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Exploiting the Structure of IP Addresses to Regulate the Affects of Topology Mismatch in Unstructured P2P Networks

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Abstract: Peer-to-Peer systems are the decentralized application layered virtual networks independently built over the underlying Internet topology for effectively utilizing the network resources and to provide better performance for the running applications. Due to the extent of benefits offered by the P2P systems, they represent a large portion of the Internet traffic. The traffic generated by a P2P system also enclose the redundant traffic introduced by the inherent topology mismatch between the overlay and underlay network. This paper presents a technique to exploit the structure of IP addresses of the overlay participating peers to moderate the affects of the topology mismatch problem. The system does not generate any additional packets for probing other peers to find distance estimates. The outcome of this technique is in reduction of total network traffic in the P2P systems.

Keywords: P2P, Topology Mismatch Problem, Overlays, Network traffic, IP Address.

1. Introduction

The architecture of peer-to-peer systems constitutes autonomous peers which organize in a distributed fashion to effectively share the network resources. Processing power, disk space or bandwidth are some of the resources which can be shared among the peers. Popular P2P applications include Gnutella, BitTorrent, P2P TV, Skype and SETI@home. Network studies [1] imply that P2P applications consistently contribute more than 50% of the total Internet traffic. Even though this traffic resulted in increase in revenue for the Internet service providers, it also imposed many traffic control challenges for them. Traffic generated by the P2P systems sometimes stalls the functioning of other application due to its excessive loads. This is mainly due to the way P2P systems function, which depends on the application layer routing based on a virtual overlay over the underlying physical network of Internet. The logical or virtual links in overlay are formed independently from the physical network. Even though the routing in overlay occurs through these overlay links or paths, but the actual transmission of the data occurs in the physical network.
The routing strategy in the overlay involves finding the best routing path from the source to destination along the virtual links connected between the peers, while the service provider tries to route through the best links in the physical network. As a result the data is routed through sub optimal paths which result in redundant network traffic.

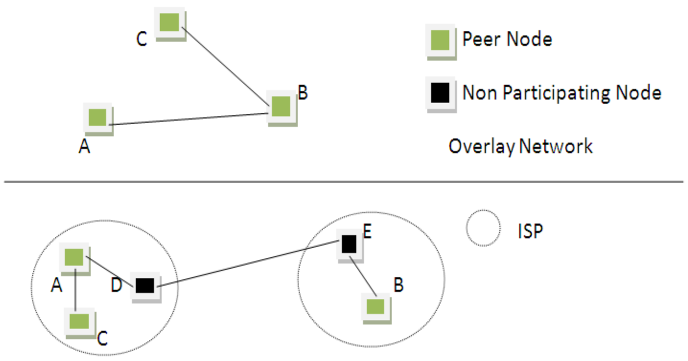

Fig 1: Topology Mismatch Problem

This situation between the overlay and underlay network is called the Topology Mismatch Problem. This can be depicted by the Fig 1.
When the traffic in the Fig 1 is considered, to send a data item from *A* to *C* involves the path *A*→*B*→*C* which is the best path in the overlay. This data transmission actually occurs in the physical network which traverses the following path i.e. *A*→*D*→*E*→*B*→*E*→*D*→*A*→*C*. Even though the peer *C* is present within the same ISP as that of *A*, it has traverse another ISP to send that data. This problem has arises due to the fact that the connections in the overlay are formed without the idea of the topology of the physical network.

Since the network traffic cost will increase when there are transmissions across the ISP's. So to improve the performance and reduce cost of communication, P2P systems have to consider locality of peers while constructing the logical overlay. The proposed technique in this system considers the peer's locality for solving the mismatch problem. The paper is organized as follows. Introduction details were expressed in section 1. Work related to the subject is presented in section 2. Section 3 describes the proposed system. Section 4 details the implementation and simulation results. The conclusion is given in section 5. The paper concludes with the references in section 6.

2. Related Word

To solve the topology mismatch problem overlay links must match with the links of the physical network. But obtaining the information about the physical network during runtime involves complex and difficult issues. So the peers are modeled to select those peers as neighbors that are in close proximity based on a network metric. This method of selecting the nodes is called proximity neighbor selection.

While solving the topology mismatch problem the following issues are considered:

a. Precision of the distance estimation between the nodes.
b. Communication overhead introduced.
c. Number of neighbors does a node have.

The methods described in [2] [3] [4] performs clustering based on the network infrastructure. The usability of this solution is dependent on the information available about the network infrastructure. For example the node does not have the idea about its autonomous system (AS) number. But The earlier work considering the IP addresses was used in clustering of web servers [4]. In this the nodes were grouped based on closeness in their topology and nodes which are under the control of a common administration. Since it was used for clustering general nodes it does not consider the properties of the P2P networks.

The initial approach for building a P2P network was made in Topology-centric Look-up service (TOPLUS) [2]. In this nodes are grouped according to their topological closeness i.e. common IP prefix. But the problem is that the solution requires global knowledge of the system which is not desirable in unstructured P2P networks. The IPv6 address structure was used in implementing the Chord overlay [6]. The resulted overlay was effective but the system does not specify how the IP addresses are assigned to the nodes.

Another solution presented in [5] uses the IP prefixes to derive the distance between the nodes and accordingly clusters them. The drawback of this approach is that the bootstrap peer maintaining the cluster routing table will become a bottleneck and a single point of failure. Other notable solutions specified to solve topology mismatch problem include LTM [7], SBO [8] and AOTO [9] use RTT's as the metric to calculate distance between nodes. But to obtain these values the nodes have to disseminate additional probe packets which add to the network traffic in the P2P systems.

3. Proposed System

To solve the topology mismatch problem, P2P network formation involves the following two steps:

a. Constructing an efficient overlay using underlay topology information.
b. Choosing those nodes as neighbors which are close, during communication.

This paper presents a simple method for building a P2P overlay using the structure of IP addresses and grouping the nodes which are present in the same region. The presented system does not introduce costly probe packets to derive or estimate the distances between the nodes. This helps to reduce the communication overhead in the P2P network. Using the techniques of clustering reduces the query delay time while still maintaining the accuracy of the distance estimates.

3.1. IP Addresses Distribution

Before 1999 the responsibility of assigning IP addresses to the users was in the hands of Internet Assigned Numbers Authority (IANA). This organization used to assign IP addresses according to the requirement of the user and they were not structured. From 1999 five Regional Internet Registries' (RIR's) took over the management of assigning the IP addresses. The RIR's can be depicted by Fig 1.

Fig 1: Regional Internet Registries

In 2003 all the five RIR's were united under Number Resource Organization (NRO). The addresses assigned within the organization are such that the nodes which are close to each other geographically are assigned address from the same block. The presented system uses the IP allocations to these regions to cluster the nodes according to the region to which the node belongs. The details regarding the blocks belong to the RIR's are given in [10]. Nodes which don't fall into any of these RIR's may affect the accuracy of the estimates. But experiments showed that even with these nodes the performance of the P2P network can greatly enhanced.

3.2. IP Prefix Match

The match between two IP addresses indicates the closeness of the nodes in physical network. The match refers to the relative physical distance between two nodes. The metric considered is the longest prefix or the IP segment which is common among two nodes IP addresses. The process starts by comparing the highest segment of the IP addresses and then goes on to compare the next segment if the first segment matches. The process will stop when the segments does not match. The longest prefix match is used to connect a node to other nodes which are close physically. This process can be presented as in Algorithm 1.

n1.n2.n3.n4/m ← *Format of the IPv4 address*
N ← *IP address of the node*
H ← *File retrieved from the Gnutella Web Cache (GWC) Containing IP addresses of other Nodes.*
M ← *File containing prefix matches*
$\forall I \in H \; Compare\ (I, N)$
M ← *(PM, I);*
Return M;

Compare (I, N)
For (t=0; t<4; t++)
Compare segment (I_t, N_t)
If (match) PM++;
Else continue; end If
End Compare segment
End For
End Compare

Algorithm 1: Prefix Match

Based on the number of matched segments in the IP address the nodes can be placed at closer to each other in the P2P network.

3.3. Overlay Formation

Formation of overlay in a general Gnutella [11] network involves the following steps:

a. The Gnutella client is initiated and host cache is loaded.
b. Connect request is sent to the Gnutella network using the host cache.
c. If there is no reply and connection to the network is not established after 'T' seconds, a query is sent to a random GWC (Gnutella Web Cache).
d. After waiting for 'R' seconds another query is sent to a random GWC.
e. Wait for 'R' seconds from the initial GWC, if no reply comes then call a new GWC each 'X' seconds.
f. After getting the replies the nodes choose the random nodes from the cache as neighbors.

The first five steps involve the general bootstrapping process in the Gnutella network. The existing implementations of Gnutella provide enough GWC servers to support the bootstrapping process. In this manner a general Gnutella node will connect to the network and choose the random nodes as neighbors. In the proposed implementation, the Gnutella overlay formation process is modified to imbibe the changes proposed in the system. Firstly the process change is made in step (c) where instead of connecting to the random GWC server; it let the node to find the closest default GWC server in a region to acquire the list of nodes querying the server for the nodes having longest prefix match. Next the step (e) is modified in such a way that if no response comes from a GWC server then next closest GWC server is queried every 'R' seconds.

In this manner the node will query the closest GWC server to retrieve the nodes which are present within the same region and derive the neighbors which are physical close to it.

3.4. Overlay Maintenance

During the formation of overlay the nodes will choose the neighbors according to the prefix match with the other nodes. First a node will select those nodes with the longest prefix match and if no such node exists then it will try to connect to the next lower prefix match nodes. In the similar fashion a node will try to get the maximum neighbors it can have. Once it reaches the max number of connections it will disconnect the node with lowest prefix match value if a better node tries to connect to the node. This process is depicted in Fig 2.

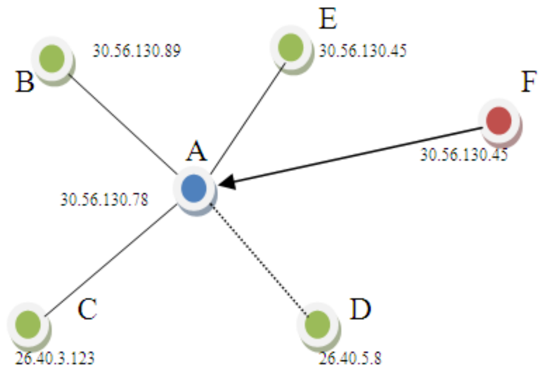

Fig 2: Removing Existing Connection

In the above figure if the node E sends a connect message to the node A which can have a maximum of 4 neighbors then it will check the prefix match with E and remove one of the existing connections i.e. node D which has smaller prefix match than the new node.

NbrA ← Neighbors of A.
Max_NbrA ← Maximum Neighbors A can have.
PMAB ← Prefix Match of A and B.
If NbrA+1 ≤ Max_NbrA then
Accept F ; Return
Else
Candidates ← C ∀ C ε NbrA with PMFA > PMCA
If No Candidates Exists
Reject F; Return
Else
Accept F;
Drop C with least PM value;

Algorithm 2: Topology maintenance

Along these lines the node will keep changing its connections when further closer nodes try to connect. Even in the case where some of the neighbors move away from the network, the node will still find the other closer nodes using the GWC servers. The process is illustrated using Algorithm 2.

4. Implementation and Simulation

The implementation changes presented for the overlay are launched into the Gnutella nodes by changing the specifications of operations performed by the node such as contacting the GWC server and choosing its neighbors based on the prefix match of the nodes. The implementation is carried out on a general purpose java simulator. A P2P system is simulated using a 500 node network and the IP addresses to nodes are assigned randomly by the simulation module. To compare the accuracy and effectiveness of this proposal first a general Gnutella network is implemented which chooses the neighbors randomly and then simulate the improved Gnutella network formation using the prefix match to find the neighbors. To access the cost effectiveness of the solution communication cost of the two networks is compared. Fig 3 shows the relationship.

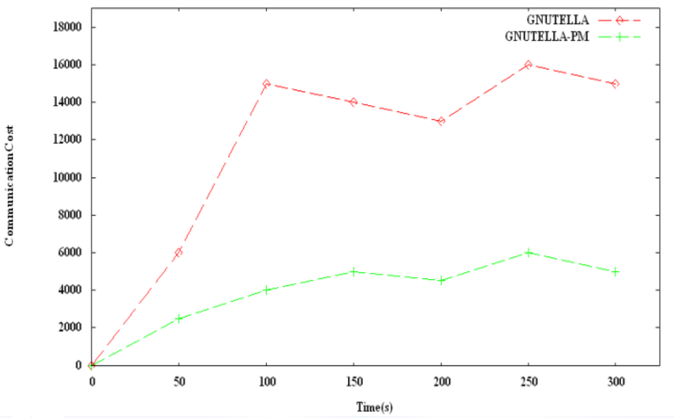

Fig 3: Communication Cost

The figure implies that overlay formed using the prefix matching method reduces the cost of communication drastically as the nodes get to choose the neighbors within the same region.

Next the simulation considers the delay involved to replay to the queries sent by the nodes. The delay is considered in time (ms) taken by the network to replay queries sent by a set of nodes. The comparison is depicted by Fig 4. It shows that delay in the presented system is far less compared to Gnutella network as the network connections across an Autonomous System are very less.

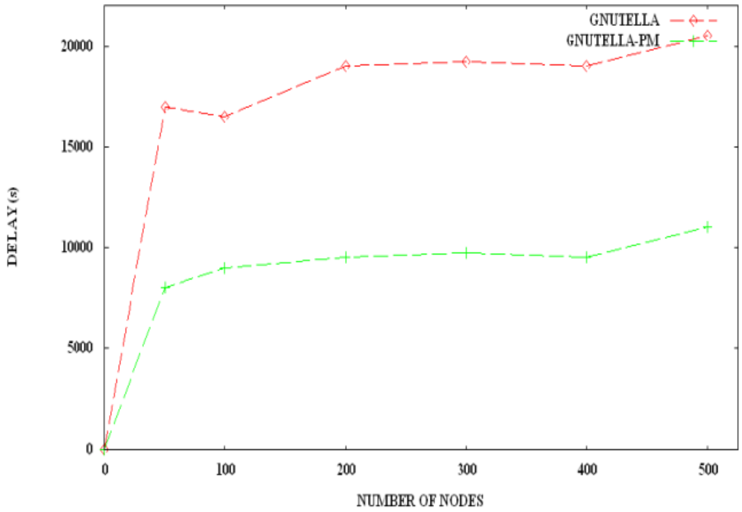

Fig 4: Query Delay

Next the average number of messages generated by the peers is taken into consideration to measure the load in the network. The average number of messages generated by a set in both the networks is given Fig 5.

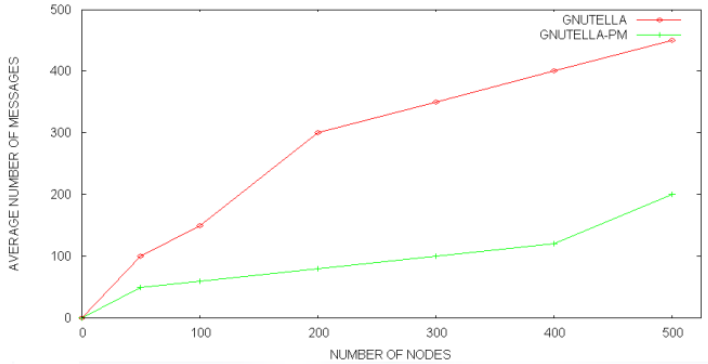

Fig 5: Average Number of Messages

As the proposed system does not generate any probe packets to derive the distance estimates it creates far lesser number of messages compared to the flooding based Gnutella network. Next the average hop length of the query is taken to derive the effectiveness of the prefix match method is helpful in solving the topology mismatch problem. This comparison is shown in Fig 6.

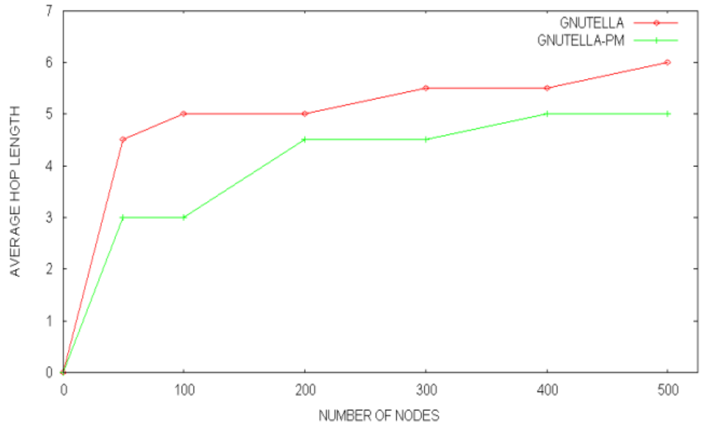

Fig 6: Average Hop Length

The simulation show that the proposed overlay formation technique using the prefix matching method greatly reduces the redundant traffic caused by topology mismatch problem without introducing additional probe packets and providing a faster query responses.

5. Conclusion

This paper presents a simple but effective approach to regulate the effects of the topology mismatch problem by constructing a P2P overlay using the IP Prefix matching between the nodes. The system does not generate any additional messages to determine the distance between nodes and provides a greater performing P2P system than the existing P2P systems.

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