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Evaluating the Performance and Delay in Unstructured Peer to Peer Networks

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Abstract: **Peer-to-Peer computing has become a popular networking paradigm for file sharing, distributed computing, collaborative working, etc. The widely used unstructured Peer to Peer protocols mainly face problems affecting their working efficiency. Topology mismatch problem between the Overlay network and its underlying network. We propose a novel topology Self-Adaptive Topology Matching. In this method, each joining peer is initially guided to find a physically close neighbor to connect with each other. After then, its overlay location is adaptively adjusted whenever a location mismatch is detected. The schemes to overcome the mismatch problem between the overlay network and the physical network, reduce the transmission latency, and provide a fully cooperative and reliable P2P environment. The results indicate that it usually required shorter time to obtain better results than the other considered methods, specially for large scale problems.**

***Keywords*:** **Unstructured peer-to-peer systems, topology mismatch, Overlay Topology, broadcast..**

1 INTRODUCTION

Peer-to-peer (P2P) model is quickly emerging as a significant computing paradigm of the future Internet. Unlike traditional distributed computing, P2P networks aggregate large number of computers and possibly mobile or hand-held devices, which join and leave the network frequently. Nodes in a P2P network, called peers, play a variety of roles in their interaction with other peers. When accessing information, they are clients. When serving information to other peers, they are servers. When forwarding information for other peers, they are routers. This new breed of systems creates application-level virtual networks with their own overlay topology and routing protocols. An overlay topology provides mechanisms to create and maintain the connectivity of an individual node to the network by establishing network connections with a subset of other nodes (neighbors) in the overlay network.

The P2P routing protocols allow individual computers and devices to share information and resources directly, without dedicated servers. Although P2P networking technologies may provide some desirable system properties for supporting pervasive and cooperative application sharing across the Internet, such as anonymity, fault tolerance, low maintenance & low administration cost, and transparent & dynamic operability, there are some well-known problems with most of the current P2P systems. For the P2P paradigm to be adopted widely, the technology must meet several challenges. We describe the general functioning of unstructured P2P networks, before discussing their drawbacks which form the source of these challenges.

Consider an unstructured overlay network represented as an undirected graph G= (V, E), where the set of nodes (i.e., participating peers) and edges (i.e., overlay links) between nodes are denoted by V and E, respectively. Any node v in V may flood messages to the nodes elsewhere in the system. Given G= (V, E), we aim to improve G such that the message flooding in G becomes efficient. By efficiency, we mean to reduce the broadcast delay from any node v to any node u V-{v}. Particularly, we intend to minimize the following:
:

$$\min_{p \in p_{v\sim u}} l_p \qquad (1)$$

Where P(v~u) G represents the set of all paths induced by the flooded messages due to v toward u, and lp denotes the total delay required for traversing the path p P(v~u)

Let p be any path in P (v~u) , given any v and u € V-{u}.Denote the number of edges (or the hop count) on p by |p|. Our second objective in this study is to minimize |p| as much as possible. Precisely, we are to minimize the following

$$\left| \arg \min_{p \in p_{v\sim u}} l_p \right| \qquad (2)$$

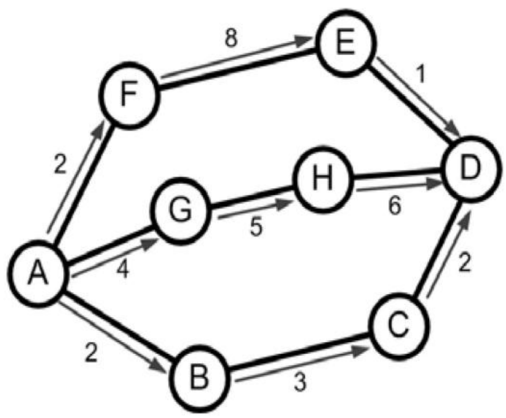

Fig.1. An example of an unstructured P2P network G=(V,E) V={A,B,C,D,E,F,G,H},E={AB,AF,AG,BC,EF,GH,CD,DE,DH} and the number aside from any *vu* ∈E denotes the delay of forwarding a message from *v* to *u*.

Minimizing |p|, in turn, maximizes the broadcast scope of disseminating a message, where the broadcast scope is defined as the number of distinct peers receiving the message with a specified TTL value. Notably, enlarging the broadcast scope is particularly important for P2P search applications since this increases the probability of discovering a requested object [14], [3], [15].

In the following discussion, the message broad casting protocol as mentioned above is called the scoped broadcast (or broadcast for short) in this paper. Fig. 1 depicts an example of an unstructured P2P network that implements the scoped broadcast.

Consider node A in the network. If TTL = 3, then the messages originated by A will follow three communication paths, namely, $p_{(A\sim D)}$ = {ABCD; AGHD; AFED}, toward D. Among ABCD, AGHD, and AFED, the path ABCD has the minimal communication latency. That is, D accepts the message from the shortest path ABCD discards those from paths AGHD and AFED. Here $|\arg min_{p\epsilon p_{A\sim D}} l_p|$ is 3, and the scope of the broadcast message due to A is 7.

In this paper, we present an analytical model to show that there exists unstructured P2P networks minimizing (1) for any pair of participating peers v and u. we propose a fully decentralized algorithm based on the Self-Adaptive Topology Matching Method to construct the intended overlay networks. In our proposal, any peer in the system connects to as many as possible of its geographically closest peers, subject to its maximum number of connections. In addition, compared with distant peers, the peers in the proximity of the physical network connect to one another in higher probability. We show that our algorithm constructs the intended overlay networks in a lightweight fashion, and each participating peer implementing our algorithm requires only local knowledge.

Reducing the average logical link latency can significantly reduce the lookup response time, which requires an overlay link to closely match its shortest IP route. Desired overlay construction algorithms correct the mismatch by selecting topologically close peers as neighbors. These algorithms need to address several fundamental issues: (1) it should be decentralized and scalable. (2) It should be accurate and adaptive to dynamically changing environments. (3) It should be of low cost.

2. RELATEDWORK

Small-world networks exhibit low diameter [5], [8], [9]. By diameter, we mean the maximum hop count of routing a message on the shortest path2 between any two nodes in a given graph network G=(V,E). Although a small-world network G has a low diameter, the "delay" of routing a message between any two nodes in G may not be necessarily small, considering that G is layered on top of a physical network (e.g., the Internet). Without relying on rigorous performance analysis, Merugu et al. in their seminal study [5] conclude that there exist some instances of small-world networks that can match their physical network topologies. Merugu et al. [5] do not detail how to create such a small-world P2P network, however. In contrast, in our study, we discuss how an unstructured P2P network that well matches the physical network topology can be constructed. Our proposed algorithm is motivated by a rigorously analytical model.

Liu et al. [14], [3], [15] present deterministic algorithms for the topology mismatch problem between unstructured P2P networks and underlying networks. To optimize the P2P network topology (denoted by G), the studies [9], [10], [11] suggest adding a new overlay link to G and removing an existing one from G iteratively such that the net operations can reduce the total delay cost of overlay links. While Liu et al.'s solutions are elegant and require only local knowledge for each peer, their proposals provide no performance guarantee. In contrast, we present a novel proposal that is driven by rigorous performance analysis. Unlike Liu et al.'s algorithms, the latency of routing a scoped broadcast message from any node v to another other node u in our presented overlay network approximates the minimum (i.e., the end-to-end delay from v to u), which is independent of the number of nodes in the system. We compare our proposal to Liu et al.'s solution in extensive simulations, and the simulation results validate the effectiveness of our proposal, showing that our design significantly outperforms Liu et al.'s.

In order to address the limitations of the above cited work, we propose a method, called SAT-Match that adaptively changes the overlay structure of the P2P system to match the underlying physical topology. By iteratively reducing the average logical link latency, the average response time of lookup routing is reduced. Moreover, it can be easily implemented on existing infrastructures like CAN without introducing new operations. Each node maintains only a small number of neighbor states. Through intensive simulation experiments on large scale CAN overlays, we have shown the effectiveness of SAT-Match.

3. THE MISMATCH PROBLEM AND OUR APPROACH

We take a torus overlay structure in CAN system as an example to explain our method, whose physical topology and logical overlay are shown in Figures 1 and 2 respectively.

Starting from the overlay network in Figure 2, we show how the mismatch can be improved through self-adaptation. If node A wants to route a message to node B, it needs to traverse the path A-C-B with the latency of 2+9+9 =20, or to traverse the path A-D-B with the latency of 12+3+9 =24, both of which are measured by latencies of physical links in Figure 1. However, node A could have routed the message to node B at the cost of 2 because there is a direct physical link with latency of 2 between the two nodes. Because of the topology mismatch, a query usually traverses some unnecessary links

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before reaching its final destination. In Figure 2, after changing the overlay structure on the left to the right one, the logical overlay can perfectly match the underlying physical topology. Compared to the two alternative routing latencies of 20 and 24 for node A to node B, the new routing latency is minimized to 2

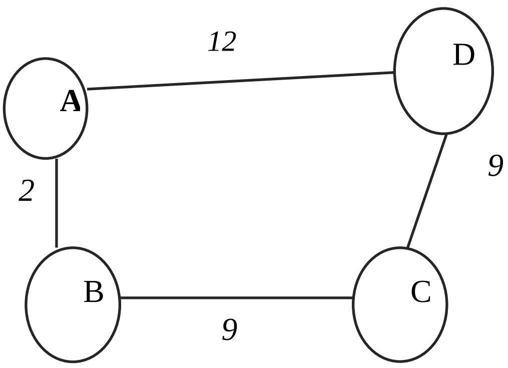

Fig 2. An example of a physical topology with 4 nodes.

We have designed a method called SAT-Match to adaptively change the overlay network connections following the ideal topology matching scenario in Figures 1 and 2 for the purpose of reducing the average latency of logical hops. This iterative process completes until it is close enough to the zone where all its physically close neighbors are located and no additional optimization is necessary. This continuously adaptive topology matching process will achieve a global topology matching optimization in a sufficiently large scope.

We define stretch as the ratio of the average logical link latency over the average physical link latency to quantify the topology match degree, where we refer the logical link to the virtual link between a node and one of its direct neighbors in the overlay.

3.1 TTL-K Flooding and RTT Measurements

A recent study shows that flooding with a low number of TTL hops is highly effective, which produces few redundant messages. The probing process of SAT-Match utilizes this effective flooding. Having joined the system based on a DHT assignment, a new node begins probing its neighborhood periodically. The source node floods out a message containing the source IP address the source timestamp and a small TTL value k to all its neighbors on the overlay. Any node that receives this message responds to the source with its IP address and decrements the TTL field in the messages by 1. If the updated TTL value does not reach 0, this responding node forwards the message to its neighbors. Since K is small, in the end of this flooding, the message covers only a limited number of nodes in a small region. We define these nodes being covered as the TTL-k neighborhood of the source node. Specifically, the TTL-k neighborhood of a node refers to this node and all its direct neighbor nodes in the overlay.

After probing in a TTL-k neighborhood and collecting a list of IP addresses, the source node uses a ping facility to measure the Round-Trip-Times (RTTs) to each of the nodes that have responded. Then it sorts these RTTs and selects two nodes with the smallest RTTs, based on which, the source node will select one zone associated with one of the nodes to node in.

4 PERFORMANCE EVALUATIONS

4.1 Simulation Methodology and Performance Metrics

We have evaluated SAT-Match comprehensively through simulation. The computing facilities are machines with Intel core 3.06GHz processors and 2GB memory running windows xp. As far as the logical overlay is concerned, we build our own Java based CAN simulator by following the protocol described in [1]. Each peer on the overlay is uniquely mapped to one node in the IP layer. We choose CAN as the platform because it adapts well to dynamic environments. However, SAT-Match can also be easily deployed in other structured P2P systems such as Chord and Pastry.

There are several parameters that can be tuned in the simulation.

1. D: the dimensionality of the Cartesian space
2. K : the scale of the TTL-k neighborhood of one node
3. N: the size of the CAN system
4. topology type, which characterizes the node distribution on the transit domain and on leaf stub domains

In our simulations, the number of nodes participating in the system is up to N =100000, and the default is 30,000. We simulate a static environment in which the nodes participating in the network do not join and leave. We also assess our proposal in a dynamic environment, and the peers in such an environment have a lifetime with the exponential distribution of the mean equal to t minutes.

Since previous studies (e.g., [7], [12], [8]) concluded that the peers in an unstructured peer-to-peer network, represented by G = (V, E), are randomly interconnected, we generate in the simulations Gs as random graphs using the algorithm suggested in [8]. In G, each node v connects to at most M=6 neighbors (i.e., the maximum number of connections v can maintain). our proposal, each simulated peer in our design can also link to six peers at most. In particular, in our proposed overlay, each peer *v* can only connect up to three peers for it's $B_v(1)$, while the size of vs w_v is no more than 3. However, unlikew_v, *v* exploits its $B_v(1)$ by rewiring the peers in an overlay network provided to our proposal. In the simulations, such a provided overlay network is a random graph in which each node only connects to three neighbors at most.

4.2 Effects of Varying the Number of Participating Peers

Corollary 2 states that our proposal minimizes the delay of sending a broadcast message between any two nodes v and u, and approximates the minimum (i.e., the lower bound of sending a message from v to u,l_{vu}) independent of the number of nodes participating in the system. We are thus interested in the effects of varying the number of participating peers in terms of broadcast delay in this section.

Fig. 3 presents the simulation result for Random, Random+THANCS, Hsiao, and Ours, given the end-to-end delays between peers due to BRIT E, by varying the number of nodes from 10,000 to 100,000. In Fig. 6, we measure which is the averaged ratio of the delay of routing a broadcast message from any node v to any other node u on the shortest path in the overlay to that of sending the message from v to u in the physical network.

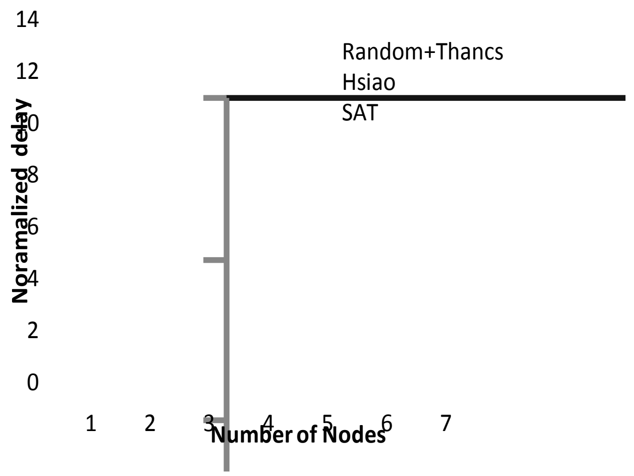

Fig. 3. The effect of varying the number of peers

As Fig. 3 depicts, our proposal performs very well and approximates the minimum delay of sending a message between any two nodes. This validates the effectiveness of our design as motivated by our analytical result in Section 3 and confirms Corollary 2. Second, while in [14], Hsiao et al. propose an overlay network with rigorous performance guarantee in which the latency of routing a broadcast message between any two nodes *v* and *u* is no more than $\theta(L)$ in expectation, what we present in this paper outperforms Hsiao, and the delay of sending a message between *v* and *u* in our design is close to the minimum l_{vu}.

5. CONCLUSION

The major achievements of this work are related to the characterization of unstructured peer-to-peer architectures. Starting from classical analytical results, we introduced several novel topological models which put the emphasis on capturing the network dynamics, and in our view are very significant for peer-to-peer systems. To the best of our knowledge, our proposal is the first design driven by the rigorous analytical model, which approximates the optimum.

In addition, our design guarantees the exponential broadcast scope. By exploiting the surrounding neighbors of peers with low communication delays, our overlay is constructed to match the underlying network topology. Based on the concept, the resources of peers in our overlay can be fully utilized.

Furthermore, we will investigate more efficient and reliable transmission schemes such as network coding and layered coding to achieve high throughput, scalable and robust peer-to-peer streaming environments.

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