Time Slot Correlation-Based Caching Strategy for Information-Centric Satellite Networks

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Abstract. With the successful manufacture of highly stable and high-performance satellite processors, caching on satellites has become possible. Information Centric Networking (ICN) is introduced to satellite networks to address the growing need for diverse data services. However, existing caching policies in ICN still suffer from the shortage of rational planning of cache locations and redundancy of cache contents. Consequently, the time slot correlation-based caching strategy for satellite networks (TSCCS) is proposed. Firstly, the index of time slot correlation is designed to quantify the neighboring time slots' coupling relationship, and then the DSAM network model with time slot correlation is established. Secondly, the significance of satellite nodes is evaluated from the local and global perspectives respectively based on the eigenvector centrality algorithm to filter out the dynamic set of cache nodes. Finally, probabilistic caching is performed at the set of caching nodes with the goal of reducing cached content redundancy, considering content popularity and access delay. The simulated outcomes indicate that the TSCCS caching policy is superior to the comparison method in the areas of cache hit rate, request latency, and server load.

Keywords: ICN · Satellite Networks · Network Model · Cache Nodes · Caching Strategy

1 Introduction

The sixth generation mobile communication network (6G) further integrates satellite networks with terrestrial networks to extend the communication scenario to land, sea, air, and underwater areas to achieve seamless global coverage. To fulfill the requirements for

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R. Li et al. (Eds.): MOBILWARE 2022, LNICST 507, pp. 43–56, 2023.
https://doi.org/10.1007/978-3-031-34497-8_4

worldwide network accessibility for users in the 6G era, satellite networks have become one of the indispensable tools for providing wide area coverage [1]. Unlike ground-based telecommunication networks, satellite communication networks have the advantage of large communication range, independent of geography and climate, and high mobility, which are widely applied in many aspects such as weather forecasting, resource detection, navigation and positioning, environmental monitoring, and mobile communication. Although terrestrial communication networks are developing rapidly, they cannot provide good communication services in special environments such as oceans, deserts, and polar regions. Moreover, satellite networks provide continuous and effective communication connections in the above regions, as well as reliable connections in unexpected situations such as earthquakes, floods, and tsunamis when terrestrial communication facilities are destroyed. However, the periodic high-speed motion of satellite nodes, inter-satellite link interruptions and reconnections, and dynamic changes in network topology leave satellite networks in a non-stationary state, which leads to problems such as large propagation delays, intermittent connections, and inconsistent round-trip links during data transmission [2].

To solve the above serious problems, ICN architecture is introduced to satellite networks. ICN is a new information-centric network architecture that differs from traditional IP networks. By directly separating content from location, ICN employs content naming as a unique identifier for data transmission and provides a publish/subscribe model to retrieve content. In-network caching technology in ICN is proven to be a highly productive approach to enhancing content distribution capabilities in the areas of throughput, latency, and energy consumption [3]. With in-network caching technology, the proximity response of user requests reduces content acquisition delay for users and improves the quality of user experience. Moreover, distributed in-network caching reduces energy consumption for link transmission, conserves bandwidth resources, and reduces server load. Meanwhile, the cache nodes continuously work to provide content for users when the content providers are offline, which enhances the stability of satellite networks. However, existing ICN caching strategies are mostly designed for terrestrial networks, which cannot adapt to the characteristics of periodic dynamic changes in satellite networks, and there are problems such as a lack of reasonable planning of cache locations and redundancy of cached contents. Therefore, designing an effective caching policy is a meaningful attempt to boost the performance of satellite networks which is also one of the research focuses of ICN. The time slot correlation-based caching strategy for satellite networks is suggested. The main contributions are shown below.

- By defining the index of time slot correlation to quantify the adjacent time slots' coupling relationship, the satellite network is simplified into the DSAM network model by integrating inter-satellite link status in the current time slot and the evolution law between adjacent time slots.
- The cache node selection algorithm based on eigenvector centrality is suggested to assess the significance of satellite nodes from a local and global point of view, thus filtering out the nodes with high significance to form the dynamic set of cache nodes. By considering the content popularity and content access delay, the probabilistic caching scheme is devised to improve the caching probability of popular content on caching nodes.

- In the simulated scenario of the Iridium constellation, the caching performance of TSCCS is evaluated by varying the content request hotness and node caching capacity and observing the change in caching performance of each strategy. The results demonstrate that TSCCS applies to satellite networks and surpasses the comparison approach in the areas of cache hit rate, request delay, and server load.

The rest parts of this paper are structured as follows. Section 2 delineates the application of caching techniques in ICN for terrestrial and satellite networks. The description of the scenarios in this paper is given in Sect. 3. The implementation steps of the TSCCS are summarized in Sect. 4. Section 5 implements and evaluates TSCCS in a simulation environment. Section 6 summarizes this work in full.

2 Related Work

Caching strategies are one of the popular research topics in ICN, aiming to enhance cache utilization and decrease bandwidth consumption by rationalizing the use of cache resources in the network. Caching policies are categorized as on-path and off-path policies depending on where the cached content is stored on the backhaul route of the data. The data packets are backhauled and cached along the transmission route in on-path policies, ignoring other nodes outside the transmission route. The classic on-path policies in ICN include LCE [4], LCD [5], MCD [5], and Prob [6], etc. The on-path policies are easy to implement and are widely adopted in practical deployments. However, network nodes in the on-path strategy lack information of global network topology and cache state, and can only collaborate with nodes on the same path, which limits the caching performance. Meanwhile, all nodes with the same caching strategy allow duplicate placement of cached content on caching nodes, resulting in excessive redundancy of cached content [7]. The off-path caching strategies are not restricted by the transmission path between the user and the server and allow the content to be placed on any node in the network. Chai et al. present a policy (Betw) that is based on the BC measure and places data on nodes with large betweenness values for fast response to user requests [8]. Caching strategies such as BEP [9] and HCache [10] optimize the placement of cached content from the perspective of network topology and region division, respectively. The off-path strategies optimize the placement of cache contents and rationalize the utilization of cache resources by collecting state information of the network, such as node capacity, request distribution, and network bandwidth. However, when collecting network information, the off-path strategy invariably requires a large amount of additional overhead, resulting in a drain on network resources [11].

In-network caching technique in terrestrial networks has proven to be advantageous in improving network performance and enhancing network throughput. To enhance the capability of data transmission in satellite networks, scholars conduct meaningful research on caching schemes applied to satellite networks. To address the serious shortage of end-to-end routes in IST networks, Yang et al. suggest a network caching mechanism (TCSC) with time-evolving coverage sets for the effective distribution of files [12]. To address the management and efficiency problems arising from traditional network architectures, Li et al. suggest a novel satellite network architecture by merging the advantages of ICN and SDN, along with a cooperative caching scheme and an encoding caching scheme to improve the performance of content extraction [13]. Zhu et al. investigate a coordinated multi-layer edge caching policy in IST networks, where base stations, satellites, and gateways collaborate to serve content to terrestrial requesters, which in turn reduces the communication delay in the satellite-terrestrial link [14]. Ngo et al. propose a full-duplex transmission model supporting two layers of caching, deploying content caches to satellites and ground stations separately, thus reducing content transmission delay [15]. Existing caching strategies for satellite networks optimize caching performance in terms of cache content placement, edge caching, multi-layer caching, and collaborative caching to enhance content distribution efficiency and improve user service experience [16].

The existing caching strategies in topologically time-varying satellite networks face some unresolved problems. The selection of cache nodes lacks the consideration of node dynamics, which is not applicable to dynamically changing satellite networks and reduces the utilization of cache space. In addition, existing studies employ a single processing method for cache contents, resulting in redundant cache contents. Hence, the TSCCS caching policy is presented in this paper, in which the nodes with high importance are selected to form a dynamic set of cache nodes by estimating the significance of satellite nodes in a single time slot and from a global perspective, to achieve reasonable planning of cache content placement locations. On this basis, the probabilistic caching solution that is dependent on the content prevalence and access latency is designed to enrich the variety of cached content, while improving the caching probability of popular content on caching nodes and reducing the redundancy of cached content.

3 Scene Description

The satellite network model consists of the server, the satellite network, and subscriber terminals, as shown in Fig. 1. The inter-satellite link is the cornerstone for interconnection between satellite nodes, which in turn constitute the satellite network. The satellite network has a wide coverage area and provides data transmission services to terrestrial subscribers throughout the covered area. The satellite nodes in the ICN-based satellite network architecture all have content memories, and the content is stored and forwarded according to the caching strategy. The service process of the satellite network model is as follows. Firstly, the request from the terrestrial subscriber is delivered to the receiving satellite and the satellite's cache memory is searched to see if the requested content is stored. If it exists, the access satellite forwards the content to the terrestrial subscriber in the form of a data packet. Otherwise, the subscriber request is forwarded to additional satellites. Then, the cache space of other satellites in the satellite network is searched. If it exists, the requested content is routed via the inter-satellite link back to the terrestrial subscriber according to the original route. Otherwise, the subscriber request is transferred to the terrestrial server via the satellite-ground link. Finally, when the satellite network cannot satisfy the user's request, the ground-based server reacts to the subscriber's request and returns the data packet according to the original route.

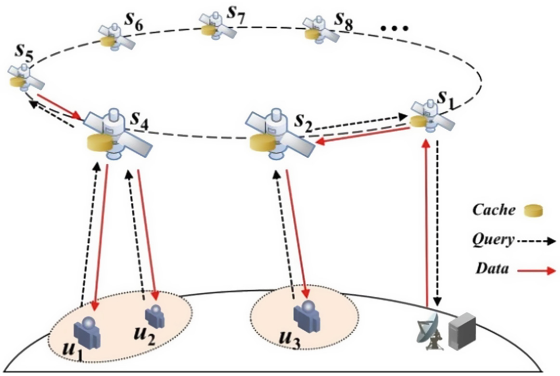


Fig. 1. System model illustration.

4 TSCCS Caching Strategy

Since caching resources are scarce in the information-centric satellite network, applying the default policy in ICN results in duplicate caching of the same content. Hence, this paper is devoted to improving the traditional caching strategy and suggests a caching policy that is predicated on time slot correlation. In this section, the DSAM network model is first detailed. The process of selecting the cache node corresponding to each time slot with the eigenvector centrality algorithm is then shown. Finally, the probabilistic caching scheme is introduced.

4.1 DSAM Network Model

The snapshot-based modeling approach in dynamic networks is a common treatment in many literatures, where a series of snapshots (time slices) are exploited to reflect the time-changing features of dynamic networks [17]. The snapshots are normally set as topology diagrams of the same duration, denoted as S_1, S_2,..., S_n. By analyzing the connection of the links between satellite nodes, it is found that the inter-star links are connected and disconnected with regularity. There is no inter-star link outage while the satellite network is in a steady state that lasts for 1 or more snapshots. Therefore, adjacent snapshots with the same topology are merged under the condition that the satellite network topology is stable. Thus, the time slot sequence is captured, denoted as P_1, P_2,..., P_T, and the duration of each time slot is noted as TS_i. Within the observed time (OT), a collection of time slots of different lengths captures the evolutionary features of the operating course of the satellite, and the inconsistency of time slots is shown by the difference in the weights. Furthermore, the weight matrix that corresponds to the time slot sequence is represented as the following equation.

$$W = [w_1, w_2, w_3, \cdots] = \left[\frac{TS_1}{OT}, \frac{TS_2}{OT}, \frac{TS_3}{OT}, \cdots\right] \tag{1}$$

Local correlation is one of the important indicators to gauge the adjacent time slots' coupling relations in dynamical networks, which mainly includes the following two measurements. The first approach reflects the local correlation of nodes from the perspective of their own neighbors in adjacent time slots, including CN [18] as well as CN-derived normalized indicators. The second is to quantify the local correlation of nodes by counting the shared neighbors of nodes in various time slots. Taking into account both research perspectives, the node correlations in adjacent time slots are derived as shown below.

$$C_j(t, t+1) = \frac{\sum_i a_{ij}(t) a_{ij}(t+1)}{\min\left[\sum_i a_{ij}(t), \sum_i a_{ij}(t+1)\right]} \tag{2}$$

where $C_j(t, t+1)$ denotes the node correlation of node j in the adjacent time slots P_t and P_{t+1}. $A_{ij}(t)$ represents the elements in the adjacency matrix of P_t. In time slot P_t, if a link exists between node i and node j, $a_{ij}(t) = 1$. Otherwise, $a_{ij}(t) = 0$. In both P_t and P_{t+1}, $a_{ij}(t) = 1$ and $a_{ij}(t+1) = 1$ if there are links between both node i and node j. In this case, $a_{ij}(t)a_{ij}(t+1) = 1$. Otherwise, $a_{ij}(t)a_{ij}(t+1) = 0$.

The variation of the adjacency relationship between nodes can be obtained by analyzing the node correlation of each node in the neighboring time slots. When the node correlation is large, it means that the majority of the satellite nodes are working online continually for a considerable period of time as well as there are stable inter-satellite links in the network. When the node correlation is small, it indicates that the proportion of satellite nodes and inter-star links that exist stably in the adjacent time slots is low, reflecting the high level of changes in network topology. On the basis of node correlation in adjacent time slots, the diagonal matrix is structured to indicate the time slot correlation, as shown in the following equation.

$$C^{(t,t+1)} = \begin{bmatrix} C_1(t,t+1) & 0 & \cdots & 0 & 0 \\ 0 & C_2(t,t+1) & \cdots & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \cdots & C_{N-1}(t,t+1) & 0 \\ 0 & 0 & \cdots & 0 & C_N(t,t+1) \end{bmatrix} \tag{3}$$

where $C^{(t,t+1)}$ denotes the time slot correlation of time slots P_t and P_{t+1}. $C_j(t,t+1)$ expresses the node correlation of node j in P_t and P_{t+1}. All elements outside the main diagonal are 0. N indicates the number of satellite nodes.

To completely portray the structure evolvement of the dynamic network and its dynamics process, the dynamic supra-adjacency matrix (DSAM) is introduced. Given that the layer-to-layer connectivity of different nodes should be different, the layer-to-layer connectivity between nodes is expressed with the node correlation in adjacent time slots, which ensures the difference between nodes. A dynamic network is picked as an instance of the DSAM network model as shown in Fig. 2. The connectivity among nodes inside a time slot is represented by a solid line in each time slot, and the connectivity of nodes in neighboring time slots is represented by a dashed line between time slots.

The DSAM network model accounts for the inter-layer and intra-layer relations of nodes and represents the impact of the network topology at the previous moment on the later moment with the ratio of time slot durations. In addition, the DSAM network

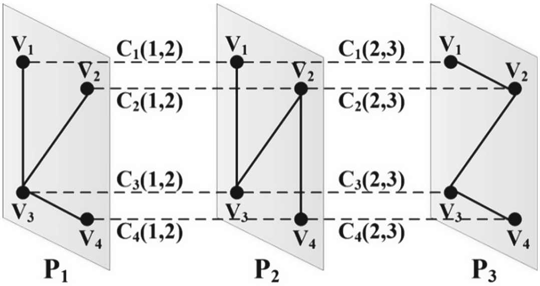


Fig. 2. Example of the DSAM network model.

model is specifically expressed as follows.

$$A=\begin{bmatrix} A^{(1)} & \frac{TS_1}{TS_2}C^{(1,2)} & 0 & \cdots \\ \frac{TS_1}{TS_2}C^{(1,2)} & A^{(2)} & \frac{TS_2}{TS_3}C^{(2,3)} & \cdots \\ 0 & \frac{TS_2}{TS_3}C^{(2,3)} & A^{(3)} & \cdots \\ \vdots & \vdots & \vdots & \ddots \end{bmatrix} \tag{4}$$

where A denotes the super-adjacency matrix based on DSAM. $A^{(1)}$, $A^{(2)}$,…, $A^{(n)}$ is represented by the corresponding adjacency matrix of each time slot. $C^{(i-1,i)}$ is indicated by a diagonal matrix composed of node correlations. TS_i shows the duration of the time slot i. The remainder of the elements in matrix A are indicated by 0.

4.2 Cache Node Selection Algorithm Based on Eigenvector Centrality

Due to the scarcity of on-board storage resources, selecting appropriate cache nodes becomes an important task to improve the cache performance and transmission performance in the network. So the cache node selection algorithm based on eigenvector centrality is suggested. In complex network theory, centrality algorithms usually evaluate the significance of nodes in a network, including DC, BC, CC, and EC. Among them, eigenvector centrality (EC) is a very effective evaluation indicator to quantify the significance of the test node by counting the significance of the neighborhood nodes that are directly linked to the test one.

$$EC(i) = \lambda^{-1}\sum_{j=1}^{N} a_{ij}e_j \tag{5}$$

where λ is the main eigenvalue of the neighboring matrix, and the feature vector is $e = [e_1, e_2, \cdots, e_n]^T$. A_{ij} denotes the connectivity between node i and node j. If a link exists between node i and j, then $a_{ij} = 1$, otherwise $a_{ij} = 0$.

The EC is exploited to find the principal eigenvector in the constructed super-neighborhood matrix A, noted as $v = \{v_1, v_2, v_3, \cdots, v_{NT}\}^T$. The EC value of each node in the time slot i is recorded as $\left\{v_{(i-1)\times N+1}, v_{(i-1)\times N+2}, v_{(i-1)\times N+3}, \cdots, v_{iN}\right\}^T$. The vector length of each time slot is N, and there exist a total of T different time slots.

Therefore, the term N × (t-1) + i in the vector v represents the significance of node i in the time slot t, resulting in an N × T matrix as follows.

$$Ws = \{ws_{it}|ws_{it} = v_{N\times(t-1)+i}\}_{N\times T} \tag{6}$$

The matrix Ws is a quantification of the local significance of the nodes. Depending on the duration of the time slots, the weight matrix W of the time slots has been computed in the previous section. Therefore, the global significance of the node, noted as We, is calculated with these two matrices.

$$We = \left\{we_i|we_i = \sum_{j=1}^{T} Ws(i,j) \times W(j)\right\} \tag{7}$$

In the information-centric satellite network, a restricted amount of cache nodes are chosen to hold content copies, which helps to boost the efficiency of the caching system and reduce user acquisition latency [8]. The selection of appropriate cache nodes requires a balance between important nodes with local characteristics and important nodes with global characteristics. In the time slot P_i, the nodes are ranked by the EC value from highest to lowest, and the top K important nodes with local characteristics are selected as cache nodes. At the same time, the significance values of nodes from the global viewpoint are sorted in descending order, and the top K important nodes with global characteristics are also selected as cache nodes. Finally, 2 × K nodes are acquired above to combine into a set of cache nodes.

4.3 Probabilistic Caching Scheme

Since the storage capacity of on-board routers is finite, the storage capacity of satellite nodes is bound to become saturated as the number of user requests increases and as time passes, which leads to the replacement of cache nodes. To lower the frequency of cache replacement, the content that has been requested by users a lot in the previous period and predicts the same popularity in the future period is screened in the network and placed on the router node. Therefore, the caching probability of content block c at satellite node p is obtained from the following equation.

$$\eta(c,p) = \frac{\rho(c)}{\max(\rho(i))} \times \frac{D_{p-S}}{D_{U-S}+1} \tag{8}$$

where $\eta(c,p)$ means the caching probability of content block c at satellite node p. $\rho(c)$ indicates the content prevalence of content block c in the current time slot, and $\max(\rho(i))$ means the maximum value of the content popularity of all content in the network. D_{U-S} means the number of hops between the user and server, and D_{p-S} means the number of hops between satellite nodes to the server. The equation takes into account content popularity and access delay to improve the caching probability of content that has a high prevalence at cache nodes while reducing the redundancy of cached content.

Content distribution is achieved through data packet and interest packet processing and forwarding in an ICN-based satellite network. The router takes on the task of forwarding both interest packets and data packets to maintain the three modules essential for network communication, which are content store (CS), pending interest table (PIT), and forwarding information base (FIB). CS stores the content copies and is the table that the user requests to view first. PIT logs the uplink request information, including the path and interface information of the interest packet route. FIB records the content name and the receiving port to provide routing information for subsequent requests.

There are two parts in this paper to completely describe the process of implementing the TSCCS caching policy.

1. In the time slot with stable topology, the interest packet is transported over the inter-satellite link and forwarded at the satellite node, where the number of hops forwarded is recorded in the new field (hop) of the interest packet. When the interest packet is accepted by the on-star router node, it searches in its CS for content that has the same name as the content. If a successful match is made, the data packet is passed back sequentially up the access port. Otherwise, the lookup continues in the PIT. If the interest packet and the PIT match successfully, the access port is added and the interest packet is discarded. Otherwise, add a new entry in the PIT and forward the interest packet to the next-hop satellite node as documented in the FIB.
2. The interest packets containing the requested information are forwarded across the satellite network. When the user request is matched with the cached content in the server or satellite node, the content asked is passed back the original way following the forwarding route of the packet of interest. The satellite nodes all have a forwarding function, while the satellite nodes in the set of caching nodes have not only a forwarding function but also caching function. Therefore, when a satellite node accepts a data packet, it initially determines if the node has caching capabilities. If the satellite node is the selected caching node and has remaining capacity in its storage space, it stores the contents contained in the data packet in the present node and forwards it to the following hop satellite. If the node is a cache node but has no extra capacity in the cache space, it replaces the stale content based on the LRU (last recently used) [7] replacement policy and forwards the data packet to the following hop satellite. If the node is not a cache node, the data packet is transmitted to the following hop satellite. The process is terminated by the reception of the requested content by the terrestrial subscriber.

5 Simulation and Evaluation

5.1 Simulation Setup

ndnSIM is an NDN emulation module equipped on NS-3, which enables various network functions under ICN architecture [12]. The performance of the TSCCS caching strategy is verified by comparing it with the caching strategies of LCE [10], LCD [11], Prob(0.5) [12], and Betw [17]. The LRU cache replacement strategy is adopted for all caching strategies to ensure the objectivity of the simulation experiments. The average cache hit rate, average request delay, and average server load are selected as the main performance indicators in this paper, and the variation of cache capacity is monitored by altering the Zipf parameter and node cache capacity. The simulated setting is built by following the information of the Iridium constellation, comprising six orbits with an altitude of 780 km and an inclination of 86.4°, totaling 66 satellites [19]. The whole experiment lasts 40 s, in which the first 10 s are treated as the pre-warming time, and the experimental data of the last 30 s are extracted for the subsequent experimental analysis. The simulation environment and experimental parameters are listed in Table 1.

Table 1. Simulation parameters.

Parameters	Default	Range of variation
Number of server nodes	1	-
Number of ground stations	22	-
Number of contents	1000	-
Data packet size/KB	1024	-
Request rate/(req/s)	200	-
Zipf distribution parameter α	1.0	0.7~1.3
Node cache capacity	30	15~45

5.2 Evaluation Indicators

The following evaluation indicators are selected to comprehensively estimate the caching capability of the TSCCS policy.

1. Average cache hit ratio (ACHR)

ACHR is the percentage of subscriber requests that hit the cache compared to the sum of subscriber requests, which is one of the major evaluation indicators of the effectiveness of a caching policy. If ACHR is higher, the greater the utility of the caching scheme.

2. Average request delay (ARD)

ARD is the mean duration of the process from the outgoing of interest packets to the receipt of data packets, which is one of the metrics to assess the user's satisfaction with the caching scheme. If ARD is smaller, the caching scheme is more efficient.

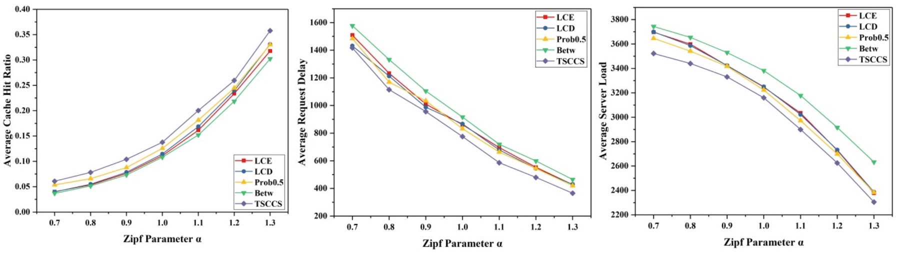
3. Average server load (ASL)

ASL is the average of the number of interest packets processed by the server per unit time in each time slot, which is a measure of the stress on the server. When ASL is too high, it causes insufficient server processing capacity and affects the stable operation of the network.

5.3 Simulation Results

5.3.1 Impact of Zipf Parameter

Figure 3 evaluates the effect of user request popularity on cache capability in three aspects of ACHR, ARD, and ASL, respectively.



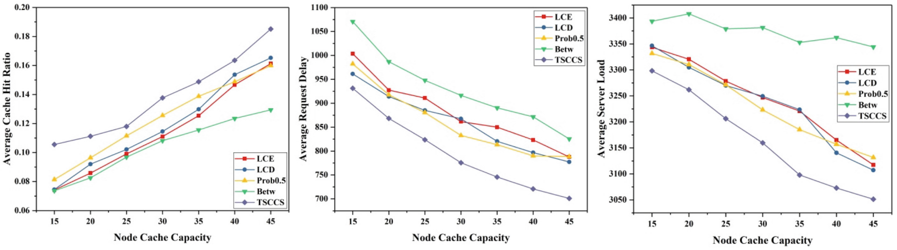
(a) (b) (c)

Fig. 3. Impact of Zipf parameter. (a) ACHR; (b) ARD; (c) ASL.

Figure 3(a) illustrates that ACHR of all policies has an increasing trend with growing Zipf parameter α. This is because user requests are more focused and cached content is more likely to fulfill user requests. Only a small amount of popular content needs to be cached to achieve a high hit rate. The TSCCS strategy outperforms other caching strategies by reasonably selecting caching nodes and improving the probability of caching popular content through the probabilistic caching scheme. Other caching strategies lack the ability to sense the hotness of the cached content, resulting in most of the cached content being non-hot content with low request rates and lower hit rates. Figure 3(b) illustrates that ARD of all policies gradually reduces as the Zipf parameter α grows. The reason is that the proportion of subscriber requests responded to at the routers is increased, which saves the transmission delay between the routers to the server and results in a more timely response to user requests. The TSCCS strategy employs the probabilistic caching scheme to promote diverse storage of cached content on cache nodes, avoiding cached data being substituted frequently and outperforming other caching strategies throughout the range. The LCE, LCD, and Prob policies have poor cached content diversity and are forwarded out of the domain when the content request does not hit the current domain, resulting in increased transmission delay. Figure 3(c) illustrates that ASL of all policies continues to decrease with the rising Zipf parameter α. This is owing to the increased proportion of cache nodes that respond to user requests, which reduces the server's burden of processing interest packets. The TSCCS strategy allocates popular content to cache nodes reasonably and enhances the diversity of cached content to improve the response ratio of content requests at cache nodes, which is superior to other policies in the caching effect. The on-path caching strategies do not distinguish between cached contents, resulting in part of the cache space being occupied by non-popular contents and an increased number of content requests responded to by the server. The Betw policy caches all the content at critical nodes, which increases the load on the server due to frequently replacing cached content on the cache nodes and the decrease in the proportion of content requests responded to.

5.3.2 Impact of Node Cache Capacity

Figure 4 assess the effect of node cache capacity on cache performance from the perspective of ACHR, ARD, and ASL, respectively.



(a) (b) (c)

Fig. 4. Impact of node cache capacity. (a) ACHR; (b) ARD; (c) ASL.

Figure 4(a) illustrates that ACHR of all policies rises as the node cache capacity rises. The main cause is that the number of cached contents rises as the cache capacity of the nodes rises, making the percentage of cache nodes hitting content requests increase. With the probabilistic caching scheme, the TSCCS strategy effectively increases the diversity of cached content, thus responding to more content requests and improving the cache hit ratio. Although the on-path strategies promote cached content to be constantly close to users, they generate a huge amount of duplicate cache in the transmission path, and the cached content is not sufficiently diverse to respond to only some of the requests. The Betw policy stores cached content at critical nodes, whose high replacement rate becomes a particular drawback, leading to frequently replacing cached content and overall performance degradation. As shown in Fig. 4(b), ARD of all policies gradually declines as the node cache capacity rises. The reason is that more content is cached in the caching system and more and more content requests are responded to at the cache nodes, which shortens the access path of user requests and reduces the access delay. The TSCCS strategy shortens the access path of content requests with time slot correlation to obtain the appropriate set of cache nodes and also stores different content copies differentially in the cache space through the probabilistic caching policy to improve the chance of popular content being cached near users and reduce the access delay. Although the Prob and LCD policies accelerate the move of cached content to the edge nodes, they ignore content popularity, making cached content replace frequently and reducing cache performance. The LCE policy caches everywhere, which results in excessive redundancy of cached content, and most content requests need to be responded to at the server. The Betw policy only stores content copies at critical nodes, which results in the content originally fetched at the cache nodes still being responded to by the server, raising the content access latency. ASL of all policies trends downward as the node cache capacity rises, as shown in Fig. 4(c). This is because the number of cached contents rises as the node cache capacity rises, which causes the probability of content requests being responded to at the cache node to rise and the number of requests responded to by the server to decline. It is clear that the TSCCS policy prevails over the other policies. This is because the TSCCS strategy takes into account both cache location and cache content, thus fully improving cache space utilization. The on-path strategies have better caching performance than the Betw policy. The Betw policy does not show significant performance improvement during the cache capacity increase.

6 Conclusion

To overcome the problems of lack of reasonable planning of cache locations and redundancy of cache contents in the existing caching strategies in ICN, the TSCCS policy is suggested. By constructing the DSAM network model, the time-varying features of the satellite networks are effectively depicted. With the goal of selecting appropriate cache nodes, the set of cache nodes is dynamically filtered out with the cache node selection algorithm based on the eigenvector centrality. Lastly, the differentiated probabilistic caching scheme is designed for content with different popularity to reduce cache redundancy and achieve reasonable placement of cached data. Simulated experiments illustrate that the TSCCS policy has advantages over the comparison scheme in the aspects of cache hit rate, request delay, and server load.

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