Dynamic Zone-Balancing of Topology-Aware Peer-to-Peer Networks*

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Abstract. Building a topology-aware peer-to-peer overlay network can bring many advantages, such as providing locality-aware connectivity and reducing routing path length. While its benefits on performance have been recognized, an uneven overlay zone distribution has emerged. Recent work has shown that topology-aware neighbor selection during construction can aggravate the unbalance of zone distribution while it reduces routing path length. The imbalance in zone sizes may lead to performance decrease and an unfair load distribution.

In this paper, we present an even topology-aware peer-to-peer network based on De Bruijn Graph by developing a dynamic zone-balancing approach.

1 Introduction

The representive structured peer-to-peer networks [1] [2] possess $\Theta\ log(N)$ diameter and $\Theta\ log(N)$ degree at each node (where N is the number of peers in the system). Several peer-to-peer overlay networks based on de Bruijn graph which achieve a constant degree k and $\Theta\ log_k(N)$ diameter have been proposed [3] [4].

However each overlay hop is likely to involve different multiple physical routing hops. So a topology-aware structured peer-to-peer overlay network will significantly improve overall performance. To build an efficient routing overlay, two different methods based on network proximity have been suggested in the recent researches, one is proximity-based ID selection [5] [6] [7] [8], the other is proximity-based routing selection.

However smart node ID selection for building a topology-aware peer-to-peer overlay can lead to an unbalanced overlay structure, the imbalance in zone sizes(responsible key space). To describe the unbalance of overlay structure, we define N_k to be the number of the nodes which zone size are larger than k times of average zone size of the overlay network, and define F_k to be the ratio of the N_k to the total nodes number N in the overlay network.

$$F_k \leftarrow N_k/N \tag{1}$$

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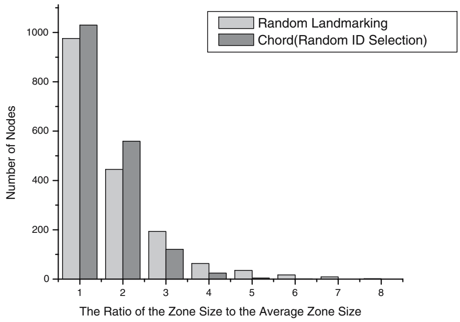

Fig. 1. Average overlay Peer zone size distribution in real-world data set(Random Landmarking [8] and Chord [2])

In the Fig 1 we illuminate the phenomenon of the unbalance overlay structure which results from a proximity-based ID selection in a Random Landmarking overlay network. There are the same total nodes number, say 1740, in both overlay networks of Fig 1. Figure 1 shows that N_2 in a Random Landmarking overlay network is 319, larger than 151 in Chord(Random ID Selection). Because the overlay uses proximity selection, some nodes in the system are more popular than others. But many performance metrics in a dynamic graph are determined by the balance of overlay ID distribution. The imbalance in zone sizes may cause increased diameter, smaller node degree, lower bisection width, and higher local congestion during routing through the graph.

In this paper, we design a new topology-aware peer-to-peer network based on de Bruijn Graph. And a novel dynamic zone balancing algorithm is proposed to handle the imbalance caused by proximity ID selection and dynamic peers join/leave.

2 Building a Topology-Aware Overlay

In the recent research it has shown that de Bruijn graphs possess both short routing distances and high fault tolerance. Several peer-to-peer overlay networks based on de Bruijn graphs have been suggested, such as koorde [4] and ODRI [3]. Our proposal based on foregoing de Bruijn graph peer-to-peer overlay.

Let 2^m be the maximum key in the system. Organize the keys space into a key circle modulo 2^m. Each existing peer holds a consecutive stretch of the key space, denoted by $[z_1, z_2]$, and $z_1, z_2 \in [0, 2^m - 1]$. Each key x in k degree de Bruijn graphs is a base-k integer H_x and its routing rules can be expressed as :

$$H_x \rightarrow (kH_x + i) \quad mod \quad 2^m, i = 0, 1, ..., k-1, \tag{2}$$

Because a shift left by one digit is equivalent to multiplication of H_x by k.

Suppose node x that owns zone $Z_x : [z_1, z_2]$,through de Bruijn equation 2, we get the corresponding the de Bruijn zone $Z_y : [y_1, y_2]$, y_1 equal to $k * z_1 \ mod \ 2^m$ and y_2 equal to $k * z_2 \ mod \ 2^m$. And node v owned zone is Z_v, There is an edge (x,v) if and only if $Z_v \cap Z_y \neq \Phi$ and v belong to the de Bruijn graph routing table R_x

Each node has a neighborhood set M which contains the nodes that are closest (according the Key space) to the local node. The neighborhood set can be used in routing messages and maintaining resilience properties. And the size L of the neighborhood set can be customized. The neighborhood set M will help the implementation of fault resilience.

2.1 Join Policy and Proximity Node Zone Selection

In this section we describe join policy for handling the zone balancing and routing locality with respect to the proximity metric in our proposed structured peer-to-peer network. The join policy will play an important rule in the topology-aware property. And there are two different locality to build a topology-aware peer-to-peer network, routing locality and neighbor locality. Our proposed join policy consider both of the routing locality and neighbor locality.

When a new node P_{new} arrives, the new node P_{new} needs to find the nearest optimal node P_o by exploiting the climbing-hill method. And we select a node P_n which is the nearest node among the de Bruijn graph routing table node P_o from the new node P_{new}. The consecutive stretch of node P_n we found in the last step will be split to two equal parts and the left part will assign to the new node P_{new}. The routing table R and neighborhood set M of the split node P_n will share with the new joined node P_{new},when the P_{new} join the peer-to-peer network all the related nodes need adjust their related information. For example, the node P_o need add the P_{new} to its routing table, and the neighborhood set M of the node P_n need be changed according to the new joined node P_{new}.

The join procedure is shown in pseudo code form in Algorithm 1.

Algorithm 1. The Join Policy

$P_n \Leftarrow 0$
$R_i \Leftarrow WellknowNodesSet$
$P_o \Leftarrow GetNearestNode(R_i)$
repeat
  if $P_n \neq 0$ **then**
    $P_o \Leftarrow P_n$
  end if
  $R_i \Leftarrow GetRoutingTable(P_o)$
  $P_n \Leftarrow GetNearestNode(R_i)$
until $Distance(P_o) > Distance(P_n)$
P_{new} insert left to the node P_n

3 Dynamic Zone Balancing

In distributed dynamic hash systems the imbalance in zone size has the consequences for increased diameter and higher congestion during routing through the graph. In a nutshell, uneven zone distribution results in hot-spots for object allocations and routing messages in certain parts of the graph. Proximity node zone selection and Proximity node ID selection may lead to unbalanced overlay structure.

3.1 Proximity Zone Selection and Zone Balance

In recent researches it has been shown that intelligent zone selection during construction can significantly improve the performance of peer-to-peer overlay network. But such intelligent zone selection can result in unbalanced overlay structure. Because some nodes will be more popular than others when the overlay is constructed exploited proximity zone selection scheme.

3.2 Dynamic Zone Balancing Algorithm

To resolve the performance problems brought on by intelligent zone selection, we proposed a novel dynamic zone balancing algorithm to balance the zone distribution in peer-to-peer overlay networks employing intelligent zone selection.

To make the zone distribution balance, several node join mechanisms have been proposed in the recent peer-to-peer researches, such as multi-point sampling methods. But the multi-point sampling methods [9] have no effect on the zone distribution balance in the zone selection mechanism based on proximity. We propose a novel dynamic zone balance in the algorithm 2 to solve this problem. The peers zone will be changed upon the zone size of peer and its neighbor when the algorithm 2 be invoked. Peers in this peer-to-peer system invoke algorithm 2 periodically. P:the current node.

P_{left}:the left neighbor of the P node.
P_{right}:the right neighbor of the P node.
$P.S$.the key stretch of the node P.
$P.S_{left}$:the left part of the stretch of the node P.
$P.S_{right}$:the right part of the stretch of the node P.
$P.R$:the de Bruijn graph routing table of the node P.
$P.R_{left}$:the left part of this routing table according $P.S_{left}$.
$P.R_{right}$:the right part of this routing table according $P.S_{right}$.

4 Peer-to-Peer Simulations

We simulated the dynamic zone-balancing system by exploiting p2psim [10] to examine the behavior and performance of this system. P2psim is a free, multi-threaded, discrete event simulator to evaluate, investigate, and explore peer-to-peer (p2p) protocols. We used the real-world data set in our simulations which

Algorithm 2. The simple dynamic zone balancing Policy

1: **if** $P.S \leq \frac{(P_{right}.S)}{2}$ **then**
2: $P.S \Leftarrow P.S \cup P_{right}.S_{left}$
3: $P_{right}.S \Leftarrow P_{right}.S_{right}$
4: $P.R \Leftarrow P.R \cup P_{right}.R_{left}$
5: $P_{right}.R \Leftarrow P_{right}.R_{right}$
6: **end if**

measured a distance matrix of RTTs among 1740 Internet DNS servers based on the King method [11]. The DNS servers were obtained from an Internet-scale Gnutella network trace.

We used the same network settings to evaluate the zone distribution. We compared 3 different approaches: Dynamic Zone-Balancing, Random Landmarking and Chord(Random ID Selection).

We compared the three approaches in the Fig 2. The total number of nodes is 1740 in the both overlay network of Fig 2. The number N_2 in Dynamic Zone-Balancing is 94 less than 319 in Random Landmarking and 151 in Chord (Random ID Selection). The ratio F_2 in Dynamic Zone Balancing is 0.054 less than 0.183 in Random Landmarking and 0.089 in Chord(Random ID Selection). As can be seen, Dynamic Zone Balancing in a proximity-based ID selection overlay which be proposed in this paper achieves a more even zone-size distribution than Chord(Random ID Selection) which doesn't consider the locality properties in the construction of the overlay network.

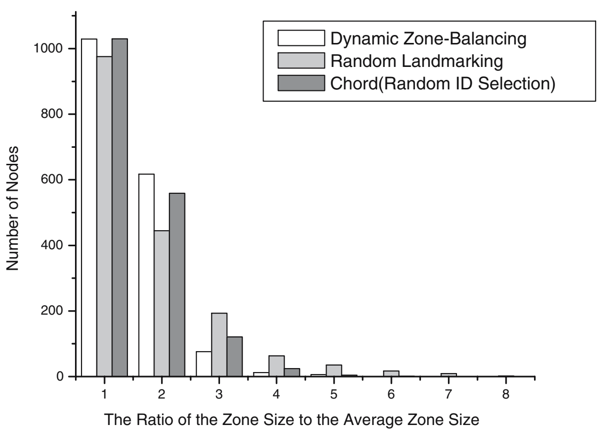

Fig. 2. Average overlay peer zone size distributions in real-world data set(Dynamic Zone-Balancing, Random Landmarking and Chord)

5 Conclusion

This paper presents an even topology-aware peer-to-peer overlay network based on de Bruijn Graph. Then proposed and evaluated a dynamic zone-balancing algorithm to build an even topology-aware peer-to-peer network. We found that the dynamic zone-balancing algorithm can build an even peer-to-peer overlay network. Future work involves mathematic analysis of the dynamic zone-balancing algorithm and more evaluations of the dynamic zone-balancing in different network topologies, parameters and settings.

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