The case for ISP deployment of super-peers in P2P networks

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Abstract— **Peer-to-peer systems like KaZaa use the notion of super-peers to improve search performance. In this paper, we analyze the impact of Internet Service Providers deploying these super-peers in their networks. The principle benefits for ISPs are the ability to perform P2P traffic engineering and to push content directly to the users, both of which translate into economic value for the ISPs. The benefit for end users is improved search performance. We propose and evaluate a technique called Topic-based Search Optimization that can be used by super-peers to improve search performance.**

I. INTRODUCTION

Peer-to-peer systems have rapidly emerged as an important and popular class of Internet applications. The success of peer-to-peer file-sharing applications like Gnutella [1] and Kazaa [2] has fuelled research into new applications and architectures for peer-to-peer systems.

Unstructured networks like Gnutella are characterized by the absence of specific mechanisms for enforcing a particular network topology and file placement. As a result, search proceeds by flooding the query to all nodes within a certain search horizon. Improvements to the flooding mechanism, such as expanding ring search and random walks, are proposed in [3].

Systems like KaZaa and more recent versions of Gnutella improve the efficiency of the search process by using certain well-provisioned peers as super-peers, search hubs that index files belonging to other nodes. In this paper, we examine the utility of Internet Service Providers deploying and maintaining these super-peers as an infrastructure service to end-users of the system. We also consider some of the economic incentives for ISPs for maintaining this infrastructure.

II. ISP-BASED MODEL

We envisage a P2P architecture in which ISP deploy and maintain super-peers in their network. These super-peers act as an explicit point of entry to the peer-to-peer system for end-user peers. All queries from these peers are routed through the super-peer they are connected to. Thus connectivity to the P2P system is provided as a service to end-users, either with or without monetary compensation, depending perhaps on the level of service. What is the motivation for ISPs to maintain these super-peers? We identify the following potential advantages to ISPs and discuss them in some detail.

- ISPs can perform policy-based traffic engineering on P2P traffic by forwarding to the peer with the most suited locations for content download.
- ISPs can support content-pushing in P2P networks

A. P2P traffic engineering

Given the popularity of peer-to-peer applications and the large amounts of multimedia data downloaded through these applications, peer-to-peer traffic is growing to form a significant volume of traffic on ISP networks. [4] analyses the impact of P2P traffic on an ISP network and concludes that, to quote, ”the high volume and good stability properties of P2P traffic indicates that the P2P workload is a good candidate for application-specific layer 3 traffic engineering in an ISP network”.

Since all end-user queries are routed through the super-peers, the ISP can control which peers these queries are forwarded to. This measure of control provides the ISP with a policy-driven framework that maximizes the economic value for the ISP with respect to neighboring ISPs.

For example, one such policy could be to, whenever possible, forward a query to peers within the ISP in preference to peers outside. This could be analogous to ”hot potato” routing but applied to P2P traffic. This ensures that the ISP forwards as little traffic to an upstream ISP. Since inter-ISP settlements are often based on traffic volumes, such a policy would minimize the economic impact due to P2P traffic that is flowing upstream. Another policy could determine, given a choice of upstream ISPs, which one to forward to. If both ISPs contain peers that can satisfy the query, it makes sense to forward to the cheaper upstream provider.

Policies could also govern which peers to forward to within the ISP network itself. The super-peer can

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exploit a detailed knowledge of the network topology to implement some form of basic load balancing and QoS. If there are multiple peers within the network that can satisfy a query, the query can be forwarded depending on factors such as congestion and latency. Not only does this result in better utilization of the ISP network, it also translates into better performance for the end-user as well in the form of faster downloads.

B. Content-Pushing

The current model in P2P systems is pull-based i.e. users receive content that they explicitly search for and request. We believe that a push-based model for content distribution is also desirable for P2P networks for a number of reasons. Current systems lack sophisticated meta-data based search capabilities, which implies that users can only find content that they have reasonable a priori knowledge of. It is difficult for users to find content that is potentially interesting but of which they are not aware of. When combined with some amount of user profiling, the super-peer architecture enables users to be pushed content they are interested in. It is also useful for content developers that wish to distribute their content to interested users. ISPs can exploit this by providing the super-peer infrastructure to deploy push-based P2P applications.

To illustrate this, consider the following hypothetical scenario. A relatively smaller publisher wishes to release a new computer game. The publisher has made available on its website demo versions of the complete game but does not have the adequate finances to either market the game (i.e. the publisher does not have access to popular advertising mediums), or be able to concurrently deliver the content to a large user base. In such a situation, the super-peer architecture could come to the aid of the publisher by providing a platform to selectively target peers who search for games or similar applications. The same scenario could be extended to a musician releasing excerpts of a new album through a P2P network. ISPs can sell a content distribution service to the content publishers. In addition, users can subscribe to a service that pushes to them content they are interested in.

Having discussed the advantages for an ISP to sustain such a model, we now comment on the end-user perspective.

C. End-user perspective

Why would a end-user subscribe to the model in which ISPs provide, and potentially sell, connectivity to a P2P network? We identify the following potential reasons that a user would preferentially connect through a super-peer provided by an ISP.

- The super-peer architecture provides better search capabilities than existing P2P networks. Current systems suffer from the drawback that it is relatively difficult to find rare items in the system. In addition, super-peers can use user profile information, collected either explicitly or implicitly, to route queries to peers more likely to have the content.
- ISPs can provide some level of QoS for P2P downloads by routing queries to peers that are likely to offer the best performance.
- Users can be offered services like content-pushing and information collected by super-peers like the most popular downloaded content.
- Super-peers can act as application-level bridges between different P2P protocols. By searching multiple P2P networks, the efficacy of search can be improved.

We believe that the first of these reasons is the most important from a user perspective. The success of a P2P file-sharing application is dependent on how well the search mechanism work. We believe that the super-peer architecture can result in significantly improved search performance. To that end, we propose and analyze a technique called *Topic-based search optimization*. This is discussed in the following section.

III. Topic-based Search Optimization

The goal of each participating Peer in an unstructured P2P system is to optimize the experience for its own benefit. After initially discovering super-peers by means of a well-known service, peers create and maintain local lists of well-known super-peers for future reference. The leaf node selects to add the super-peer to its local list only if the super-peer performs sufficient useful work for the leaf node. Useful work means the super-peers responsiveness to messages originating at the leaf node.

Super-peers in Gnutella typically allow about a 100 peers to connect to them as leaf nodes. On the other hand leaf nodes, in an ideal state, typically try and remain connected to roughly 8 super peers. No matter what the situation, it is highly likely that a particular super-peer is indeed competing with other super-peers to offer its service to the leaf node.

The irony here is that the decision to connect or disconnect to a super-peer is not determined by the end user but by the application logic. Leaf nodes remain in search for greener pastures. There is this constant ongoing process to find better super-peers to associate with to improve their chances for finding their desired objects.

Therefore if we are a super-peer and we want to ensure that the leaf node will stay connected to us for not only the entire duration of its current session but also for future sessions. Then the super-peer needs to ensure that it efficiently responds to all messages with the focus on Query messages originating at the leaf node.

To achieve a high Query response rate an effective first step is to associate our super-peers with a larger number of leaf nodes. This can increase the probability of the Queries being answered within our set of leaf nodes.

As a next step, we introduce a new paradigm for query routing in our super-peers, which we call *"Topic-based search optimization"*. We take into account that i) peers are likely to respond to the types of queries that they themselves make, and ii) queries originating at various peers may show topic based locality in shared interests.

To establish the Topics of interest we analyze the meta-data contained in the Query Response messages routed via our super-peer. Meta-data associated with an object typically contains a set of key-value pairs pertinent to the type of the object. For example, in the case of an audio file the meta-data may contain one or more values in the following fields: *Title, Artist, Album, Category, Release Year, Bitrate, Length, Description, and Keywords*. In addition to meta-data the Query Response message also provides a unique 'signature-key' for every item returned. This signature key is typically a MD5 digest created from the data contained in the file.

Figure 1 shows meta-data information gathered from real Query Hit responses, and figure 2 shows a view of this information in a multidimensional name space structure. Topics can be created by considering Type of objects, or the category, or the Artist or any representative combination of the fields that can be gathered from the meta-data.

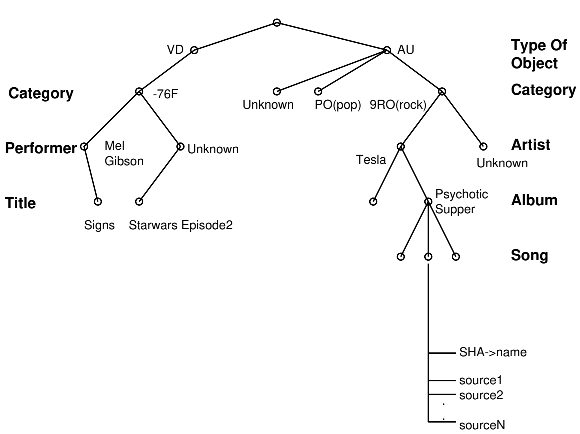
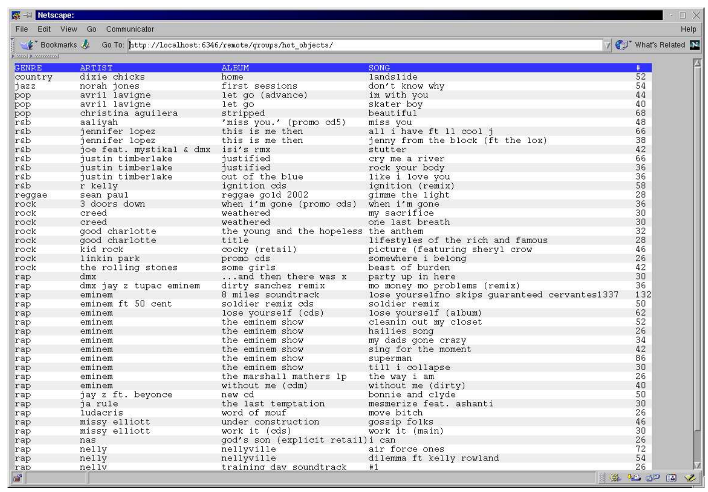


Fig. 2. A Multidimensional Name Space Search Structure.

To optimize the response rate for future queries we can consider creating replicas of objects being queried for at the super-peers. However we believe that utilizing our topic based search optimization provides us with a good selection of perspective candidate peers who are likely to have the content we are Querying for, thus ensuring that a high Query hit rate is maintained without the need for replication.

As an additional service super-peers can provide to requesting users, categorized topics of interest, so that users may make a selection from the list of available objects as opposed to querying for objects on the network. Figure 3 shows a list of objects filtered by the criteria that there be at least 25 peers actively sharing the object. Further in order to perform general queries we can consider filtering the topics of interest to get our results as opposed to a flooding type mechanism. For example the query for 70s music, translates to a filter for music files released between 1970 and 1980. Considering the utility of this feature there is justification if we were to provide it for some type of a credit based scheme.



GENRE	ARTIST	ALBUM	SONG	#
country	dixie chicks	home	landslide	52
jazz	norah jones	first sessions	don't know why	54
pop	avril lavigne	let go (advance)	im with you	44
pop	avril lavigne	let go	skater boy	40
pop	christina aguilera	stripped	beautiful	68
r&b	aaliyah	'miss you.' (promo cd5)	miss you	48
r&b	jennifer lopez	this is me then	all i have ft ll cool j	66
r&b	jennifer lopez	this is me then	jenny from the block (ft the lox)	38
r&b	joe feat. mystikal & dmx	isi's rmx	stutter	42
r&b	justin timberlake	justified	cry me a river	66
r&b	justin timberlake	justified	rock your body	36
r&b	justin timberlake	out of the blue	like i love you	36
r&b	r kelly	ignition cds	ignition (remix)	58
reggae	sean paul	reggae gold 2002	gimme the light	28
rock	3 doors down	when i'm gone (promo cds)	when i'm gone	36
rock	creed	weathered	my sacrifice	30
rock	creed	weathered	one last breath	30
rock	good charlotte	the young and the hopeless	the anthem	32
rock	good charlotte	title	lifestyles of the rich and famous	28
rock	kid rock	cocky (retail)	picture (featuring sheryl crow	46
rock	linkin park	promo cds	somewhere i belong	26
rock	the rolling stones	some girls	beast of burden	42
rap	dmx	...and then there was x	party up in here	30
rap	dmx jay z tupac eminem	dirty sanchez remix	mo money mo problems (remix)	36
rap	eminem	8 miles soundtrack	lose yourselfno skips guaranteed cervantes1337	132
rap	eminem ft 50 cent	soldier remix cds	soldier remix	50
rap	eminem	lose yourself (cds)	lose yourself (album)	62
rap	eminem	the eminem show	cleanin out my closet	52
rap	eminem	the eminem show	hailies song	26
rap	eminem	the eminem show	my dads gone crazy	34
rap	eminem	the eminem show	sing for the moment	42
rap	eminem	the eminem show	superman	86
rap	eminem	the eminem show	till i collapse	30
rap	eminem	the marshall mathers lp	the way i am	26
rap	eminem	without me (cdm)	without me (dirty)	40
rap	jay z ft. beyonce	new cd	bonnie and clyde	50
rap	ja rule	the last temptation	mesmerize feat. ashanti	30
rap	ludacris	word of mouf	move bitch	26
rap	missy elliott	under construction	gossip folks	46
rap	missy elliott	work it (cds)	work it (main)	30
rap	nas	god's son (explicit retail)	i can	26
rap	nelly	nellyville	air force ones	72
rap	nelly	nellyville	dilemma ft kelly rowland	54
rap	nelly	training day soundtrack	#1	26

Fig. 3. A list of objects that are being shared by atleast 25 active hosts.

Exploiting user interests to improve search is an approach taken by [5] and [6]. However in our approach the user information is collated at the super-nodes and is transparent to the end users. Therefore all the participating peers in network can benefit from the optimizations without the need to upgrade the software at the client side.

IV. Evaluation

For the purpose of evaluation we implemented a Gnutella client based on the publicly available Mutella [7] source code. Our version of the Gnutella client actively participates in the Gnutella network as super-peers while collecting data for analysis. The participating clients do not introduce any new traffic into

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"OBJECT TYPE"   = "VD"
"Title"         = "[TMD]StarWars.Episode2.Attack.of.the.Clones.(2of2)"
"Author"        = "starwars pt2"
"Category"      = "-76SF"

"OBJECT TYPE"   = "VD"
"Title"         = "[tmd]signs.(twciso).tc.(1of2)"
"Author"        = "TMD"
"Performers"    = "Mel Gibson"
"Description"   = "A Movie 'bout some aliens"
"Language"      = "-68EN"
"Category"      = "-76SF"
"Release Year"  = "2002"

"OBJECT TYPE"   = "AU"
"Title"         = "Call It What You Want"
"Artist"        = "Tesla"
"Album"         = "Psychotic Supper"
"Description"   = ""
"Category"      = "9RO"
"Release Year"  = "1991"
"Bitrate"       = "182"
"Length"        = "4:30"
```

Fig. 1. Meta Information Gathered from Real Query Hit Responses

the network and only gather the data that the super-peer would typically see. The clients allow between 20 and 200 leaf-nodes to connect to them. This study is different from previous work by [8] as we extensively utlize the Gnutella v0.6 [9] protocol.

For the purpose of this simulation we considered a randomly selected 2-hour period from the trace files.

Figure 4 represents two curves of interest:

a) Curve SC : We consider this as there have been numerous research papers that propose to replicate [3], [10] the objects to enhance the efficiency of the network. Although we did not replicate the physical objects in the super-peer, we maintain the actual file-signatures for an infinite period of time as a representative of the data. The curve SC represents the cache hit rate for successive queries to this pool of previously cached objects.

b) Curve TC : represents the number of queries which had overlapping interest with at least 1 topic group. Although The number of queries that match this criteria is much higher than the number of queries that match the cached objects, we cannot directly compare the two as the TC curve represents the number of matching topics, however there are no guarantees that we will find the data we are looking for in any of the peers sharing content related to the topic.

To further understand our results we consider the results obtained from a second crawler as follows:

To understand whether the peers indeed share and search for similar objects we wrote a second crawler based on the Gnutella protocol. These crawlers connect to a large number of peers and upon receiving a query from a neighboring peer, it extracts the first two words from the query, and creates a new query from these words and sends them to the neighbor the query had originated at. Even though this does not precisely capture the users interest topic, as many times the first two words signify nothing in particular, the results of the crawler represented in Figure 5 provide us with a promising start. It is clear from the figure that approximately 15% of the peers do indeed respond to the queries that we are sending to them.

What is interesting is that if we are to consider this 15% as representative of the response rate then we can infer from figure 4 that 15% of the queries that had found a match in a topic category, and likely to find objects by querying the set of peers in the topic category. What this means is that even at worst we have a response rate with

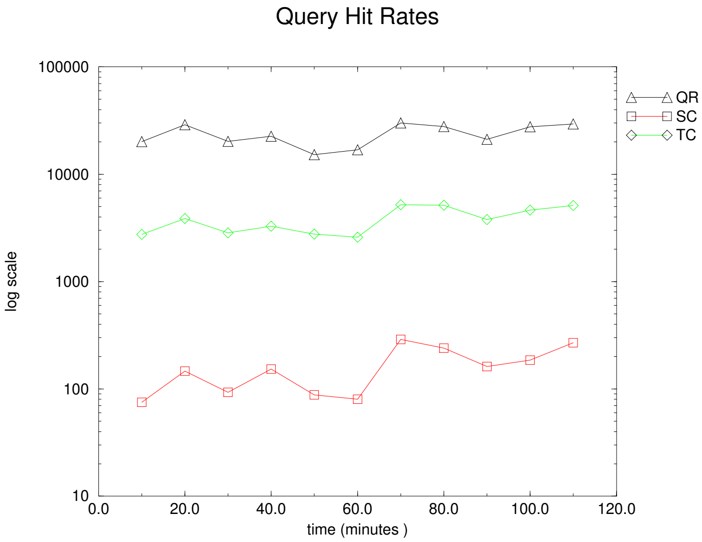

Fig. 4. The curve QR represents the number of queries, the curve SC represents the cache hit rate for objects matching exactly, and the curve TC represents the hit rate for the queries matching a topic of interest.

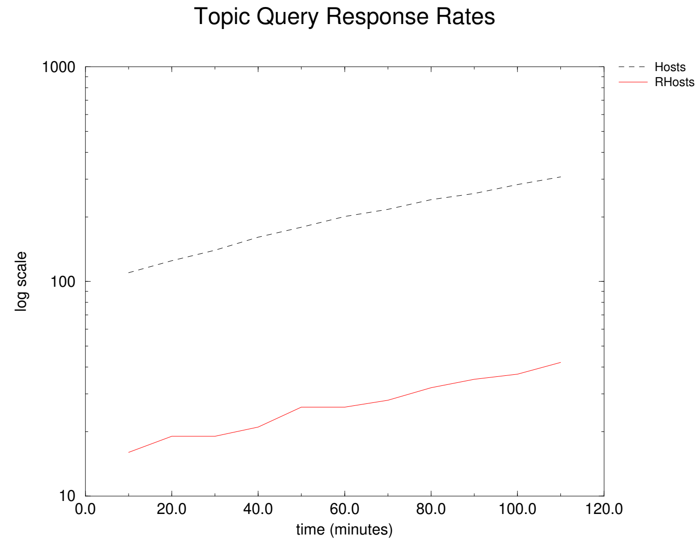

Fig. 5. This graphs compares the number of neighboring hosts making queries (Hosts), to the number of these hosts (RHosts) responding with useful results when sent a query with a topic extracted from their orignal query.

expected chances for success as good as querying across an infinitely large cache.

V. Conclusion

In this paper, we attempted to argue that there is value in ISPs deploying super-peers as a infrastructure service. Controlling super-peers allows ISPs to engineer P2P traffic on their networks. The main benefit from the user point of view is improved search. We proposed and evaluated a technique called Topic-based Search Optimization that improves search performance using super-peers.

There is significant scope for future research. A comprehensive evaluation of the effect of Topic-based search on search performance is to be done. We also intend to quantitatively assess the utility of different policies for traffic management for ISP networks including QoS for end users.

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