A Comprehensive Study of Some Recent Proximity Awareness Models and Common-Interest Architectural Formulations Among P2P Systems

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Abstract

Performance of a peer-to-peer system is commonly assessed by the ease of scalability it offers, level of fault tolerance it can handle and querying latency it results. Especially for a P2P system meant for file sharing, efficient search mechanism is crucial. Such efficiency of file querying is noticeably improved when participating peers are grouped based on their shared interests. Peers when clustered by their geographic proximity can also yield better search latency. Current works use both location proximity and common interest as the basis for clustering and these works take advantage of both the methodologies. This survey talks about various P2P proximity-based clustering models and common-interest based network formulations and to the best of our knowledge there does not exist any survey paper that considers the topic which we have considered in our present work.

Key Words: Interest-based network formation, P2P networks, proximity awareness models, performance, clustering.

1 Introduction

With the constant growth of Internet popularity, the rise of P2P file sharing systems went up. BitTorrent is a reflection of the above-mentioned statement. Additionally, P2P systems are scalable, self-organizing and distributed. This makes them be a popular option in the distributed system domain. P2P systems are divided into two categories: structured P2P systems and unstructured [5] P2P systems. Peers in unstructured systems are arranged arbitrarily. The lookup of data in unstructured systems is aided by flooding. Churn - the problem of frequent peer joining and leaving the system, is successfully addressed in unstructured system. However, it makes a trade-off between data query performance and much needed flexibility. Furthermore, lookups are not guaranteed in unstructured networks. Structured overlay networks, on the other hand, enable deterministic data discovery bounds. They offer scalable network overlays based on a distributed data structure that enables deterministic data lookup behavior.

File querying efficiency is a key way to judge a P2P system. Numerous methods have been proposed to bump up this efficiency. Super-Peer technology, proximity-awareness models [27, 33, 42], interest-based models usually are the well-spoken methods to make the querying process more efficient. This study summarizes multiple popular works which are based on proximity awareness models and interest-based clustering. To the best of our knowledge there does not exist any survey paper that considers the topic which we have considered in our present work.

2 Various Works on Proximity Based Clustering

In this section, various works that has proximity clustering like G-LocON, PAIS, P3ON and CA-P2P are discussed.

2.1 G-LocON

G-LocON [27] is a P2P framework responsible for achieving a network architecture that is location based. One of the revolutionizing smartphone functions called the global positioning system (GPS) is used as the means for capturing the location information [30] of a peer in this P2P communication frame-work. Mobile phones are considered as peers in this work and these peers are expected to be part of various networks like cellular, Wi-Fi and others already. Irrespective of the kind of

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integral network that they are a part of, peers can form an overlay network with each other. For the sake of successful connection and communication between any two peers, a location tracking server is used here. This server is known as L-tracker and it maintains the location information of peers along with their unique identifiers. This message consists of peer related metadata and the location information of the peer. Every peer present in the system periodically registers itself with the L-tracker following the above-mentioned process. This way, L-tracker has all the location information of all the peers and the metadata to uniquely identify them. In the process of discovering the neighbors, a peer sends a request to the L-tracker and only after receiving the information from the L-tracker, direct P2P connections are formed. Similar to periodical updates, neighboring peer information request should also be up to date. This is how a hybrid P2P system like G-LocON works. An overall outline of the proposed system is presented in Figure 1.

Every peer in G-LocON has a focusing area. This area acts as the cut-off range until which a peer in this system is interested for neighbor discovery. A peer can only be logically connected to another if both the peers fall under the focusing area of either one. Additionally, each peer can have the liberty to size its own focusing area. All the logical overlay networks that are formed between these peers are managed efficiently by expanding or contracting the focusing area limits. This gives a great edge over ad hoc mobile networks as peers in such networks finds difficulty forming connections in areas especially if the area is not densely populated. Only the peers which are within the range of communication can form connections in an ad hoc network with isn't the case in G-LocON system.

For any peer to establish a connection with another, it needs to be aware of the destination peer's address bindings. Translated IP address and port information constitute address bindings. Translated IP and port information of any peer are automatically allocated when its first packet goes through a NAT gateway. Hence, binding request is the first step in this G-LocON system. And for this purpose, a STUN [34] server has been deployed. This is a server that is hosted on the public networks and is used for IP address translations. Additionally, in the process of peer connection, metadata will be exchanged between peers. Metadata like PeerID is used by the L-tracker for unique identification of peers. For assignments of peerID, a signaling server is used in this work. A peer requests a peerID by sending a registration request to the signaling server.

The sequence of steps that takes place when a new peer joins the G-LocON system is described below:

- When a new peer joins the system, an address binding request is sent to the STUN server first. Once received, this sever responds back with IP address and port numbers from its own perspective.
- After receiving the address bindings, the peer sends a peer registration request to the signaling server. This request contains the address bindings created by the STUN server to which a unique identifier registration is processed. All the information is stored in the database here. The signaling server responds back with the newly created peerID.
- Once the peer receives the peerID from the signalling server, it sends a join message to the L-tracker along with the location information of the peer traced from GPS.

After a successful connection is established between a peer and the L-tracker, the peer is set to be P2P connection ready. Then,

- A query including the current location information of the peer along its interested focus area radius is sent to the L-tracker. L-tracker then lists out all the neighboring peers which fall under the interested focusing area radius and then sends the list as a response to the peer.
- Once the neighboring peers list is received, taking the help of the signaling server, the peer establishes P2P connections with its neighboring peers. [25]

G-LocON has a process in place of peer leaving.

- All the P2P connections established by neighboring peers will be closed by sending out connection closing messages. Once there are no more connections established, the peer sends out a leave message to the L-tracker. After this message, all the peer information with the L-tracker is erased. An acknowledgment is then sent to the peer.

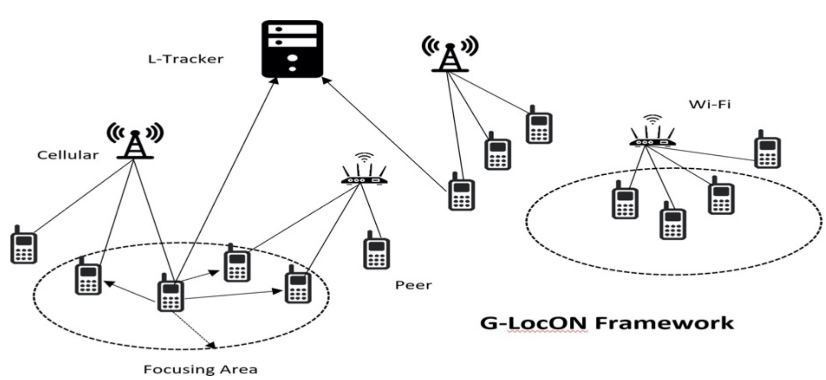

Figure 1: L-tracker managed overlay P2P network

- Once the peer receives this acknowledgment, a peer unregistration request is sent to the signaling server. All the peer information is then deleted at the signaling server. A final acknowledgement is then sent to the peer after this process.

Every peer maintains all the active P2P connections that were established. Using the said list, simultaneous and redundant P2P connection initiations can be tracked and managed. This way, a location based P2P system is formed yielding great efficiency in query management [4]. G-LocON achieves the average transmission delay in tens of milliseconds between peers. However, this increases with increase in the neighbor peer count. Average total delay in terms of hundreds of milliseconds which increases gradually with increase in neighbor peer count. G-LocON also states that the said system was developed as an android application.

2.2 PAIS

This work includes both proximity awareness and interest-based clustering together. PAIS [36] stands for proximity aware interest clustered P2P file sharing system. Generally, topological information in P2P networks are gathered by proximity routing, geographic layouts and proximity-neighbor selection. The above mentioned G-LocON framework is an example of for proximity-neighbor selection methodology. PAIS proposes a P2P network which is based on the Cycloid work [38]. Cycloid is a P2P structured network that combines Pastry and CCC graphs. CCC stands for Cube-Connected-Cycles. Any d-dimensional Cube- Connected-Cycles graph is the same dimensional cube with vertices replaced by a cycle of d nodes. Cycloid uses consistent hashing for mapping keys to nodes. So, both the keys and nodes have identifiers which a distributed uniformly. Total number of nodes present in a Cycloid is calculated by the formula $d*2d$, where d is the dimension count. So, for a 3 dimensional Cycloid, there would be 24 nodes all together. A time complexity of O(d) is achieved per lookup with the help of O(1) neighbors per node is achieved here.

Every node in the Cycloid is represented by a cyclic and cubical index pair. It is (k, $a_{d-1}a_{d-2}...a_0$) where k is the cyclic index which ranges from 0 to d-1 and the latter part is a cubical index which ranges from 0 to $2d$ -1. PAIS clusters all nodes with close physical proximity together for efficiency. These clustered nodes are further segregated into sub-clusters based on the node interests [16]. Figure 2 represents a typical PAIS structure.

As per PAIS, all the nodes that are of close proximity have the same cubical index. All these nodes with the same cubical index are formed in a cluster in which these nodes are ordered by the cyclic index mod d. All these clusters are ordered based on their cubical index mod 2^d on level-1 circle; the big one. Once the clusters are made and ordered, all the nodes in these clusters are further segregated into sub-clusters based on their common interests. In Figure 2, interests like books, music and movies are considered for common interest [3, 15, 29] clustering.

PAIS follows a land-marking method to determine the proximity closeness between nodes on the network. This landmarking method is based off a concept called distributed binning [33, 44]

2.2.1 Distributed Binning.

The primary objective of a distributed binning scheme is to cluster nodes in various bins based on their proximity closeness. All the nodes that are placed into a single bin are relatively close to each other when compared to nodes that are placed in a different bin. The assumption that distributed binning begins with is that there are machines placed on the Internet as landmarks. Addresses of these machines can be retrieved from the DNS. These landmark machines are placed in a manner such that when the distance between any node to these machines is calculated, a clear idea about the positioning of nodes can be figured out. This acts as the key factor in clustering nodes into bins. The

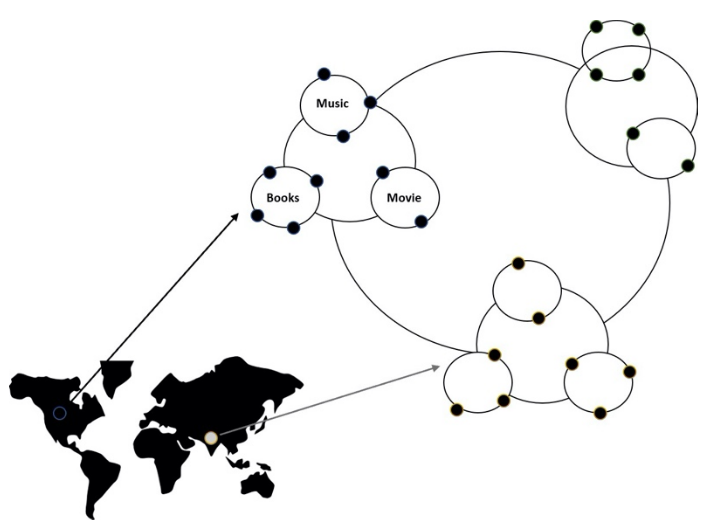

Figure 2: PAIS structure

relative distance between nodes to these landmark machines is considered as the latency. This latency is calculated in the form of the round-trip time. In this work, every node calculates its round-trip time to the set of landmark nodes and sorts them in an increasing order. As mentioned above, this order factors into bin placement. For example, if there is a set of three landmark nodes placed on the Internet, every node has to calculate its round-trip time to all three of the landmark nodes resulting in a set of three round-trip times sorted in an ascending order.

The idea behind this distributed binning is that all the nodes that are topologically closer or in other terms have similar round-trip times are likely to be placed in the same bin. By following the landmarking process and ordering the round-trip times, two kinds of information are achieved. One, the relative distance of nodes from the landmark machines. Two, the absolute value of the said distances. The values that are obtained by calculating round-trip times are then converted as levels. In the mentioned example, we get three round-trip times after the distance calculation is done. These three times could be 80ms, 123ms and 232 ms. In distributed binning, they took an example of level-0 be given to the range of round-trip times 0 to 100 ms, level-1 be given to the range of 101 to 200ms and anything greater gets level-2. So, in Figure 3, if a specific node has L_1:160, L_2:245 and L_3:12 as the set of latencies it has, the levels we are looking for this node is [1,2,0].

When these values are ordered as per the work, we get $L_3L_1L_2$. This $L_3L_1L_2$ is nothing but a level vector. These level vectors decide what nodes to be placed in what bin. So, all the nodes that have level vectors starting with the same level can be placed in a common bin. The positive aspect of this work is that, nodes need to calculate the distance between them and the landmark machine and need not worry about how distant these set of landmark machines are located. On top of it, as we have numerous landmark machines, there's no possibility of single point failure. Hence, distributed binning is considered as robust. However, a small set of landmark machines can degrade the performance of this binning mechanism.

In PAIS, Hilbert curve which is a space-filling curve [1] is used for mapping all the vectors obtained through the landmarking process into real numbers. Similar to the way levels are produced in the above mentioned process, Hilbert number is what is produced in PAIS to denote the closeness between two nodes. Hashing function like SHA-1 is used to produce collision-free unique hashes for nodes and files.

2.2.2 Clusters and Sub-Clusters. Cubical indices were used in PAIS to intelligently separate nodes based on their proximity and cyclic indices were used to further distinguish them based on their interests. PAIS uses the Hulbert number as its cubical index and the hash value of the node's interest item generated by SHA-1 to mod-d as the cyclic index. Combination of these two forms the ID of the node. In PAIS, a node can have multiple interests. That translates to having multiple cyclic indices. So, a node can have a set of IDs with varying cyclic indices. Using these IDs, nodes with close proximity [39] are clustered and then, clustering of common interest is done. So, all the nodes have the same Hilbert number if they belong to the same cluster and nodes in within the sub-cluster have the same ID.

2.2.3 PAIS Network Construction & Maintenance. When a new node with an ID that is identical to an existing ID, it gets added to the respective sub-cluster. When the joining node has an ID that is non-identical to an existing one, it becomes head node or super-node of the sub-cluster. In PAIS, there's a concept of backup node where a node acts as a secondary node to the sub-cluster head which comes in effect when the sub-cluster head's down. All the newly joining nodes will connect to the secondary node from here on. Basically, head of each sub-cluster is a centralized server to a subset of clients. This head node takes the responsibility of maintaining an index of files in clients.

When clients want to search for a specific item, the query is directed to the sub-cluster head. And these servers are in turn connected to all other servers in a cycloid [38] like structure. PAIS uses proximity neighbor selection method to build each peer's routing table.

PAIS proposes its own churn handling algorithms and file querying algorithms too. PAIS does a decent job in gaining efficient file querying through the proximity based clustering and interest based clustering.

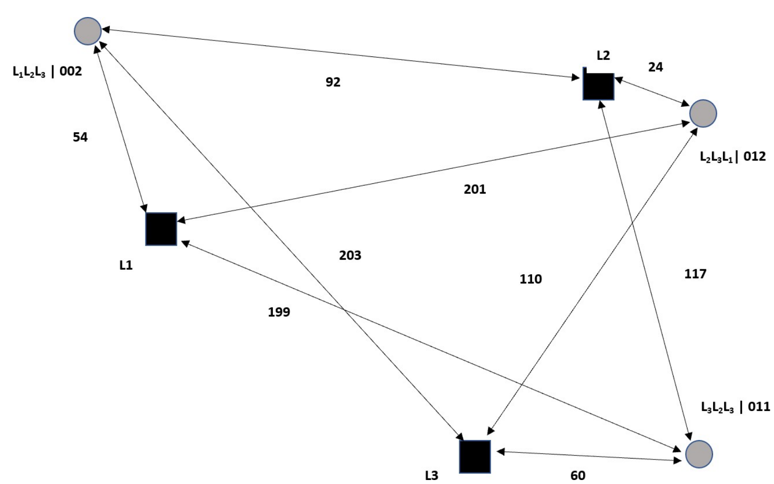

Figure 3: Ordering of level vectors in distributed binning

2.3 P3ON

Proximity based P2P Overlay Network(P3ON) [31] is a hierarchical ring network. This P2P network has two logical overlay rings, high tier ring and low tier ring. High tier ring is also known as a global overlay ring. This ring acts as the platform for every acting node in this P3O network. The low tier ring has another name called local overlay. This local overlay ring acts as a single AS - autonomous system. All the acting nodes which are of close proximity grouped together as a single autonomous system. When the geographical distance decides the hop count between two nodes and if a specific time is being searched more than once based on its popularity, the time it takes to lookup such item in a P2P network based on P3ON will be significantly lowered by an algorithm pair of ID assignment based on proximity and a two-phase searching is proposed in his work. And both these algorithms are de-centralized.

2.3.1 ID Assignment. In P3ON, it is assumed that a unique identifier is given to every acting node. A defined process is pro- posed in generating these unique identifiers. SHA-1, MD5 or any other hashing techniques are chosen to generate a hash for the acting node's IP address. This way a collision resistant hash could be generated and assigned. Based on the proposed hashing principle, P3ON proposes an algorithm for hierarchical ID assignment. For this, an assumption is proposed. A node should be able to successfully trace its own autonomous system (AS) identification number. What this means is, all identical AS numbers (ASN) [22, 26] are assigned to nodes that are from the same AS. In P3ON, all the acting nodes that belong to a specific AS are managed by a centralized authority and for this a node from the same AS is nominated. In P3ON, all the identifiers are selected from a 176 bit name space. Every acting node gets 16bit address space to represent what autonomous system it belongs to. So, ASN takes the first 16 bits out of the 176 bits NodeID. The remaining 160 bits are generated by using SHA-1 to hash out node's IP address. Concatenation of 16bits of ASN and 160 bits of node IP hash forms the NodeID. This is unique due to the principles of hashing and no node can have the same IP address. To take advantage of distributed hashing, itemID also has the same size as a nodeID. So, in this case, itemID also has a size of 176 bits. Similar to NodeID, the last 160 bits of the address are generated by implementing SHA-1 to output hash on the item name. However, as items don't have the idea of an autonomous system that they pertain to, the first 16 bits of the address are opted by simply copying the last 16 bits of the latter 160 bits. Below Figure 4 gives a quick glance at how NodeIDs and itemIDs are generated.

2.3.2 Two Level Ring Hierarchy. As mentioned earlier, P3ON has two tiers. The high tier ring maps all the acting nodes and it the primary overlay in P3ON. Following the proposed ID assignment algorithm, all the close proximity nodes which are of the same autonomous system are mapped next to each other on the high tier ring. Once the mapping is done, the high tier ring is then segregated into multiple units based on the autonomous system of the nodes. As a result, low tier rings are formed. This means that the number of autonomous systems participating equals the number of low tier rings. To form these low tier rings, an additional link per autonomous system [9, 31] is required. This link is used to connect the node with the highest ID and the node with the lowest ID in the AS.

If a specific node's ASN is not similar to its predecessor's ASN, it means that the node is with the lowest ID and is first in the list. Now this node should reach out to the highest ID node to make a low tier connection. This is the lowest ID node's responsibility. Similar to Chord [40], finger tables are maintained to manage high tier and low tier rings.

2.3.3 .Two-Phase Searching Algorithm. *Low Tier Ring Search:* Whenever a node is trying to search for a specific item, it starts the lookup process within the low tier ring first. To initiate this searching process, a local itemID is created. This local itemID is obtained by concatenating the node's 16 bit ASN and the 160 bit hash result of SHA-1 worked on the item's name. The lookup process begins once the local itemID is generated. Unfortunately, this process results in a hard miss as all the keys are initially located in the high tier ring. If by any chance, a low tier peer that has stored previously queried keys, possesses the item that matches with the current local itemID, it begins responding to the query. This peer is also known as local target node. For low tier peers to accommodate storage of previously queries keys, independent local cache is required. Every time a

NodeID = ASN || SHA-1(node's IP address)

ItemID = (last 16 bits of SHA-1(item name) || SHA-1(item name)

Figure 4: P3ON identifier generation

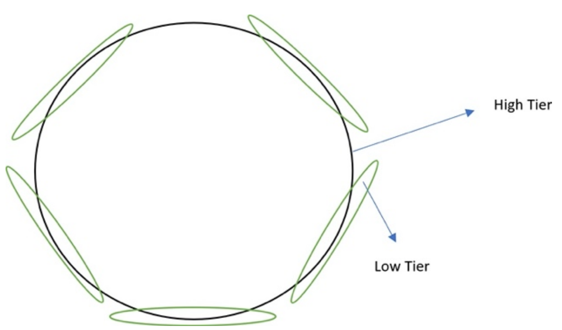

Figure 5: P3ON two-tier overlay hierarchy

previously queries key is to be recorded in the cache, information like itemID, position of the item and the latest query originator is important. As the originator has the actual item itself, it will help provide the actual location of the item. So, the item can be downloaded within the AS if a search happens for it when there's a matching entry in the local cache. P3ON uses LRU - Least Recently Used policy to manage the local cache.

High Tier Ring Search This is the second phase of the Two-Phase searching algorithm proposed in P3ON. In this phase, the local target node is the originator. Instead of using the local itemID that was used in Phase-1, original itemID that was defined in Figure 5 is used. P3ON uses the Chord lookup procedure as the High tier ring searching mechanism. There's absolutely no state of search failure as every item and node of the distributed address space are located on the high tier ring. Once the result is met, the response is pushed to the query originator via local target node. Local target node then makes an entry into the local cache to limit the query processing internal to the low tier when the same item was searched in the future [8].

This work also talks about dynamic load balancing, lookup latency simulation and load distribution in detail. Considering everything proposed in this work, P3ON can be considered as a fast, scalable lookup system. Replication of popular keys to low tier nodes is the key for P3ON to work effectively. P3ON is stated to outperform Chord in terms of lookup time and achieving balance in load distribution. However, the underlying topology is key to the said performance of P3ON.

2.3.4 CA-P2P. To overcome the P2P challenges due to the factors like networks being infrastructure less, peers being service or application oriented, range of use cases being vast, limitations in configurations of participating devices and massive increase in the presence of IOT [17] devices, CA-P2P [23] proposes an advanced range of features. Context-awareness is one of such features. CA-P2P stands for context-aware P2P system. Similar to the other systems studied in this paper, CA-P2P also focuses on proximity awareness as context-awareness includes location knowledge as well. This is what the existing systems like WiFi-Direct, Bluetooth as shown in Figure 6 have limited to no support. This work points to the context-awareness in its functional system design through provisions like peer discovery, peer association and frame structure. CA-P2P is primarily focused to overcome challenges in infrastructure-less environments but CA-P2P works in infrastructure environments too. The nature of infrastructure environments will make CA-P2P even more efficient. Context awareness is all about acquiring information that would help analyze the situation and surroundings of a specific node. In a P2P systems there are several kinds of context information. In this work, all these kinds are categorized into several classes which are mentioned in Figure 7.

Location of the node, mobility status and other configuration information constituted to Device Information class. Bandwidth, congestion, link connection quality constitutes to Network Information class. User class deals with specific service/application user's information whereas service class relates to the characteristics of the service. All the mentioned classes of information is divided into types - static or dynamic. Incorporating static information into the system design is not as complicated as having dynamic information incorporated. To achieve this, CA-P2P came up with two steps - context management and context exploitation

Context Management step is all about collecting and passing dynamic context information. Dynamic information here could be network information which is always changing. Assuring the accuracy of the collected information is not easy especially considering the nature of the information collected. Once collected, an identifier is assigned to information for management reasons. This will help a lot especially when the collected information is shared across multiple protocol layers. **Context exploitation** is all about using the context information

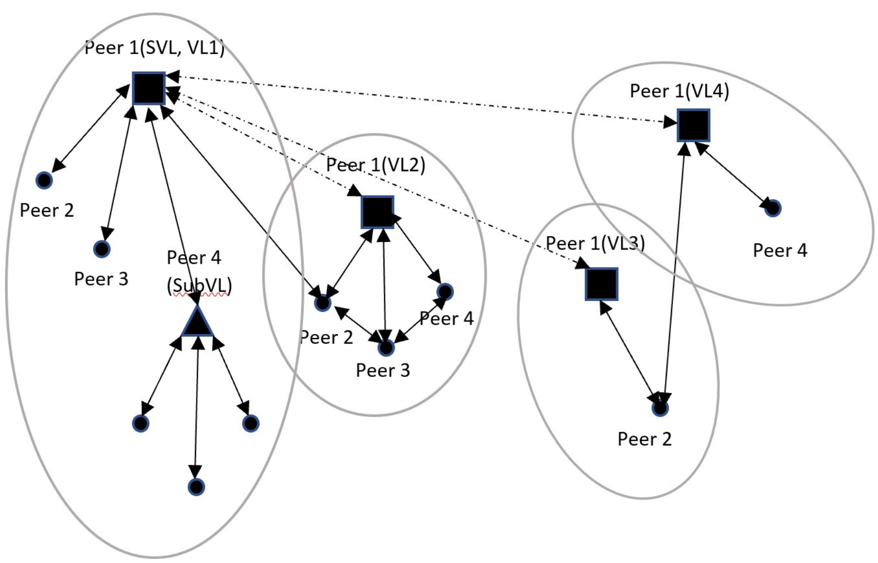

Figure 6: CA-P2P control schemes

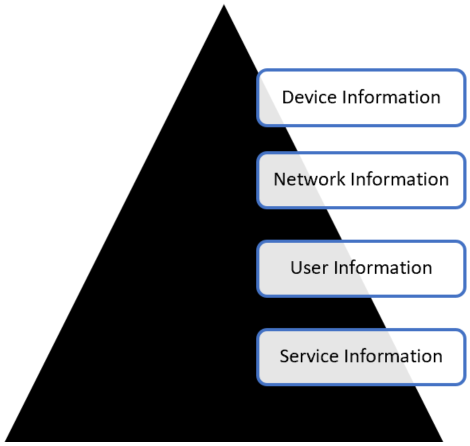

Figure 7: Various classes of context information

information that was managed to design P2P communication protocols. For example, proximity information can be used in designing protocols for efficient communication and processing. Gaming, file sharing, searching, resource pooling over P2P systems can be efficiently managed when proximity context information is integrated while developing protocols.

Similarly, to mitigate the challenges possessed by infrastructure less architecture in P2P systems and the vast range of use cases, this CA-P2P work has come up with three control schemes.

- Virtual Leader (VL)
- Super Virtual Leader (SVL)

From the group of peers that are grouped together as they share the same context-based service, a peer is picked to represent the group, manage it and coordinate the P2P communications as the Virtual Leader. There can only be one VL per application. In the majority of the cases, the peer that has initiated the whole P2P network would be considered as the VL. The peers from the group get to pick a new VL too. A Super Virtual Leader is the peer that was selected among multiple VLs. This Super VL is picked to coordinate with all VLs. SVL is the top leader among hierarchical chain. Similar to the VLs, the peer that has initiated the whole P2P networks is the default SVL until a new one is picked. Sub VL is the one that is selected to ex-tend the range of P2P network through multi-hop. Sub VL is usually under a specific Virtual Leader. Sub VL acts as a subset of VL. This hierarchy model and control will offset the infrastructure less network.

2.3.5 Context-Aware Peer Discovery. Finding peers that are in close proximity is done through a process called Context-Aware Peer Discovery.

The resultant of this process is a candidate list of peers that are discovered with desired service in mind and are close to each other. There are three main stages of peer discovery shown in Figure 8.

In the peer discovery scan, a peer looks out for other peers that are close to its location and interested in the same service/application. Once a peer is found, the scanning [45] peer enters into a peer discovery evaluation stage where it qualifies the discovered peer. Multiple peers can also be discovered in the scanning process at once. If by any chance, no peer is discovered in the scanning stage or fails to qualify for the interested service/application, the initiated peer enters the third and final stage of discovery requesting. In this phase, the original peer makes itself available for discovery. So any peer can have two roles in this process either to-discover role or to-be-discovered role [24]. If a peer is qualified, it gets added to the candidate list. The moment a discovered peer is through the evaluation process and added to the candidate list, the initiating peer has a choice to continue scanning for more peers or enter the "to-be-discovered" mode. Once the candidate list is finalized, it gets passed on to the context-aware peer association procedure.

2.3.6 Context-Aware Peer Association. This is the phase where a logical connection gets set between peers. Device based, service based and user based are the three associations that any peer can possibly have with another. Every such association will have its own identifier here. This identifier is known as AID-Association Identifier and the information related to these associations is known as ACI-Association Context Information. Device based association has an identifier named DAID. Similarly, service-based association's identifier is SAID and UAID is the user-based association identifier. Between any two peers there will at most be one association which is device based and multiple service or user-based associations. After a peer receives the candidate list that was generated in the peer discovery process, it opts for a peer which is appropriate to it. This selection is based on the link quality, bandwidth, security etc. When the peer selects one out of the candidate list, it sends an association request. Association happens when it receives an association response from the targetpeer. Communication happens once an association is established. Similarly, when a peer decides to leave the association, disassociation process is triggered.

Figure 8: Peer discovery stages

This way, CA-P2P acts as a modular solution proposed to establish context-aware communication directly between two peers within proximity.

3 Various Works on Common-Interest Based Clustering

In this section, peer-to-peer network architecture formulations on common-interest clustering models are discussed. P2P networks based on Chinese Remainder Theorem, Residue Classes, Pyramid Tree are studied.

3.1 CRT Modeled Common-Interest Based P2P System

An interest based [13, 32, 45], non-DHT based hierarchical P2P architecture is conceived in this work. Each level of this architecture is structured and diameter of each network is 1 overlay hop. This work [12] is supposed to be the first successful attempt made to design structured hierarchical P2P networks with a diameter of 1 overlay hop in every sub-network it constitutes. The proposed architecture uses a mathematical model based on the Chinese Remainder Theorem (CRT) to define the neighborhood relations among the peers to obtain small diameters. In this work, a very efficient intra-group as well as inter-group data look up algorithms with *O*(1) time complexity exploiting the above mentioned low diameter features of the P2P system is presented. In addition, algorithms related to peers joining with new and existing resource types are also defined in this work.

A resource is defined as a tuple < R_i, V> , where R_i denotes the type of resource and V is the value of the resource. A resource can have many values. For example, R_i denotes the resource type ‘songs’ and V’ denotes a particular singer. Thus, < R_i, V’> represents songs (some or all) sung by a particular singer V’. In the proposed model for interest-based P2P systems, it is assumed that no two peers with the same resource type R_i can have the same tuple; that is, two peers with the same resource type R_i must have tuples < R_i, V’>.

3.1.1 Two Level Hierarchy. A two-level overlay architecture is proposed and at each level structured network of peers exist. At level 1, we have a network of peers such that peers are directly connected (logically) to each other. In graph theoretic term, the network at level 1 is a complete graph. Hence, the network diameter is 1 overlay hop. The periphery of this network appears as a ring network, and we name it as transit ring network. This network consists of the peers Pi (0 < i<r-1). Therefore, number of peers on the ring is r, and we have assumed that this number represents the number of distinct resource types of the P2P system. Each of these r peers will be termed as a group head. The periphery of this network as well as the direct links connecting any two peers in this network can be used for efficient data lookup. At level-2, there are r numbers of completely connected networks of peers. Each such network, say N_i is formed by the peers of the subset PR_i, (0< i < r-1), such that all peers (ε PR_i) are directly connected (logically) to each other, resulting in the network diameter of 1 overlay hop. Each such N is connected to the transit ring network via the peer Pi, the group-head of network N_i. From now on network N_i will be called as $group_i$ (in short as G_i) with P_i as its group-head. Sometimes N_i will be referred to as the i^{th} cluster as well. The proposed architecture is shown in Figure 9.

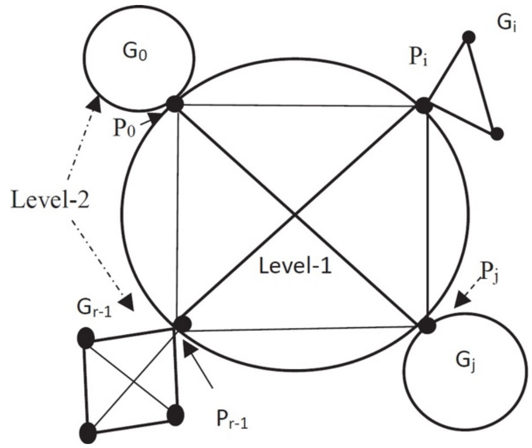

Figure 9: Two level architecture

3.1.2 Chinese Remainder Theorem. A simultaneous solution (a positive integer) of a given system of linear congruencies is determined to form the architecture. More solutions are then determined depending on the architecture. To achieve this, a mathematical model called Chinese Remainder Theorem is used in this work. Each such solution will become the logical address of a group head uniquely. At the same time, we will determine separately the solutions of each linear congruence as needed and these solutions will represent the logical addresses of the peers present in a group.

Chinese Remainder Theorem (CRT) states the following: Suppose $m_0, m_1, m_2, \ldots, m_{r-1}$ are r integers such that no two of which have a common factor other than 1. Let M = $m_0 m_1 m_2 \ldots m_{r-1}$. Also suppose that $a_0, a_1, a_2, \ldots, a_{r-1}$ are integers such that gcd (a_i, m_i) =1 for each i. Then the r congruencies given as $a_i x$ b_i (mod m_i), 0 ™ i ™ r-1 have a simultaneous solution X that is unique modulo M and is given as X = $c_o n_1 n_1^{\sim} + c_2 n_2 n_2^{\sim} + \ldots + c_{r-1} n_{r-1} n_{r-1}^{\sim}$ where $n_i = M/m_i$ and gcd (n_i, m_i) = 1; that is, n_i $n_i^{\sim}$ 1 (mod m_i); and c_i is the least positive integer such $a_i c_i$ b_i (mod m_i), for 0 ™ i ™ r-1. Also, note that each congruence, $a_i x$ b_i (mod m_i) has a solution x_i, which is unique modulo m_i because any solution x_{ij} of it is congruent to x_i modulo m_i. The reason for this is that gcd (a_i, m_i) = 1 for each i.

An example:

$$x \equiv 2 \pmod 3 \quad (1)$$
$$x \equiv 3 \pmod 5 \quad (2)$$
$$x \equiv 2 \pmod 7 \quad (3)$$

These three congruencies satisfy all restrictions of CRT. We see that $a_1 = a_2 = a_3 = 1$ and $c_1 = 2$, $c_2 = 3$, $c_3 = 2$; M = 105; also $n_1^{\sim} = 2$, $n_2^{\sim} = 1$, $n_3^{\sim} = 1$.

Therefore, the simultaneous solution satisfying all these three congruencies is 23 (the least positive solution) and all solutions are congruent to 23 (mod 105). That is, all solutions of the form 23+k.105 (k is an inte-ger) are mutually congruent as well since ‘congruence’ is an ‘equivalence’ relation.

3.1.3 Architecture Construction. ’r’ linear congruencies are considered, a_ix bi (mod mi), 0 ™ i ™ r-1, which satisfy the CRT’s requirements as mentioned earlier. Each such congruence is also known as linear Diophantine equation (LDE) [33] and note that each congruence, a_ix b_i (mod m_i) has a solution xi, which is unique modulo m_i. As mentioned earlier, the P2P architecture will be a 2-level structured one such that at each level, network(s) will have a diameter of one overlay hop. It will greatly enhance the speed of data lookup algorithms [34].

Level-1 Address Assignment. Suppose that P_0 is the first peer to join the system with resource type R_0. Therefore, P_0 is considered as the group head of group G_0 that has currently only one peer, namely, P_0. The logical address X (the simultaneous solution X) is assigned. Later when other peers with the same resource type join, they are placed in the group G_0. Next, suppose that peer P_1 is the first to join the system with resource type R_1 among all other peers that have the same resource type. Therefore, P_1 becomes the group head of group G_1. It will get the logical address (X+ M). Observe that the solutions X and (X + M) are mutually congruent. The process of assigning logical addresses to group heads implies that group head P_i with resource type R_i joins the system before the group head P_{i+1} with resource type R_{i+1}. Hence, for assigning logical addresses to group heads, the sequence of their arrivals is used; therefore, in general, the logical address of a group head Pi becomes (X + iM). Observe that all these addresses are mutually congruent. Besides, the resource type Ri of Pi gets the code [X + iM].

Congruence relation is used to create logical links between peers in this work. Therefore, because of the ‘equivalence’ property of ‘congruence’ relation, all logical addresses are mutually congruent. Hence, we link each P_i directly with any other P_j, j *f*= i. Observe that such overlay links among the peers have created a network (a complete graph) of r peers at Level 1. That is, the diameter is 1 overlay hop.

Level-2 Address Assignment ’r’ congruencies are used to assign addresses to the members of different groups. It is considered that the i*th* congruence, viz., a_ix b_i (mod m_i) for address assignments for peers in G_i. Note that this congruence has a solution xi, which is unique modulo m_i. any solution x_{ij} of it is congruent to x_i modulo m_i. In addition, all solutions of the form [x_i + k.m_i], where k is an integer, are mutually congruent since ‘congruence relation’ is an ‘equivalence relation’. We assign x_i as the Level-2 address for the group head P_i. Later based on the sequence of arrivals of peers possessing the same resource type, peer p_j (G_i) will get the address (x_i + j.m_i) and pj+1 (G_i) will get address [x_i + (j+1).m_i] assuming that p_{j+1} joins after p_j, and so on. As before, based on our mathematical model two peers are neighbors if their logical addresses are mutually congruent; meaning thereby that two peers in a group are directly linked if their logical addresses are mutually congruent. Therefore, because of the equivalence relation, each peer in G_i is logically connected to every other; hence, the diameter of the group G_i (i.e., the cluster N_i) is 1 overlay hop, making the cluster a complete graph.

This novel two level hierarchical P2P network architecture in which diameter of each cluster at Level- 2 is just 1 overlay hop and diameter of the network at Level-1 is also 1 overlay hop. Churn handling and data lookup algorithms were also proposed in this system that take full advantage of this directly connected network.

3.2 RC Modeled Common-Interest Based P2P System

A two-level overlay architecture has been proposed in this work [10] and at each level structured networks of peers exist as shown in Figure 10. At level-1, a ring network consisting of the peers P_i (0 <i <n-1) is present. The number of peers on the ring is n which is also the number of distinct resource types. This ring network is used for efficient data lookup, and so we name it as transit ring network. At level-2, there are n numbers of completely connected networks (groups) of peers. Each such group; say Gi is formed by the peers of the subset P*Ri*, (0 ™i ™ n-1), such that all peers (P*Ri*) are directly connected (logically) to each other, resulting in the network diameter of 1. Each G_i is connected to the transit ring network via its group-head P_i. Each peer on the transit ring network maintains a global resource table (GRT) that consists of n number of tuples.

GRT contains one tuple per group and each tuple is of the form <Resource Type, Resource Code, Group Head Logical Address>, where Group Head Logical Address refers to the logical address assigned to a node by our proposed overlay P2P architecture. Also, Resource Code is the same as the group-head ogical address. Any communication between a peer $p_i \in G_i$ and $p_j \in G_j$ takes place only via the respective group-heads Pi and P_j. Consider the set S_n of non-negative integers less than n, given as S_n = {0, 1, 2, (n – 1)}. This is referred to as the set of residues, or residue classes (mod n). That is, each integer in S_n represents l a residue class (RC). These residue classes can be labeled as [0], [1], [2], …, [n – 1], where [r] = {a: a is an integer, a≡ r (mod n).

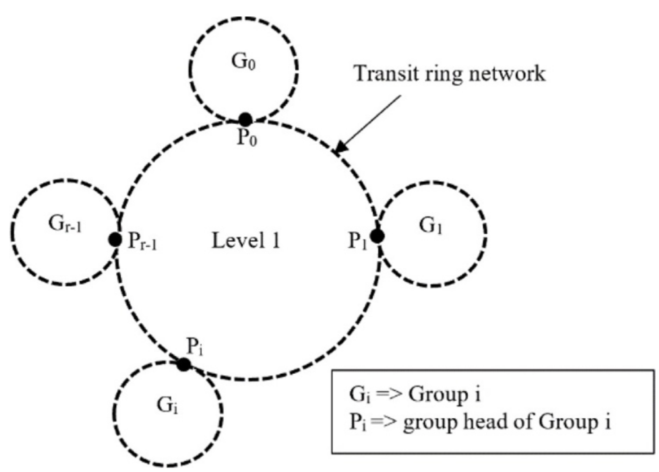

Figure 10: RC based two level hierarchical network

For example, for n = 3, the classes are:

[0] = {. . . ., – 6, – 3, 0, 3, 6, }
[1] = {. . . ., – 5, – 2, 1, 4, 7, . . . }
[2] = {. . . ., – 4, – 1, 2, 5, 8, . . . }

Thus, any class r (mod n) of Sn can be written as follows:

[r] = {.. . . , (r - 2n), (r - n), r, (r + n), (r +2 n), (r+ (j-1). n), (r + j.n), (r + (j+1). n), }

In the proposed P2P architecture, we shall use the numbers belonging to different classes as the logical addresses of the peers; therefore, for the sake of simplicity we shall use only the positive integer values. Before we propose the mechanism of logical address assignments, we state the following relevant property of residue class. Any two numbers of any class r of S_n are mutually congruent. Diameter of the transit ring network is n/2. Each group G_r forms a complete graph. In the proposed overlay architecture, the positive numbers belonging to different classes are used to define the following parameters:

1. Logical addresses of peers in a subnet P*Ri* (i.e. group G_i). Use of these addresses will be shown to justify that all peers in G_i are directly connected to each other (logically) forming an over-lay network of diameter.
2. In graph theoretic term, each Gi is a complete graph
3. Identifying peers that are neighbors to each other on the transit ring network.
4. Identifying each distinct resource type with unique code.

The assignment of logical addresses to the peers at the two levels and the resources happen as follows:

1. At level-1, each group-head P_r of group G_r is assigned with the minimum non-negative number (r) of residue class r (mod n) of the residue system S_n.
2. At level-2, all peers having the same resource type R_r will form the group Gr (i.e., the subset P*Rr*) with the group-head P_r connected to the transit ring network. Each new peer joining group Gr is given the group membership address (r + j.n), for j = 0, 1, 2, . . .
3. Resource type R_r possessed by peers in G_r is assigned the code r which is also the logical address of the group-head P_r of group G_r.
4. Each time a new group-head joins, a corresponding tuple <Resource Type, Resource Code, Group Head Logical Address> is entered in the global resource table (GRT).

Features of RC-Based Structured P2P Network is summarized below:

1. It is a hierarchical overlay network architecture consisting of two levels; at each level the network is a structured one.
2. Use of modular arithmetic allows a group-head address to be identical to the resource type owned by the group.
3. Number of peers on the ring is equal to the number of distinct resource types, unlike in existing distributed hash table-based works some of which use a ring network at the heart of their proposed architecture.
4. The transit ring network has the diameter of n/2. Note that in general in any P2P network, the total number of peers N >> n.
5. Each overlay network at level 2 is completely connected. That is, in graph theoretic term it is a complete graph consisting of the peers in the group. So its diameter is just 1. Because of this, the smallest possible diameter (in terms of number of overlay hops) the architecture offers minimum search latency inside a group.

3.3 Pyramid-Tree Modeled Common-Interest Based P2P System

In this work, it is assumed that no peer can have more than one resource type. Generalization of the architecture is not considered in this work. In pyramid tree [10, 35], Figure 11 there are n numbers of completely connected networks (groups) of peers [47]. Each such group, say G_i is formed by the peers of the subset P*Ri*, (0 ™i ™n-1), such that allpeers (P*Ri*) are directly connected (logically) to each other, resulting in the network diameter of 1. The group-heads of the n groups are connected to form the edges (links) of the pyramid tree. Any communication between a peer $p_i \in G_i$ and a peer $p_j \in G_j$ takes place only via the respective group heads P_i and P_j and with the help of tree traversal. Modular arithmetic described in the above RC based approach is used in this work.

In this P2P architecture, the numbers belonging to different classes as the logical addresses of the peers were used; therefore, for the sake of simplicity only the positive integer values were considered. Assume that in an interest-based P2P system there are n distinct resource types [21, 43]. Note that n can be set to an extremely large value a priori to accommodate large number of distinct resource types. Consider the set of all peers in the system given as S = {P*Ri*}, 0<i <n-1. Also, as mentioned earlier, for each subset P*Ri* (i.e.group G_i) peer P_i is the first peer with

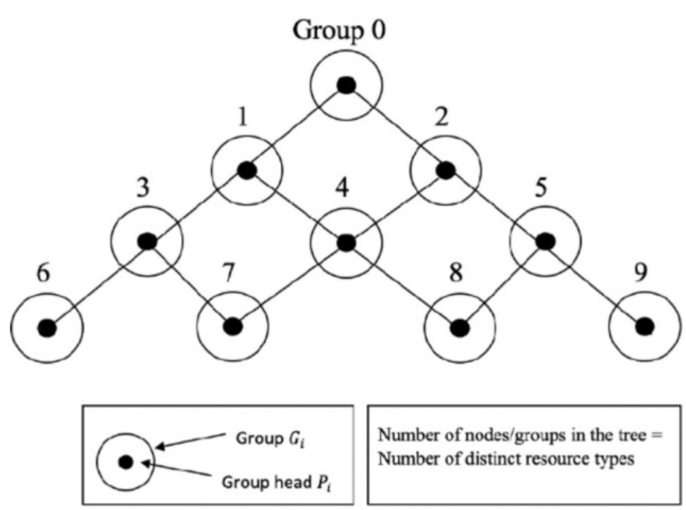

Figure 11. Pyramid tree-based network

resource type R_i to join the system. Logical addresses of peers in a subnet PR_i (i.e. group G_i). Use of these addresses will be shown to justify that all peers in G_i are directly connected to each other (logically) forming an overlay network of diameter 1. In graph theoretic term, each G_i is a complete graph. Identifying the edges (links) that connect different group-heads of the n groups in the tree [20].

Address assignment is done by the following way, each group-head P_r of group Gr is assigned with the minimum non-negative number (r) of residue class r (mod n) of the residue system S_n. All peers having the same resource type R_r will form the group G_r (i.e. the subset PR_r) with group-head Pr. Each new peer joining group Gr is given the group membership address (r + j.n), for j = 0, 1, 2, . . . Resource type R_r possessed by peers in G_r is assigned the code r which is also the logical address of the group-head Pr of group Gr. Any two numbers of any class r of S_n are mutually congruent. Each group G_r forms a complete graph.

Features of the pyramid tree approach are mentioned below:

1. Use of modular arithmetic allows a group-head address to be identical to the code used to identify the resource type owned by the group.
2. Each overlay group is completely connected. That is, in graph theoretic term it is a complete graph consisting of the peers in the group. Therefore, its diameter is just 1. Because of this smallest possible diameter (in terms of number of overlay hops), the architecture offers minimum search latency inside a group.
3. In a complete pyramid tree, multiple paths exist between most of its nodes. Such a structural characteristic can be helpful from the viewpoints of designing communication protocols that are load balanced as well as robust.
4. Search latency for inter-group data lookup algorithm is bounded by the tree diameter and is independent of the number of the distinct resource types as well as the total number of peers present in the system.

3.4 Other Interest Based Works

In this section, several noteworthy interest-based P2P systems have been discussed along with their main features. All these works have incorporated the idea of peer heterogeneity in their design. In doing so the work in [19] has used the existing idea of super peer. Besides, gossiping has been used for cluster formation with peers of common interest. The work in [6] uses the idea of popular peer which is quite similar to the idea of super peer. The base architecture is an unstructured network. In [41], authors have considered super peer. It is a hybrid architecture that uses both chord and unstructured network. In [28], gossiping has been used for cluster formation. Besides, at the time of joining a new-peer searches from a list of known peers for a particular peer which has most links among all in the list and then gets connected to it. In [36]. authors have considered DHT-based structured P2P system considering both proximity - aware and interest-based cluster formation. Aim is to improve file location efficiency considering physically close peers with common interest. The work starts with the formation of a cluster consisting of physically close peers; it then forms sub-clusters with peers having common interest. Reasonable improvement of file location efficiency has been achieved. However, they have not considered the following highly probable situation: assume that there are q number of such clusters scattered around; each of them has a sub-cluster formed with physically close peers with the same interest, say i. Then what will be the inter-sub-cluster lookup efficiency? This problem has not been addressed in this research. Therefore, the work remains incomplete, even though the basic idea is good. In [14], a pastry-based P2P e-commerce model based on interest community has been proposed. Users with similar interest from an interest community and the users in such a community are not necessarily physically close. Authors have assumed that all such users are directly connected, i.e., such a cluster has the over-lay diameter of one hop. However, there is no mathematical basis for such an assumption. In [2], authors have considered the adaptation of P2P architecture to support social network characteristics. This P2P architecture is based on the idea of Chord. Peers with similar interest are linked and these links are created dynamically based on previous communication messages among the peers. These links are called interest links. Authors have proposed an efficient routing algorithm based on such links.

4 Conclusions

Several noteworthy P2P works that are based on proximity-awareness modeling and interest-based clustering have been discussed in this survey. It's evident that these works play a positive role in making the file querying very efficient. Further research may continue in the area of P2P Federation; especially the idea of interest-based systems may be applied to design architecture and protocols for P2P Federation.

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