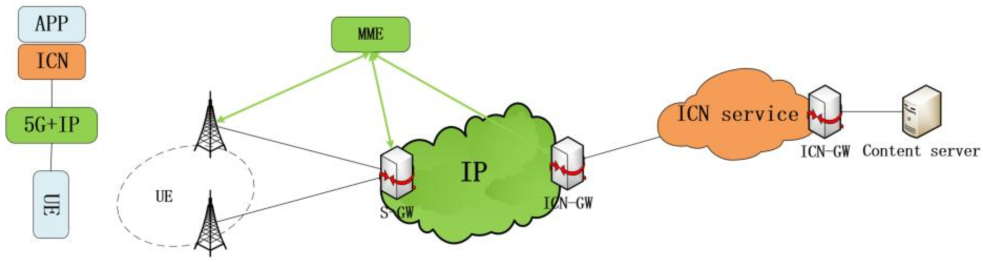

Figure 1. 5G-ICN network architecture.

2.2. 5G-ICN Cache Technology

Literature [11] divides content placement strategies into two main categories: (1) vertical management, which tends to choose the best content cache location to meet well-defined application scenarios; and (2) horizontal management, which tends to push popular content to the edge network to meet as many users as possible.

Vertical management can be divided into three categories: centralized, distributed, and collaborative. In the centralized caching scheme, the controller entity or the server is used as the necessary network element to determine the cache location. Classic centralized schemes include ProbCache [17] and Random [18]. In the past three years, there have been many excellent centralized schemes proposed, such as BEP [19] and PPCS [20]. BEP is an improvement on the traditional intermediary strategy. PPCS is a progressive popular aware caching scheme. Nodes use local factors and metrics to determine content caching, which improves network efficiency by reducing the exchange of information between nodes. Classic distributed cache placement strategies include LCE [21], LCD [22], EC [23], and betweenness [24]. In recent years, some distributed caching schemes have also been proposed, such as MAGIC [25], Greedy Cache [26], and SDC [27,28]. In the collaborative scheme, nodes in the communication path can establish cooperation and exchange information with each other to explore more functions and better use network resources. The classic caching mechanism is WAVE [29]. In recent years, collaborative caching technology has also been studied and developed, such as GAC [30], COD [31], and other strategies. GAC is a gain aware two round cooperative caching scheme, which reduces data redundancy in the network while enhancing content diversity. COD is a cooperative on-demand caching strategy. COD tends to reduce the number of nodes that cache content in the network.

In the strategy of horizontal managements, paper [32] proposes an edge cache architecture for 5g-icn networks, which aims to improve cache performance in global edge networks. The main idea is to achieve a compromise between the computing cost and cache revenue. Paper [33] proposed an intelligent caching heuristic algorithm to mine the central effect of consumer behavior to extract consumer content preferences in each slot. Paper [34] proposed a caching strategy based on user group interest preferences. Paper [35] proposed an analysis framework based on ICN edge caching scheme.

Besides, paper [36] points out that the existing caching strategy in CCN wired networks will not be able to meet the needs of mobile CCN network caching because it does not consider user mobility, so a caching strategy suitable for mobile CCN networks is proposed. The author uses a semi-Markov model to model user mobility, establishes a mathematical model between user mobility and content popularity, and uses a multiple linear regression model to predict the popularity of the next time for caching. Paper [16] proposes an ICN-enabled RAN architecture for 5G edge computing environments. The base station provides device-to-device communication and ICN application layer support. The author also sets thresholds based on content popularity and provides a content prefetching strategy based on ICN naming.

NRS plays an important role in ICN cache. NRS is mainly used to establish, maintain, and publish the mapping relationship between the information name and the address of the information or the information provider, and provide a fast name resolution function [37]. The Host Name and Identifier System (HNIS) [38] developed for 5G-ICN adopts an ID/LOC separation architecture. It is used for hostname and identifier mapping, which is suitable for 5G networks and emerging network architectures. HNIS designs a corresponding name registration and resolution mechanism, and realizes cross-domain mobile resolution through the dynamic binding of names to global location identifiers and local location identifiers. The ITU-T Recommendation Y. 3031 [39] standard document proposes a pass-through identifier mapping architecture suitable for future networks that can help build seamless services in heterogeneous networks.

3. Path Segmentation-Based Hybrid Caching

3.1. 5G-ICN Bearer Network

The ICNoIP mode is used by the 5G-ICN BN in Figure 2, and it makes use of the LTE framework's architecture and the ICN methodology for service systems. This approach is based on the integration of ICN architecture with 5G BN and collaborative service with DN, as opposed to the academic deployment of ICN on IP BN. Between the next-generation Node B (gNodeB) and UPF at the network's edge, the BN applies 5G-ICN network. It offers network features including in-network caching, boosts network performance 5G-ICN BN is closer to users than 5G-ICN DN. Cache and other services can be arranged on the 5G-ICN BN to improve user experience by significantly reducing access time and link load of the upper network, such as the DN.

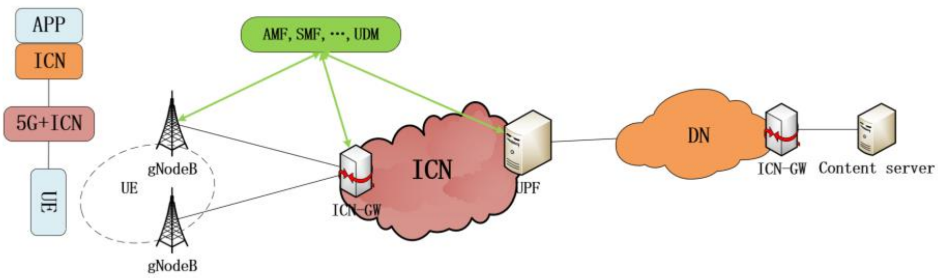

Figure 2. 5G-ICN BN architecture.

5GC includes access and mobile management functions (AMF), session management function (SMF), unified data management (UDM), UPF, and so on. Important functions including user management, uplink and downlink data notification, and UE mobility management notification are provided by 5GC to gNodeB and ICN-GW in the 5G-ICN BN architecture. ICN can handle and uphold mapping relationships between content identifiers and locators thanks to NRS. When a request for content is made again, NRS checks the cached content in the area and promptly replies with the results. Inherent support for name-based networks, network memory, edge computing, security, mobility, and other 5G capabilities is provided by the model.

3.2. Caching Idea Based on Time Segmentation

The main objective of mobile wireless networks is to ensure that users can still receive high-quality services in a high-speed mobile state. We are aware of the existence of tidal phenomena in mobile networks. For instance, roadside base stations experience an increase in network demands during morning and evening rush hours. This change in access frequency is periodic. Cycle T = 24 h. Mobile users are numerous and mobile speeds are high during peak hours. At other times, the situation is reversed. This gives us the concept of dividing a cycle into high liquidity periods and low liquidity periods.

With the combination of GIS technology, the base station can make intelligent traffic statistics in custom areas by user-requested messages [40], and the access frequency is reflected by time series. The base stations in a certain region have similar time series trends, thus, can be clustered together. We start by clustering base stations that have a cycle of consistent time series. The time series data set for the clustered area is then fitted as a single series. The result of the partition is communicated to the cache nodes of the BN in this region. Finally, we identify partition points of the fitted time series.

The TSBC scheme is based on path partitioning, and we use network packets to deliver messages to the ICN routers in the BN. In addition to normal request packets and data packets, we need to add several fields to the header of the packet to carry some special information like partition result. Next, we will introduce the four fields that need to be added in TSBC. The first field carries the division result message, and the other three are important fields used in the caching strategy of different time periods.

- The period identification field: After finding special points of final time series, we record it in the ICN-GW between the base station and the 5G-ICN BN. Each request packet transmitted by the base station into the BN passes through the ICN-GW, where the ICN-GW fills in the identification of the corresponding period in the field of the packet according to the time. Select different caching strategies by copying the same period identity in the packet that carries the content when the content hits.
- The min_heat and node_addr field: min_heat is used to store the minimum popularity value of the content of the return path. Popularity value is the number of content visits in nodes. The node_addr field is used to store the node address of the minimum popularity value. The min_heat is initialized to the lowest content popularity value in the next node of the node hit on the path.
- The hop_count field: record information about *Hop* in low liquidity period.
- The popularity and time_stamp field: record information about *Popularity* and *Freshness* in low liquidity period.

3.2.1. Base Station Clustering

Two neighboring base stations have similar user access time series due to their close location, so we use K-means clustering algorithm to regionalize the base stations. K-means clustering algorithm is an iterative solution clustering analysis algorithm. The step is to randomly select K objects as the initial clustering centers, then calculate the distance between each object and each seed clustering center, and assign each object to the nearest cluster center. Algorithm 1 details the process of base station clustering. *K_class* represents the number of clusters and Z is the base station location data collection. First, the cluster centers are randomly initialized. Next, cluster each node to the nearest center (step 2). Then, for each class j, recalculate the center of the class, $\mathrm{c}(i) = \arg\min_j \|Z_i - \mu_j\|^2$, of which $\mu_j = \sum_{i=1}^{N} l\{\mathrm{c}(i) = j\}Z_i \Big/ \sum_{i=1}^{N} l\{\mathrm{c}(i) = j\}Z_i$. Repeat step 2 until the cluster center no longer changes significantly. Set V is the final set of different class.

Algorithm 1: K-means clustering algorithm

Input: K_class, $Z = \{Z_1, Z_2, \ldots, Z_n\}$
Output: V
1: Random Initialization k_ Class Cluster Centers
2: calculation c(i)
3: **if** the cluster center does not change significantly **then**
4: go back to 2
5: **else**
6: get cluster set $V = \left\{V_1, V_2, \ldots V_j, \ldots V_{k\_class}\right\}$
7: **end if**
8: **return**

3.2.2. Time Series Fitting and Time Division

Select a V_i from the clustered set V, and the time series set T of all base stations in the area can be obtained. We select a cycle of 24 h based on "tidal phenomena". Time Series Collection of Base Stations: $T = \{X_1, X_2, \ldots, X_n\}$, and $X_i = \{f_{i,1}, f_{i,2}, \ldots, f_{i,m}\}$. Next, we fit n time series, and the final time series: $X_{n+1} = \sum_{i=1}^{n} \mu_i \times X_i$, $\mu_1 + \mu_2 + \ldots + \mu_m = 1$. In X_{n+1}, each data satisfies $f_{n+1,j} = \sum_{i=1}^{n} \mu_j \times f_{i,j}$. Based on the derivative definition, we use Formula (1) to find special points of final time series. After the segmented nodes are determined, the high and low liquidity periods are divided, and the segmentation is completed.

$$\frac{f_{i+1,1} - f_{i,1}}{\Delta t} \tag{1}$$

3.3. Caching in High Liquidity Period

The high moving speed and big number of mobile users, which produce a high frequency and variety of requests, are the distinguishing characteristics of the high liquidity period. Priority can be given to the diversity and richness of cached content in order to satisfy the needs of a wide variety of users. Paper [30] proposes a lightweight on-path cooperative caching strategy to ensure the diversity of content, called GAC. In GAC, caching decisions are divided into two phases. However, it does not consider scenarios of user mobility and the two rounds of caching decisions increase latency. We improved the GAC and applied it in high liquidity period.

We use only one path traversal to find the least hot cached copy and replace the current content with it. The user will receive messages once the information has been found in the network. The min_heat and node_addr of each node will be continually updated in the message on the return path. The cache node we choose is the node_addr in the message that was finally returned to the destination. By adding new fields to the message that is returned and capturing the node information there, the new approach increases traversal efficiency by 50%.

Algorithm 2 shows the specific method. The requested content is initially parsed in the current region, and when the parsing is successful, the user is immediately sent to the cached content. Otherwise, get the data from the source and initialize min_heat and node_addr field. On the returned path, minimum content popularity value of the current node will be compared with min_heat, the value of min_heat and node_addr will be constantly updated. After traversing all the nodes of the path once, content will be cached into the node that the node_addr field eventually records. Since ICN-GW and gNodeB do not participate cache in the 5G-ICN BN, we use request_node to represent the end of the path in step 8. It will analyze the received data packets and pass the content to the node recorded by node_addr. As shown in Figure 3, the node 3 with the lowest min_heat on the return path is selected as the cache point.

Algorithm 2: Cache strategy in high liquidity period

Input: Request package (Rpt)
Output: Operation Statement
1: cache_addr $\leftarrow$ $NameResolutionByNRS(Rpt.ID)$
2: **if** cache_addr $\neq \varnothing$ **then**
3: get_content (cache_addr)
4: **else**
5:     get Data package (Dpt) from source
6:     Dpt. min_heat = Source.heat
7:     Dpt. node_addr = Source.addr
8:     **if** next hop is request_node **then**
9:         cache_content (node_addr)
10:     **else**
11:         move to next hop
12:         **if** Dpt. min_heat > Current_Node.min_heat **then**
13:             Dpt. min_heat = Current_Node.heat
14:             Dpt. node_addr = Current_Node.addr
15:         **else**
16:         go back to 8
17:         **end if**
18:     **end if**
19: **end if**
20: **return**

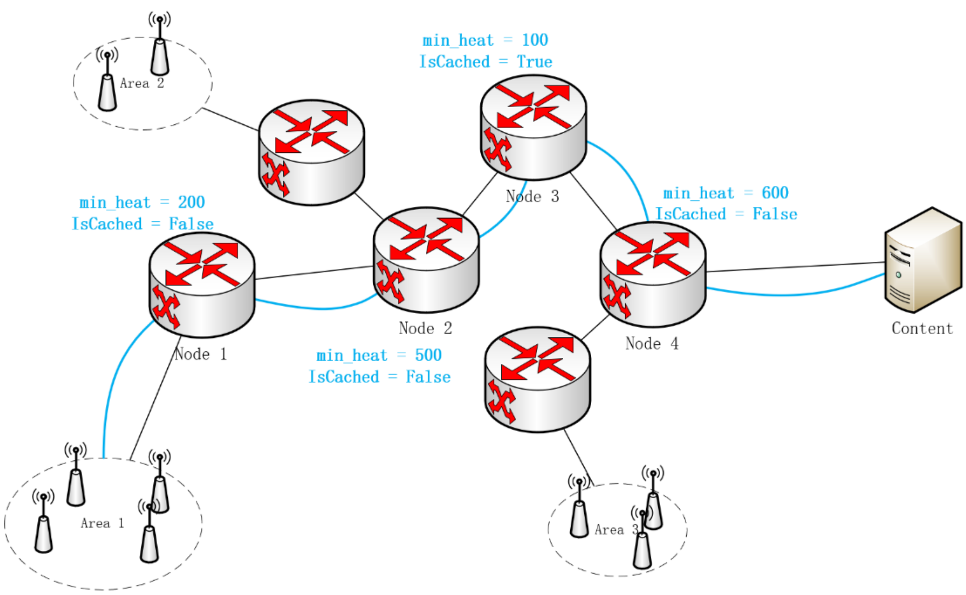

Figure 3. The process of selecting a cache node.

3.4. Caching in Low Liquidity Period

The slow movement speed and small number of mobile users, which cause low frequency, fewer types of requests, and stable user interest, are the distinguishing characteristics of the low liquidity period. Therefore, we concentrate on the acceptance and freshness of user-requested content. We will utilize these variables as inputs while calculating the cache value. Paper [41] proposes content freshness according to mobile characteristics and consider content popularity at the same time. It designs a new path-associated active caching scheme to shorten the time delay of users obtaining content. However, the strategy of selecting only one migration node proposed by [41] is not suitable for large-scale base stations.

The approach in Section 3.3 is no longer relevant. To make cache decisions, we opt to compute the node cache value. All nodes on the message return path whose cache values satisfy the specifications can cache by establishing a threshold. Still, all that is required for our algorithm to finish is one traversal round. We innovatively consider all nodes on the path in low liquidity period by adding a third parameter for calculating the cache value: the distance between the user and the node. Formula (2) shows the calculation of cache value. Due to the magnitude bias of different data, we use the minimum-maximum method to standardize the data [42], i.e., $N\ (x)$ function.

$$\text{Cache}_{value} = \ \omega_1 \times N(Hop) + \omega_2 \times N(Freshness) + \ \omega_3 \times N(Popularity) \tag{2}$$

The definition and initialization of the three parameters are as follows:

- Hop: because of the ICNoIP model, we can directly use the time-to-live field (TTL) to calculate the data transmission distance (hop). We initialize it as the hop between the hitting node and the ICN-GW, and record it by hop_count field mentioned in Section 3.2.
- Freshness: the freshness of the current packet is the timestamp when the content hits. On the return path, we first compare the timestamp in the packet with the earliest timestamp in the current cache node freshness list. The result of the operation is the final freshness of the content in that node. If the earliest timestamp of the freshness list does not exist in the node, the final freshness is set to zero. We record it by time_stamp field mentioned in Section 3.2, which is initialized to the time the hit occurred.
- Popularity: we define content popularity in a cache node as the number of content visits in that node. We initialize popularity to the popularity of that content on hit nodes, and record it by popularity field mentioned in Section 3.2.

Algorithm 3 shows the specific method, after the content is obtained from the data source, hop_count, popularity and time_stamp fields will be initialized. If the current cache value is higher than the threshold, nodes will cache on the return path. As shown in Figure 4, if the threshold is set to 1, then Nodes 1 and Node 2 with cache values higher than 1 on the return path are selected as cache points.

Algorithm 3: Cache strategy in low liquidity period

```
Input: Request package (Rpt)
Output: Operation Statement
1: get Data package (Dpt) from Hit_Node
2: Dpt.hop_count = getTTL (Rpt.Hit_Node, Rpt.Request_Node)
3: Dpt.Popularity = Hit_Node.Popularity
4: Dpt.time_stamp = time ()
5: if next hop is request_node then
6:     return
7: else
8:     move to next hop
9:     freshness = Calculate (Dpt.time_stamp, Current_Node. time_stamp)
10:     Cache_value = Calculate (Dpt.hop_count, Dpt.Popularity, freshness)
11:    if Cache_value > Current_Node.maxvalue then
12:        node.is_cache = True
13:    else
14:        node.is_cache = False
15:    end if
16:    go back to 5
17: end if
18: return
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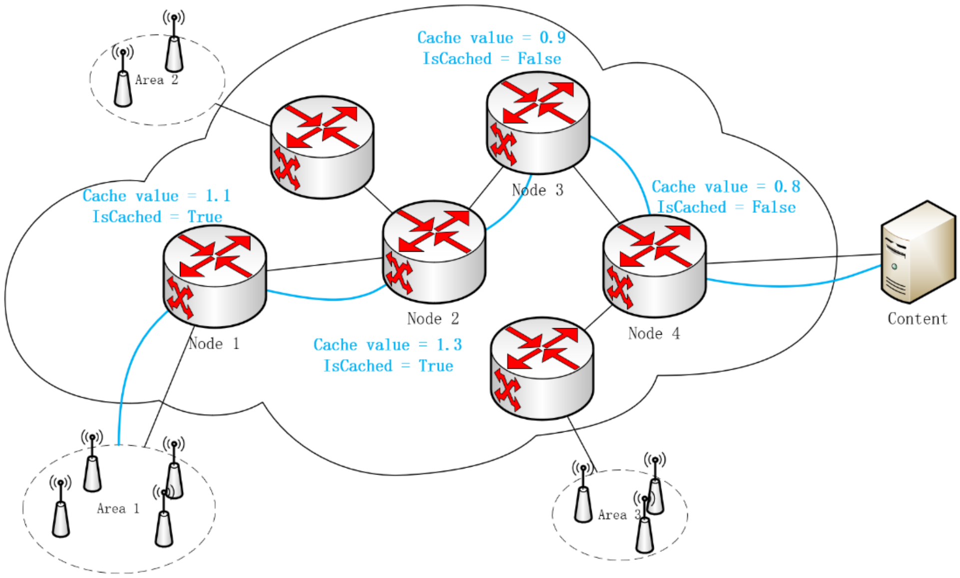


Figure 4. The process of determining whether a node is cached.

4. Simulation and Results

In this part, we will simulate the proposed TSBC. First, the setting of simulation environment is introduced, and then the simulation results are given. The results show the characteristics of our mechanism and its performance under different real network topologies.

4.1. Setting of Simulation Environment

For the cache strategy, we choose LCE, LCD, CL4M, and ProbCache, as the comparison cache placement strategy. Their specific introduction is as follows:

- Leave Copy Everywhere (LCE): LCE is a typical on-path cache. In this strategy, the content will be cached in all nodes it passes through. This caching strategy will cause a lot of redundancy of network content replicas, which will also lead to low network utilization. In addition, frequent content replacement also reduces ICN cache utilization [21].
- Leave Copy Down (LCD): the mechanism of this strategy is that when the content in the network hits, the replica will be copied down its path to the user. This will eventually place the content as close to the user's network edge as possible [22].
- Cache Less for More (CL4M): the strategy is triggered only once in the cache path, and the content is cached in the node with the largest mediation centrality [24].
- Probabilistic Caching (ProbCache): this strategy caches the contents in the cache path according to the probability. ProbCache attempts to reduce redundancy between network caches. That is, it aims to maximize the number of different content items cached along the delivery path [17].

We use Icarus as the simulation software [43]. Icarus is a Python-based ICN caching experiment simulator, licensed under the terms of the GNU GPLv2 license, which can be applied to various caching strategies and network topologies, and its object-oriented packaging supports flexible function and module expansion for experimenters. In addition, the Icarus simulator can support millions of warmups or requests in a short period of time.

To fully measure the performance of our architecture, we chose the following cache performance metrics: cache hit ratio and latency. We choose LFU as the cache replacement algorithm. Since the gNodeB caching capability and the user's own D2D communication mechanism are not considered, in the simulation topology, we regard the internal node with degree 1 as the base station. The simulation parameters are shown in Table 2. To simulate a real-world scenario, the number of contents is approximately 10 times the number of requests, depending on the actual situation. We set the number of network contents to 10^5, the number of test requests to 10^4 (here refers to the total number of requests from mobile users), and the number of system warm-up contents to 10^4 before the experiment starts. Setting a higher preheating value will help to obtain more stable results in subsequent experiments. We assume that users follow a Poisson distribution, and assume that user requests satisfy the Zipf popularity distribution. We set the ratio of the cache space to the total content size to be 0.04. We set the parameter skewness (α) of the Zipf popularity distribution to have a range of [0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2]. We set the user request rate in the low liquidity period to 10, and we set the range of user request rate in high liquidity period to [100, 200, 400, 600, 800, 1000]. Each simulation is carried out five times, and the result is the average of the five experiments.

Table 2. Experiment parameters.

Parameters	Value
Cache Replacement Policy	LFU
Number of contents	10^5
Requests number for system warm-up	10^4
Total mobile user requests	10^4
Ratio of the cache space to the total content size	0.04
User movement rate in high liquidity period	[100, 200, 400, 600, 800, 1000].
User movement rate in low liquidity period	10
skewness (α)	[0.6, 0.7, 0.8, 0.9, 1.0, 1.2]
Experiment run time for each scenario	5

In our experimental scenario, in order to verify the scalability of PSBC in different network topologies, we chose the following real network topologies: GEANT (European Academic Network) and WIDE (Japanese Academic Network). The topology is shown in Figure 5.

(**a**) GEANT (**b**) WIDE

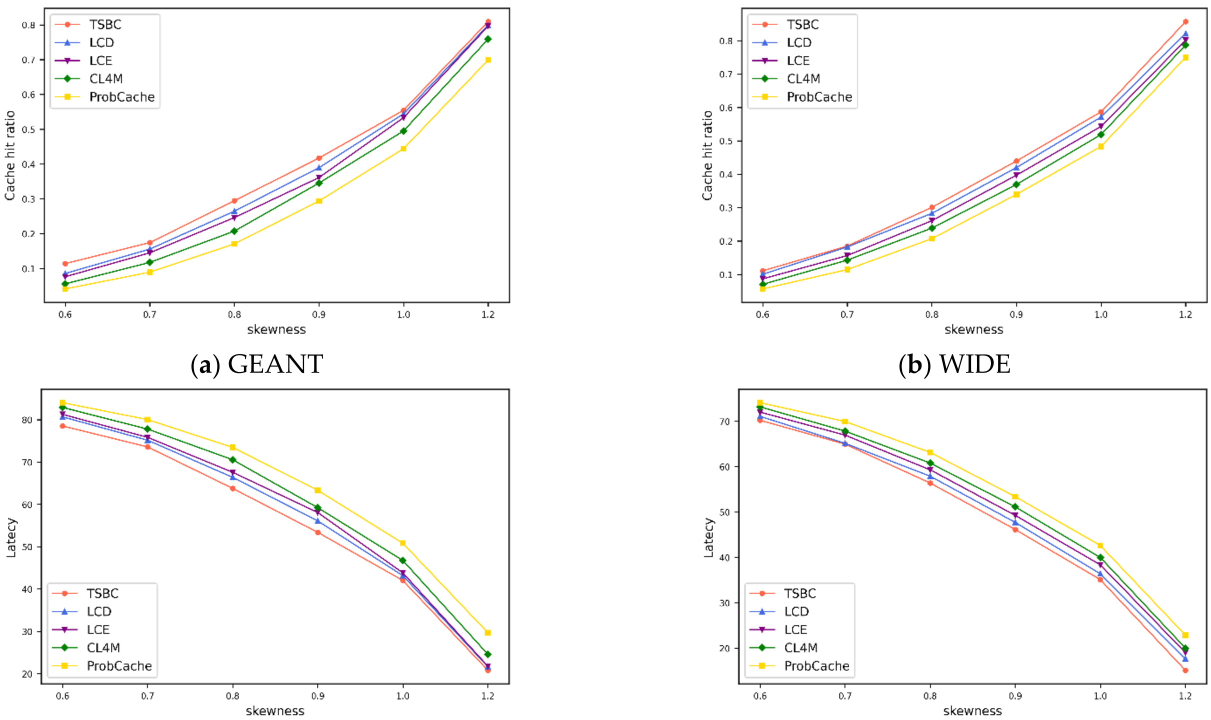
Figure 5. Simulation topologies.

4.2. Simulation Result

The quality of service (QoS) is very important in computer network research, which is mainly reflected in the latency. Latency is the average time for the recorded request content to finally reach the user terminal, and it is also one of the key performance indicators for evaluating a caching scheme. The total latency includes queuing latency, processing latency, and propagation latency. The queuing latency and processing latency are negligible compared to the propagation latency, so we only consider the propagation latency. Node cache hit ratio refers to the ratio of content requests cached by nodes to the total number of requests arriving at nodes. In this paper, we calculate the overall average cache hit ratio. Next, we will conduct comparative simulation from two aspects. The first is to fix the mobile rate of users in the high liquidity period, gradually increase the content popularity from 0.6 to 1.2, and observe the network performance of our scheme. The second is to set the content popularity to 0.8, gradually increase the user mobility rate in high circulation periods from 100 to 1000, and observe the stability of our caching scheme in terms of cache hit rate and latency in this process.

4.2.1. Impact of Skewness

We change the skewness (α) to observe the impact of the two network topologies on cache hit ratio and average latency. In this part of the experiment, the user movement rate is set to 400 in the high liquidity period. The results are shown in Figure 6. Greater skewness means that users have more requests for popular content. In both network topologies, ProbCache evaluates the remaining cache space and caches content request and return paths based on probability. In high liquidity period, users requesting content have the feature of frequent movement, which results in poor performance. CL4M triggers only once, so the contents of the cache are cached first at the node with the largest centrality, which not only results in uneven replica storage, but also in greater latency and lower hit rates. LCD and LCE show similar performance. In low liquidity period, users no longer switch 5G base stations frequently. Because LCD has the feature of keeping content as close to the edge of the network as possible, it should have a better advantage for users who are also on the edge of the network. However, in high liquidity period, active users will move to different base stations in a short period of time, and the latency of LCD will be affected. Our PSBC scheme clearly performs best. The results show that with the increasing skewness(α) of content, hits and latencies in all scenarios have been improved, but PSBC has maintained its lead: The average access latency of TSBC is lower than that of the other four cache strategies, and the hit ratio is higher than that of the other four cache strategies. This is because in dealing with the cross-transformation between high and low liquidity, we consider the movement rates of different users and divide the user traffic into periods. The diversity and richness of cache contents are given priority in the high liquidity period, which increases the content categories within the network and reduces the delay of content requests to the external network. Users need the popularity and freshness of content during low liquidity period, therefore the calculation of the cache value using the aforementioned parameters might increase the hit rate.



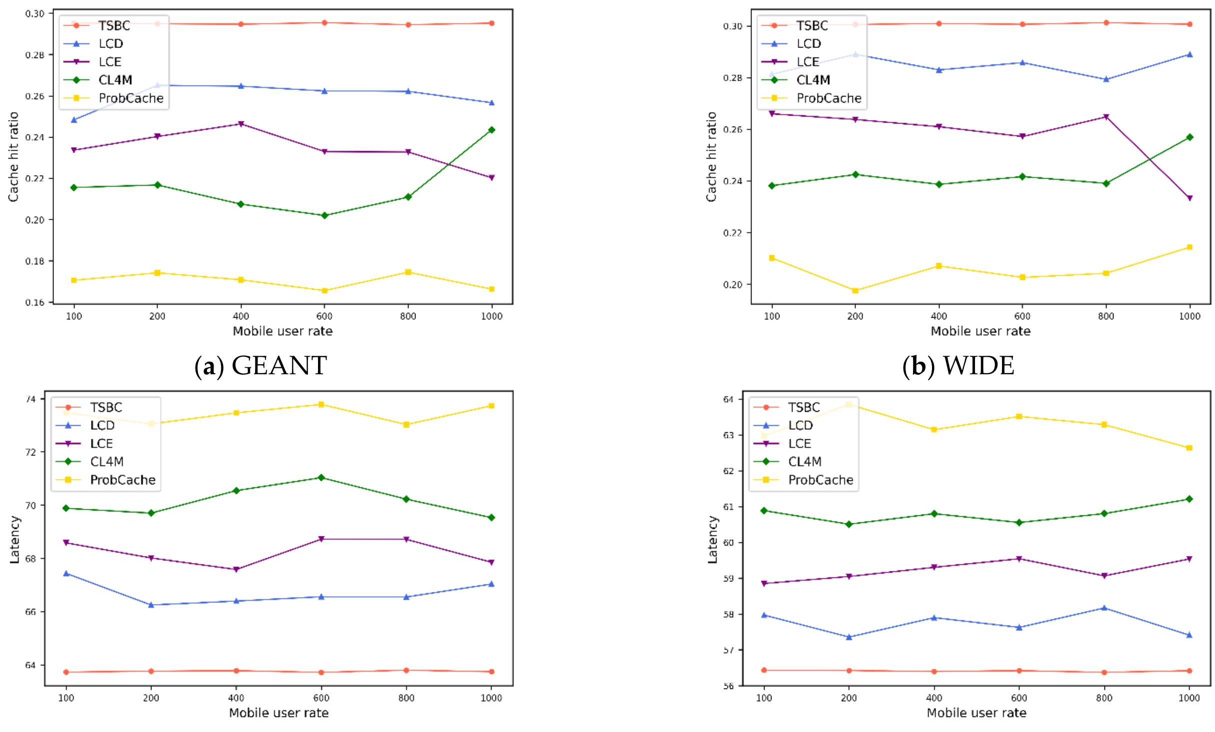
(**a**) GEANT (**b**) WIDE

(**c**) GEANT (**d**) WIDE

Figure 6. Cache performance with different skewness.

4.2.2. Impact of Mobile User Rate

We changed the user movement rate during the high liquidity period to see the impact of the two network topologies on cache hit rates and latencies. In this part, skewness (α) is 0.8. The result is shown in Figure 7. In both network topologies, we can see the poor performance of ProbCache, which has the lowest hit rate and the highest latency. ProbCache, CL4M, LCE, and LCD, fluctuate significantly in scenarios that change the speed of user movement. Especially for LCE, when the rate of movement reaches 1000 in high liquidity period, the hit ratio decreases significantly in both topologies. Therefore, in the 5G-ICN BN scenario, these four scenarios are unstable for mobile caching. On the one hand, TSBC has an advantage in performance. On the other hand, when the user movement rate increases and the frequency of users accessing the network through the base station increases, the TSBC still maintains a stable hit rate and delay. To sum up, our scheme is more adaptable to changes in user traffic. The idea of piecewise caching can be used to explain this: We are able to maintain steady network performance exactly because we use various strategies at various points in time.



(**a**) GEANT (**b**) WIDE

(**c**) GEANT (**d**) WIDE

Figure 7. Cache performance with different user movement rate.

5. Conclusions

In this paper, we propose a time-segmentation-based hybrid caching strategy based on the regional "tide phenomenon" of 5G mobile user access frequency. The strategy divides a time cycle into two distinct phases: a high liquidity period and a low liquidity period. We ensure the network's general speed, the variety and popularity of the cached content in the macro, and the timely availability to information for mobile users. The simulation findings demonstrate that, when compared to four various cache metrics, our TSBC strategy performs significantly better in terms of cache hit ratio and latency.

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References

1. Ahlgren, B.; Dannewitz, C.; Imbrenda, C.; Kutscher, D.; Ohlman, B. A survey of information-centric networking. *IEEE Commun. Mag.* **2012**, *50*, 26–36. [CrossRef]
2. Xylomenos, G.; Ververidis, N.C.; Siris, A.V.; Fotiou, N.; Tsilopoulos, C.; Vasilakos, X.; Katsaros, V.K.; Polyzos, C.G. A Survey of Information-Centric Networking Research. *IEEE Commun. Surv. Tutor.* **2014**, *16*, 1024–1049. [CrossRef]
3. Ravindran, R.; Chakraborti, A.; Amin, O.S.; Azgin, A.; Wang, G. 5G-ICN: Delivering ICN Services over 5G Using Network Slicing. *IEEE Commun. Mag.* **2017**, *55*, 101–107. [CrossRef]
4. Zhou, W.; Zhou, Z. An Optimized Idea for Tidal Effect of Mobile Network. *Commun. World* **2019**, *26*, 57–58. [CrossRef]
5. Koponen, T.; Chawla, M.; Chun, B.G.; Ermolinskiy, A.; Kim, K.H.; Shenker, S.; Stoica, I. A Data-Oriented (and beyond) Network Architecture. In Proceedings of the 2007 Conference on Applications, Technologies, Architectures, and Protocols for Computer Communications, Kyoto, Japan, 27–31 August 2007; Association for Computing Machinery: New York, NY, USA, 2007; pp. 181–192.
6. Zhang, L.; Estrin, D.; Burke, J.; Jacobson, V.; Thornton, J.D.; Smetters, D.K.; Zhang, B.; Tsudik, G.; Massey, D.; Papadopoulos, C.; et al. *Named Data Networking (NDN) Project*; Relatório Técnico NDN-0001; Xerox Palo Alto Research Center-PARC: Palo Alto, CA, USA, 2010.
7. Fotiou, N.; Nikander, P.; Trossen, D.; Polyzos, G.C. Developing information networking further: From PSIRP to PURSUIT. In Proceedings of the International Conference on Broadband Communications, Networks and Systems, Athens, Greece, 25–27 October 2010; pp. 1–13.
8. Dannewitz, C.; Kutscher, D.; Ohlman, B.; Farrell, S.; Ahlgren, B.; Karl, H. Network of Information (NetInf)—An informationcentric networking architecture. *Comput. Commun.* **2013**, *36*, 721–735. [CrossRef]
9. Ravindran, R.; Suthar, P.; Chakraborti, A.; Amin, O.S.; Azgin, A.; Wang, G. Deploying ICN in 3GPP's 5G NextGen Core Architecture. In Proceedings of the 2018 IEEE 5G World Forum (5GWF), Silicon Valley, CA, USA, 9–11 July 2018; pp. 26–32. [CrossRef]
10. Gür, G.; Porambage, P.; Liyanage, M. Convergence of ICN and MEC for 5G: Opportunities and Challenges. *IEEE Commun. Stand. Mag.* **2020**, *4*, 64–71. [CrossRef]
11. Serhane, O.; Yahyaoui, K.; Nour, B.; Moungla, H. A Survey of ICN Content Naming and In-Network Caching in 5G and Beyond Networks. *IEEE Internet Things J.* **2021**, *8*, 4081–4104. [CrossRef]
12. Yang, S.; Qiu, X.; Xie, H.; Guan, J.; Liu, Y.; Xu, C. GDSoC: Green dynamic self-optimizing content caching in ICN-based 5G network. *Trans. Emerg. Telecommun. Technol.* **2018**, *29*, e3221. [CrossRef]
13. Li, H.; Ota, K.; Dong, M. ECCN: Orchestration of Edge-Centric Computing and Content-Centric Networking in the 5G Radio Access Network. *IEEE Wirel. Commun.* **2018**, *25*, 88–93. [CrossRef]
14. Zhang, Z.; Lung, C.-H.; Lambadaris, I.; St-Hilaire, M. When 5G meets ICN: An ICN-based caching approach for mobile video in 5G networks. *Comput. Commun.* **2018**, *118*, 81–92. [CrossRef]
15. Liang, C.; Yu, F.R.; Zhang, X. Information-centric network function virtualization over 5g mobile wireless networks. *IEEE Netw.* **2015**, *29*, 68–74. [CrossRef]
16. Ullah, R.; Rehman, M.A.U.; Ali Naeem, M.; Kim, B.-S.; Mastorakis, S. ICN with edge for 5G: Exploiting in-network caching in ICN-based edge computing for 5G networks. *Future Gener. Comput. Syst.* **2020**, *111*, 159–174. [CrossRef]
17. Psaras, I.; Chai, W.K.; Pavlou, G. Probabilistic in-network caching for information-centric networks. In Proceedings of the Second Edition of the ICN Workshop on Information-Centric Networking, Helsinki, Finland, 17 August 2012; pp. 55–60.
18. Suksomboon, K.; Tarnoi, S.; Ji, Y.; Koibuchi, M. PopCache: Cache more or less based on content popularity for information-centric networking. In Proceedings of the 38th Annual IEEE Conference on Local Computer Networks, Sydney, Australia, 21–24 October 2013; pp. 236–243.
19. Zheng, Q.; Kan, Y.; Chen, J.; Wang, S.; Tian, H. A cache replication strategy based on betweenness and edge popularity in named data networking. In Proceedings of the ICC 2019–2019 IEEE International Conference on Communications (ICC), Shanghai, China, 20–24 May 2019; pp. 1–7.
20. Nguyen, Q.N.; Liu, J.; Pan, Z.; Benkacem, I.; Tsuda, T.; Taleb, T.; Shimamoto, S.; Sato, T. PPCS: A progressive popularity-aware caching scheme for edge-based cache redundancy avoidance in information-centric networks. *Sensors* **2019**, *19*, 694. [CrossRef] [PubMed]
21. Jacobson, V.; Smetters, D.K.; Thornton, J.D. Networking named content. In Proceedings of the 5th International Conference on Emerging Networking Experiments and Technologies, Rome, Italy, 1–4 December 2009; pp. 1–12.
22. Laoutaris, N.; Che, H.; Stavrakakis, I. The LCD interconnection of LRU caches and its analysis. *Perform. Eval.* **2006**, *63*, 609–634. [CrossRef]

23. Dabirmoghaddam, A.; Barijough, M.M.; Garcia-Luna-Aceves, J.J. Understanding optimal caching and opportunistic caching at "the edge" of information-centric networks. In Proceedings of the 1st ACM Conference on Information-Centric Networking, Paris, France, 24–26 September 2014; pp. 47–56.
24. Chai, W.K.; He, D.; Psaras, I. Cache "less for more" in information-centric networks (extended version). *Comput. Commun.* **2013**, *36*, 758–770. [CrossRef]
25. Ren, J.; Qi, W.; Westphal, C. Magic: A distributed max-gain in-network caching strategy in information-centric networks. In Proceedings of the 2014 IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS), Toronto, ON, Canada, 27 April–2 May 2014; pp. 470–475.
26. Banerjee, B.; Seetharam, A.; Tellambura, C. Greedy caching: A latency-aware caching strategy for information-centric networks. In Proceedings of the 2017 IFIP Networking Conference (IFIP Networking) and Workshops, Stockholm, Sweden, 12–16 June 2017; pp. 1–9.
27. Kamiyama, N.; Murata, M. Spatially-dispersed caching in information-centric networking. In Proceedings of the 2018 IEEE International Conference on Communications (ICC), Kansas City, MO, USA, 20–24 May 2018; pp. 1–7.
28. Kamiyama, N.; Murata, M. Dispersing content over networks in information-centric networking. *IEEE Trans. Netw. Serv. Manag.* **2019**, *16*, 521–534. [CrossRef]
29. Cho, K.; Lee, M.; Park, K. WAVE: Popularity-based and collaborative in-network caching for content-oriented networks. In Proceedings of the 2012 Proceedings IEEE INFOCOM Workshops, Orlando, FL, USA, 25–30 March 2012; pp. 316–321.
30. Zhi, J.; Li, J.; Wu, H. GAC: Gain-aware 2-round cooperative caching approach in information-centric networking. In Proceedings of the 2018 IEEE 37th International Performance Computing and Communications Conference (IPCCC), Orlando, FL, USA, 17–19 November 2018; pp. 1–8.
31. Liu, W.X.; Li, J.; Cai, J. COD: Caching on demand in information-centric networking. *Telecommun. Syst.* **2018**, *69*, 303–319. [CrossRef]
32. Zhang, K.; Leng, S.; He, Y. Cooperative content caching in 5G networks with mobile edge computing. *IEEE Wirel. Commun.* **2018**, *25*, 80–87. [CrossRef]
33. Zeng, Y.; Xie, J.; Jiang, H. Smart caching based on user behavior for mobile edge computing. *Inform. Sci.* **2019**, *503*, 444–468. [CrossRef]
34. Shan, S.; Feng, C.; Zhang, T. A user interest preferences based on-path caching strategy in named data networking. In Proceedings of the 2017 IEEE/CIC International Conference on Communications in China (ICCC), Qingdao, China, 22–24 October 2017; pp. 1–6.
35. Liu, Y.; Liu, A.; Xiong, N.N. Content propagation for content-centric networking systems from location-based social networks. *IEEE Trans.Syst. Man Cybern. Syst.* **2019**, *49*, 1946–1960. [CrossRef]
36. Han, J. Research on Network Cache Strategy of Mobile Content Center. Master's Thesis, Chongqing University of Posts and Telecommunications, Chongqing, China, 2018. [CrossRef]
37. Liao, Y.; Sheng, Y.; Wang, J. A Survey on the Name Resolution Technologies in Information Centric Networking. *J. Netw. New Media* **2020**, *9*, 1–9.
38. Kafle, V.P.; Otsuki, H.; Inoue, M. An ID/locator split architecture of future networks. In Proceedings of the 2009 ITU-T Kaleidoscope: Innovations for Digital Inclusions, Mar del Plata, Argentina, 31 August–1 September 2009; pp. 1–8.
39. ITU-T. *Recommendation ITU-T Y.3031 Identification Framework in Future Networks*; ITU-T: Geneva, Swizerland, 2012.
40. Wu, S.; Luo, J.; Zhou, Y.; Lin, J.; Shu, Z. Method of real-time traffic statistics using mobile network signaling. *Comput. Appl. Res.* **2014**, *31*, 776–779.
41. Zhou, T.; Sun, P.; Han, R. An Active Path-Associated Cache Scheme for Mobile Scenes. *Future Internet* **2022**, *14*, 33. [CrossRef]
42. Patro, S.; Sahu, K.K. Normalization: A preprocessing stage. *arXiv* **2015**, arXiv:1503.06462. [CrossRef]
43. Saino, L.; Psaras, I.; Pavlou, G. Icarus: A Caching Simulator for Information Centric Networking (ICN). In Proceedings of the SIMUTools '14: 7th International ICST Conference on Simulation Tools and Techniques, Lisbon, Portugal, 17–19 March 2014.