Research on Content Priority-based Caching Strategy in NDMANET

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Abstract—**Most research on NDMANET cache strategy does not take the priority of content into consideration, which will affect the usability of important content in the mobile environment. Aiming at solving this problem, this paper proposes a cache replacement strategy based on content priority. First, the content is prioritized according to the different needs for the availability of different content. Then, the priority of the content is used as a reference factor for cache replacement to make a cache replacement decision, and the goal is to improve the hit rate and availability of important content. At the same time, the simulation results of ndnSIM show that the strategy can significantly increase the number of cached important content without affecting the global hit rate and response delay, thereby improving the availability of important content.**

Keywords—Named Data Networking, Mobile Ad hoc Networks, cache replacement strategy, content priority, high availability

I. INTRODUCTION

With the rapid development of mobile Internet, the existing network system has become increasingly become a bottleneck in scalability, mobility and security. In order to adapt to the changing needs of the Internet, information-centric networking (ICN)[1], a new network architecture emerged. The named data networking (NDN)[2] is an ICN architecture, which has attracted wide attention. In NDN, users get the content by the content name, without caring where the content comes from. At the same time, the content will be cached along the way according to the cache policy.

Due to the advantages of NDN, the research on the application of the combination of NDN and mobile ad hoc network (MANET) is gradually carried out[3][4][5]. Traditional MANET is based on TCP / IP protocol, but the dynamic change of network topology caused by the movement of nodes and the continuity of links in MANET makes it difficult to establish a stable end-to-end link, which not only makes the network difficult to achieve efficient data transmission, but also hinders the practical application of MANET. Considering that most of the communication in MANET is "content-centered" information sharing, and it doesn't care which terminal the data is carried on or generated by, NDN is naturally suitable for MANET[6][7][8], which is more conducive to data transmission than adopting "host-centered" IP routing protocol.

The research of named data mobile ad hoc network (NDMANET) is just in its infancy, and many problems need to be solved. Among them, the caching strategy is a key technology in NDN[9][10][11]. Due to the mobility of nodes in MANET, the dynamic nature and the distributed characteristics of network, and the existing cache mechanism in NDN is not be suitable for NDMANET. Therefore, how to effectively ensure the availability of data, improve the hit rate of higher priority content, increase the response speed of requests, and reduce data redundancy under MANET with limited space resources and free movement of network nodes are the key problem in the research of NDMANET data caching mechanism. Considering the limited cache capacity of mobile nodes, unlike the wired environment, which can expand the larger cache capacity, the research on cache replacement strategy is particularly important.

At present, cache replacement strategies mainly include FIFO, LRU[12] and LFU[13]. Since most of these strategies are inherited from the existing network, many aspects are not considered. On the one hand, they do not consider the characteristics of the content itself, such as content priority, content access frequency, etc., on the other hand, in the MANET application scenario, when the important nodes move freely, the availability of the important content is caused when the important nodes are off the network. Therefore, they are not the most suitable for the new network architecture like NDMANET.

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In this paper, we start from the NDN network and propose a content priority cache replacement strategy based on the information conveyed by the content itself, such as content priority, content access frequency and other indicators. The purpose of our proposed scheme is to increase the cache hit rate of important content without affecting the average cache hit rate, thereby improving the availability of important content. The work of this paper are as follows:

- We propose a cache replacement strategy based on content priority.
- We add a new TLV field "priority" in the data packet and propose a decision function to replace the cached content.
- We perform simulations on the ndnSIM platform and compare the performance of the strategy in this paper with commonly used cache replacement algorithms.

II. RELATED WORK

The research of the cache mechanism includes cache placement strategy, cache replacement strategy and cache consistency maintenance strategy and so on. The cache replacement strategy is used to decide how to replace some old objects when the cache is full and new objects need to be cached, so as to make room for new objects. In NDMANET, the limited capacity makes the cache replacement strategy more challenging. NDMANET's cache research can be viewed from two aspects, one is MANET's cache research, and the other is NDN's cache research.

In the related research literature on MANET, many researchers have proposed various caching techniques. For example, Iyer et al.[14] proposed a cache software called SQUIRREL, which can be integrated into the nodes in the Internet to allow multiple nodes in the same area to share its cache. In [15], the author proposed three caching schemes: CachePath, CacheData and HybridCache. CachePath focuses on storing location and path information of data, and CacheData saves time by storing data instead of paths. The third solution HybridCache is a hybrid solution. However, these MANET caching strategies are based on TCP / IP networks, and they need to store the IP addresses corresponding to the content, which does not apply to NDN networks.

In the relevant literature of NDN, most of them use strategies such as LRU, FIFO, LFU, or Random as cache replacement strategies. To improve the performance of NDN, researchers have also designed many caching algorithms for NDN. In [16], the author provided an investigation on the caching mechanism in the information-centric networking (ICN). The author outlined different parameters, such as cache time, the content itself, its relevance, and lifetime in the cache. These parameters affect the performance of the cache in the ICN. Lal et al.[17] proposed an ICN cache replacement strategy. They regarded the popularity of content as an indicator of replacement. They also considered the global popularity in the network. However, this strategy does not apply to NDMANET: on the one hand, for NDMANET, the global content popularity is not realistic, and it will add more burden to CS management; on the other hand, this will increase the cache retrieval time. In [18], another kind of popularity-based cache replacement strategy was brought forward, called popularity-based fine-grained cache FGPC. FPGC uses only the frequency of requests to determine content replacement. In [19], the author proposed a cache replacement strategy with hierarchical popularity. They divided the content popularity into five levels. Each content belongs to a popularity level. When the cache is full, the least popular content in the cache will be replaced. However, this also leads to a problem. Some important content is not necessarily popular, simply using popularity to determine cache replacement is unfair for some specific content. Panigrahi et al.[20] proposed a general cache replacement strategy, that nodes can comprehensively determine replacement content through various indicators, including request frequency, node distance, and node reachability. However, the weighting coefficient of the content measurement system(CMS) proposed in this paper is determined according to the distance of the nodes from the center of the network, but for a decentralized network such as MANET, this is obviously not reasonable. Ostrovskaya et al.[21] added the node position to the cache replacement decision, but its decision function considered more factors, and the calculation complexity was higher, which would increase the computational cost of replacement and increase response time.

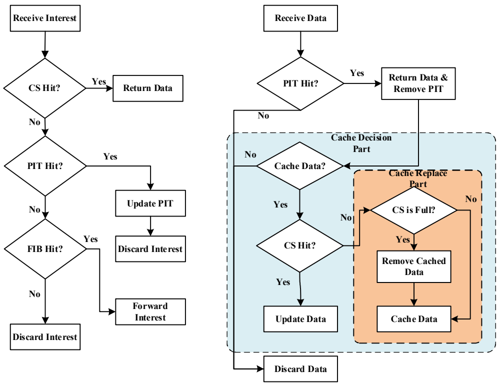
It can be seen from the existing literature survey that the study of MANET cache is based on IP networks and is not suitable for NDMANET networks. The cache replacement strategy for NDN is not suitable for NDMANET, they do not considered some of the characteristics of NDMANET, such as node mobility and decentralization of the network. Moreover, most caching strategies do not consider the priority of the content itself. Considering the frequency of content requests, this paper starts from the content priority and proposes a cache replacement strategy based on content priority.

III. SYSTEM MODEL

An effective cache replacement strategy improves cache hit rates and improves content distribution performance. However, on the one hand, the existing work does not cover the characteristics of NDMANET that are different from traditional NDN networks: (1) distributed control, no central node; (2) the free movement of nodes leads to changes in the network topology and the situation in which some nodes may "drop"; (3) the resources of the node are limited. On the other hand, the existing cache only involves the popularity of the content, ignoring the priority of the content itself, which can lead to a decrease in the availability of important content. Once the producers of important content leave the network, the request may not respond. In this section, we propose a cache replacement strategy based on content priority, and detail the ideas and algorithms for that replacement strategy.

A. NDN Caching Mechanism

The NDN's communication model is consumer-driven, and consumers send interest packets to request the appropriate data packets. After the node receives an interest package, if there is matching content in its content store (CS), the node returns the data package. If not, the node first goes back to query the pending interest table (PIT) to see if there are records. If there is no record, the interest package will be further forwarded based on the forwarding information base (FIB) in the network. After the packet is received, the node first checks whether the relevant request is in the PIT. If the request for the data is still pending, the data is further forwarded to the downstream in the network, otherwise, the data will be discarded. At the same time, nodes can store data in CS based on the appropriate caching decision scenario. If the CS reaches its maximum capacity, CS is replaced according to the cache replacement policy. The NDN's communication flowchart is specifically shown in Fig. 1.



(a) Interest Processing Flow **(b)** Data Processing Flow

Fig. 1. NDN communication flow chart

B. *Content Availability and Priority*

For NDMANET, the availability of content refers to whether the consumer can still be responded after some nodes failure in the network. In some actual NDMANET application scenarios, such as military operations, rescue operations, etc., nodes may frequently be disengaged from the network due to the complexity of the environment. If the node caches important content, it may result in the unavailability of the important content. Therefore, availability is not less important than hit rate, response delay, and other indicators for NDMANET.

The general way to guarantee availability is to keep copies of the content in multiple places, and for the NDN architecture, the caching capabilities with each node can solve this problem well. However, this is based on condition that the cache capacity is large enough. In mobile scene, a large cache means less mobility. Hence, high availability needs to be combined with cache replacement strategies.

We cannot to increase the usability of all content, the goal is to increase the availability of important content. We prioritize content based on the availability of the content that the node produces. That is, a content is important and requires high availability in the network, so its priority is correspondingly higher.

In our model, we prioritize content by adding a new TLV field "priority" in the packet, and the higher the value of the priority, so does the priority of the content.

C. *Cache Replacement Strategy*

Next, we analyze what parameters should be included in the decision function for cache substitution. First, based on the previous description, content priority must be considered; second, we expect that the global average hit rate to be of little impact after the content priority is introduced. Because the essence of NDN's cache is to improve network performance by providing a copy of the content for subsequent requests, including request response time, throughput, and network load. If the priority is the only concern, there is bound to be some impact on global performance, and some of the more popular content may be replaced because it is not marked as important. So we want to introduce the request frequency of them. The request frequency measures the number of times content is requested in the CS of the current node. The request frequency can reflect to some extent whether the content is popular. If it is, the content request frequency will be relatively high, and vice versa. Furthermore, considering the limitation of the mobile ad hoc network node cache capacity, the size of content should also be used as a measure. Based on the above analysis, we need to generate a computing module for each content k that reaches CS:

$$R(k) = P(k) \times \frac{c_f F(k)}{c_s S(k)} \tag{1}$$

Among them, $P(k)$ represents the priority of content k, $F(k)$ represents the request frequency of content k in the current CS, and $S(k)$ represents the size of content k. c_f is the $F(k)$ normalization coefficient, and c_s is the $S(k)$ normalization coefficient.

However, a closer look at the formula shows that $R(k)$ grows linearly with $F(k)$, that is, when there are many nodes requesting the same content k, $R(k)$ may become very large, but if no one requests content k for the next period of time, it will always be cached in the CS because there is no larger $R(j)$ to replace it. To solve this problem, we consider the content generation cycle into the replacement strategy, each time the new content arrives CS will detect whether the content in the cache is out of date, and if so, then delete the content, freeing the cache space.

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Algorithm:
while incoming data C(k) reach CS do
    if Cache hit for C(k) then
        Update R(k)
    else if CS has enough space for C(k)
        Cache the data C(k) in CS
    else if R(k) ≤ min {$R(j)$ , $j \in CS$}
        No replacement happens
    else
        Find $min_j\{R(j)\}$
        Replace data C(k) with C(j)
    end if
    Discard the data which out of time
end while
```

Fig. 2. Content priority based cache replacement strategy

The pseudo-code for a content priority-based cache replacement strategy is shown in Fig. 2. When a content k reaches the CS, we will first check whether the content is already in the cache, if it is, the value of $R(k)$ will be updated. Otherwise, the cache space will be detected, and if it is not full, the content will be cached. If the cache is full, we will calculate the $R(k)$ value, and compare it with the R value of other CS

content, then eliminate the content with the smallest R value. Finally, The expired content will be cleaned.

IV. SIMULATION EXPERIMENT

In this section, we will analyze the performance of the cache replacement strategy for content priority by simulation. At the same time, we also selected the more commonly used cache strategies LRU and FIFO as a control, and compared with the performance of the content priority cache strategy (PFC).

A. Experimental Environment

To evaluate our proposed caching strategy, we use the ndnSIM platform for simulation experiments. The experimental topology is a mesh topology of 50 nodes, each of which is both a content producer and a content consumer. For content producers, different producers have different priority tags for the content they produced. In order to facilitate analysis, we divide the content priority into important content and ordinary one, of which 10% are important, and the rest are ordinary, all content popularity is subject to the Zipf-mandelbrot distribution, and consumer node requests for content follow the Poisson distribution, with a request rate of 10 req/s. Also, to simulate the scenario of a mobile network, when the simulation is carried out to 5 minutes, we change the network topology by controlling link continuity between nodes. Additionally, the experimental settings are shown in Table 1.

B. Analysis of Results

The cache hit rate is the ratio of the number of requests hit when the request reaches the cache node to the sum number of requests that reach the cache node. Fig. 3 illustrates the relationship between cache hit rate and cache size under different cache replacement strategies, and we can see that as cache capacity increases, so does the number of copies of the content that can be cached, and the hit rate of the content.

Fig. 4 is a graph of the relationship between the hit rate of important content and the size of the cache. The hit rate of each strategy increases as the cache capacity increase, however, it is clear that the content priority caching strategy we have proposed significantly improves the cache hit rate for important content, especially when the cache capacity is small. This is because when the cache size is limited, the PFC chooses to prefer content to be higher priority, that is, to eliminate relatively unimportant content. As the size of the cache increases, more copies of content can be cached, but the content priority cache still has a higher cache hit rate for important content than LRU, k-LRU and FIFO.

TABLE I. EXPERIMENTAL PARAMETER SETTING

Parameters	***Value***
Content priority *P(k)*	{1,3}
Content size *S(k)*	1
Amount of content *N*	10,000
Node cache capacity *n*	50-300
Network bandwidth *B*	10Mbps

Fig. 5 shows how the proportion of important content cache changes with the size of the cache capacity. We can see that when the capacity is small, the cached content is more important and more requested. When the cache capacity increases, the proportion of important content caches begins to decrease. The percentage of the graph starts at 100% because the size of cache is small and the number of important content is greater than the cache capacity. Our strategy shows that the result is to cache all the important content and replace the unimportant one. The other three strategies, LRU, k-LRU and FIFO, have roughly the same percentage of important content caching, because they do not distinguish between important content and ordinary one.

Fig. 6 shows how the average response hop count changes with the cache capacity. We can see that, the cache reduces the average response hop for requests. While the cache capacity increases, the number of response hops decreases, allowing content requesters to get content faster. This is because as the user keeps requesting, the content of interest to the user is cached at a node close to the user, and the number of response hops decreases.

To test the performance of our proposed caching strategy in improving content availability, we also design a simple 10-node mini-topology. There are 2 nodes in the network that produce important content, and in the third minute of the simulation, we disconnect 0, 1, and 2 important nodes from the network, and then continue to calculate the content hit rate after 10s, which reflects the availability of content. The results are shown in Fig. 7, where 100%-topo indicates that neither node is disconnected, and 0%-topo means that both nodes are disconnected. From the figure, we can find that when no node is disconnected, the hit rate of the three cache strategies is similar, and with the disconnect of important nodes, the hit rate of content decreases, because after the content producer node is disconnected, the user needs to go to other potential content owners to request, the original route may not request the content, resulting in a decrease in hit rate. But the PFC algorithm is slow to decline because we prioritize the cache of important content, so we have more copies of important content in the network and are easier to hit.

V. CONCLUSION

This paper studies the NDMANET's cache replacement strategy, and proposes a cache replacement strategy based on content priority, which can improve the cache hit rate of important content without affecting the global average hit rate, thus enhancing the availability of important content and for the NDMANET network, it not only optimizes the performance of the network, including hit rate and response time, but also the availability of important content and the network's invulnerability.

For now, we simply prioritize the content. Future, we will prioritize it in a more precise way. The specific way is to determine the priority given by the producer through the gaming between producer nodes and some economic indicators. Therefore, we expect to be closer to actual production and living, to make our proposed strategy more reliable.

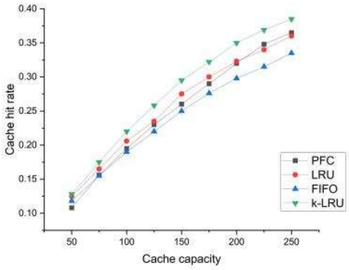

Fig. 3. Trends of average cache hit rate with cache capacity

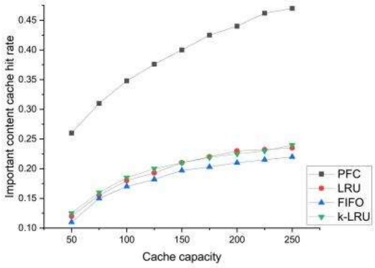

Fig. 4. Trends in cache hit rate with cache capacity

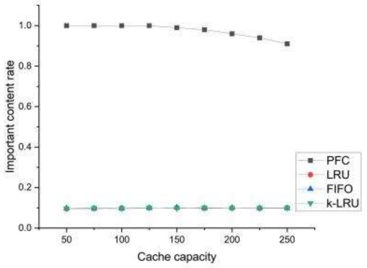

Fig. 5. Trends in the proportion of important content caches with cache capacity

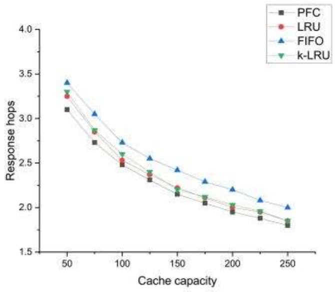

Fig. 6. Trends of average response hops with cache capacity

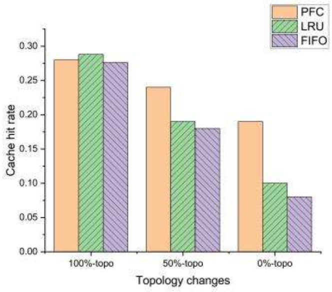

Fig. 7. Trend in cache hit rate with topology changes

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