PREFIX-BASED ADVERTISING AND SEARCHING SCHEMES FOR DISTRIBUTED SERVICE DISCOVERY IN LARGE-SCALE P2P NETWORKS

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By

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ABSTRACT

Service discovery is one of the most critical features in resource sharing over a large-scale network to ensure every service available in the network can be delivered when requested. Traditional approaches may employ a server to index a pool of resources so that users are able to query the server for the available resources. However, these approaches are not scalable and could risk the network performance by introducing single point failure. To resolve these issues, different algorithms have been proposed for distributed service discovery based on peer-to-peer architecture. However, they either adopt a brute-force method that floods a query over the network to search for a requested service, or are unable to provide locality awareness in which service providers in the close proximity should have better chance to be located than those that are far.

In this dissertation, a novel approach based on Pastry, a structured peer-to-peer system is introduced to address the aforementioned issues by using prefix-based advertising and searching for distributed service discovery. With the approach, two algorithms are further proposed. Simulation results demonstrate that the proposed algorithms are able to reduce the query traffic generated in a network with yet achieving high service discovery rate. Moreover, the algorithms are also able to support locality awareness with low routing complexity when compared with other approaches.

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APPROVAL SHEET

This dissertation entitled "**PREFIX-BASED ADVERTISING AND SEARCHING SCHEMES FOR DISTRIBUTED SERVICE DISCOVERY IN LARGE-SCALE P2P NETWORKS**" was prepared by TEOH EE NA and submitted as partial fulfillment of the requirements for the degree of Master of Computer Science at Universiti Tunku Abdul Rahman.

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DECLARATION

I hereby declare that the dissertation is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UTAR or other institutions.

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LIST OF ABBREVIATIONS

P2P	Peer-to-peer
DN	Directory node
SC	Service consumer
SP	Service provider
TTL	Time to live
BFS	Breadth first search
PASS	Prefix-based advertising and searching scheme
CPASS	Cumulative prefix-based advertising and searching scheme

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CHAPTER 1

INTRODUCTION

1.1 Background Information

Distributed service discovery has become a future trend due to the advent of sophisticated applications that require high computing power and communication between users. Over the Internet, sources of data can come from different part of the world due to the overwhelming number of networks and normally the data collected need extensive processing in order to produce useful information or specific services for users. In the past, such tasks were normally carried out in servers associated with expensive hardware. Quite many computers are nowadays equipped with server-grade computing capability as the cost of computing devices are getting lower and affordable, thus they can render their services to other users. As these computers could be located anywhere over a wide geographical area, or even over the world, hence there is a need for an efficient service discovery system that enables such tasks to be processed by using distributed resources available over the Internet.

Conventional service discovery approaches for resource sharing require centralised registries. The registries are usually managed by a dedicated server designed to hold information about the resources available in the network including the types and locations of the resources. However, centrally controlled servers usually come with such issues as traffic congestion at the servers and the risk of single-point failure. One of the solutions to resolve the issues is to replicate the servers (Bowman, et al., 1994). For example, the name servers that translate domain names into IP addresses where each domain name must have at least two name servers and the second server will be used as a backup server in case the first server is down (Christensson, n.d.). However, having multiple servers in the domain name system (DNS) requires synchronization between the servers and additional expensive hardware to achieve good performance. Furthermore, with the tremendous growth of new and much more complicated applications, it is difficult for such an approach to handle a huge number of new queries which are for a wide variety of services.

Thus, the future trend in service discovery requires distributed servers that offer users with alternatives to ensure the issues that come with centralised servers will not occur. In order to have a distributed service discovery approach, many researchers have started to integrate peer-to-peer (P2P) system with service discovery (Awan, et al., 2004; Guo, et al., 2006; Zhou, et al., 2011). The reason is three-fold. First, all peers in a P2P network is cooperative and plays equal roles. Secondly, each peer could host different resources and share the resources with other peers in the network. Thirdly, they can also serve as query servers, which host part of the network information, for each other.

Using P2P systems in service discovery can fully utilize the computers in the network that possess various computational capabilities, and largely reduce the dedicated resources required. Another advantage of using P2P network is that it offers better scalability and robustness compared with centralised registries.

1.2 Problem Statement

There are several issues that need to be addressed in using P2P system as an approach for service discovery in a large scale network. First, there should be a systematic routing procedure for service advertisement and discovery by peers in the network. This is to ensure that any peers are able to find and use the services in the network.

Second, the peers should be enabled, where it is possible, to find and use the resources in their close proximity in order to reduce the processing delay and the traffic of sending jobs over long distance in the network. Hence, locality awareness is important in service discovery.

Third, P2P system is commonly and intensively used for file sharing. The searching performance for file sharing can be improved by duplicating and storing the files in different peers thus making it easier for users to find the files they need. However, resources or services such as storage, computational power and peripherals cannot be duplicated from one peer to another. Hence, the performance in searching may greatly degrade causing high traffic and low success rate.

1.3 Motivation

There are only a few of distributed service systems available currently. One famous example is grid computing. In grid computing, each computer's resources such as compute power, memory and storage can be shared among each other in the network. However, a control node or dedicated server must be put in place to administrate the pool of resource in the network (Strickland, n.d.), which may suffers from the issue of single-point failure. A popular example is the SETI@home project by Cobb, et al. (2002).

Another example is Domain Name System (DNS), a distributed database implemented in a hierarchy of name servers. A DNS client sends a query to a DNS server in order to resolve hostnames to IP addresses. Initially, local name servers are queried first and if the local name servers are unable to resolve the query, the query will be sent to dozens of root servers. The bottleneck and single point of failure issues are prevented when a network of name server exists (Young, 2013). However, a query may take a long time to resolve as the query must follow each level of the hierarchy and repeat the request on each level if the local name server does not have the information required.

One of the main issues that need to be resolved in distributed service discovery on P2P network is, without a centralised server, the service of a peer may not be discovered by another peer who needs it. Generally, when a peer has services or resources to share with other peers, it has to advertise its capabilities at a server. Otherwise, the peers who are in need of services will have to resolve it with a brute force method by flooding the network.

In order to achieve a completely distributed service discovery, an approach is to have all peers in the network to be a part of the service discovery system. In this way, all peers in the network are able to not only share resources but also cooperate among each other for service queries. Besides, the hardware and software capabilities of each machine connected to the network can be fully utilised.

Since there is no centralised server to control the resources in the network, each node is responsible to control their own resources, resulting in better load distribution. Besides, nodes leaving the network may have little effect in resource sharing as there may be other nodes in the network that can provide the same service. Furthermore, service discovery using P2P is more scalable when compared with centralised service discovery.

1.4 Objectives

The following are the objectives of this research:

1. To investigate the existing approaches in distributed service discovery that can be integrated with peer-to-peer systems in order to demonstrate the efficiency of those approaches.
2. To design efficient approaches for distributed service discovery that is able to provide:
    a. Low complexity in routing
    b. Locality awareness in routing
    c. High success discovery rate
3. To analyse and compare performance, efficiency of the existing approaches with the proposed solution.

1.5 Research Contributions

The major contributions of this research are as follows:

(1) The proposed approaches introduce a prefix-based method to define “directory node”, and uses the directory nodes as a platform for service providers to advertise their capabilities and to allow other nodes to find these service providers. As the directory nodes are chosen based on the

prefix of the node identifier, this enables any node in the network to become a directory node hence, the service discovery is more distributed and scalable.

(2) Based on the directory node scenario, two distributed service discovery schemes are proposed in this dissertation, namely Prefix-based Advertising and Searching Scheme (PASS) and Cumulative Prefix-based Advertising and Searching Scheme (CPASS). In particular, CPASS is a novel approach and a patent has been filed for the scheme.

(3) Simulations are conducted in order to measure the performance of PASS and CPASS compared with the existing approaches. Through these experiments, PASS and CPASS are shown to have superior performance based on the simulation results. That is, both PASS and CPASS are able to:

   a. Maintain locality and deterministic routing with log order complexity using Pastry as the underlying P2P system
   b. Achieve good success rate without generating high volume of traffic in the network

1.6 Organisation of dissertation

The remainder of this dissertation is organised as follows. In Chapter 2, thorough literature review is presented in order to justify the research design. In Chapter 3, the discussion on unstructured and structured P2P for distributed service discovery is presented. Simulation results are also shown to verify our argument regarding the shortcoming of unstructured P2P service discovery approaches. In Chapter 4, the proposed scheme, PASS is described and simulation results of PASS are also shown. In Chapter 5, PASS is improved and CPASS is introduced and the simulation results of CPASS are discussed as well. The resiliency of CPASS is tested and the simulation results are shown in Chapter 6. Finally, Chapter 7 is the concluding chapter and future work is also described here.

CHAPTER 2

LITERATURE REVIEW

2.1 Basic concepts

In general, P2P systems can be categorized into unstructured and structured P2P. Structured P2P networks maintain a logical structure among all the peer nodes at the P2P layer (Lua, et al., 2005). As such, they require certain proactive coordination among nodes prior to nodes being able to forward messages. Compared to unstructured P2P, however, structured P2P provide more efficient routing when a node needs to forward its updates or queries to the corresponding nodes which host the resources. In this project, a structured P2P network, namely Pastry (Rowston & Druschel, 2001), is employed as the underlying network architecture to support the distributed service discovery schemes that we propose. Although our work can also be extended to other structured P2P approaches, Pastry shows its superiority in providing locality awareness. In the following subsections, existing P2P systems and some distributed service discovery approaches are reviewed and discussed in order to justify our design.

2.2 Unstructured P2P

Searching in unstructured P2P system is simple and straightforward as there is no rule that define neighbours' nodes or where files should be stored (Li & Wu, 2005). Hence, many researchers proposed using unstructured P2P to solve the bottleneck and scalability issues in resource sharing because unstructured P2P system requires less maintenance and there is no special network structure as nodes join and leave as they wish. However, there are several issues with unstructured P2P networks. Firstly, the searching strategy in unstructured P2P involves blind search or informed search, i.e., nodes in the P2P network have no information about other peers whereas nodes in informed search keep some data location information. Secondly, when searching for certain resources in a network, unstructured P2P uses message flooding by broadcasting messages to all directly connected peers in the network. When there exist too many requests, in unstructured P2P, the number of messages in the network would be too many and this could cause traffic congestion. Besides, unstructured P2P systems are usually for file sharing application. Popular files will have better availability and stability because more peers are sharing them (P2PNews, 2012). However, this could become a problem when peers are sharing information about one popular resource provider as this could cause the popular resource provider to become more popular, causing unbalanced load distribution among providers who can offer the same resource.

One of the examples of distributed service discovery on unstructured P2P network was proposed by Awan, et al., (2004). The author proposed a distributed architecture for sharing processor cycles in an unstructured P2P network. One of the assumptions made in the proposed approach is that a job, can be broken down into a few independent subtasks and these subtasks can be grouped into batches. The consumer will submit each batch job to a neighbour node chosen randomly by performing a random walk. In order to protect the resiliency of the proposed method, a replication factor, *r* is attached with each batch job to enable a batch job to be processed by *r* different nodes. The author argued that redundancy in such an approach is important to account for node failures and validate the reported results. However, this approach could result in decreased productivity and wasted resource. Besides, since the approach only focuses on sharing processor cycles, selecting peer nodes for job submission using random walk may be appropriate but this may become a problem in successfully finding peer nodes if the required resource is anything other than processor cycles.

Tie, et al. (2006) proposed a Peer-Tree approach that consists of two layers which are the peer layer and the tree layer. Similar service types are grouped into a tree and the root of the tree is named as a super peer. The peer layer consists of only super peers and uses unstructured P2P as the routing protocol for searching. The approach is able to minimize the number of nodes in the peer layer by grouping peers who can provide similar services into a tree, hence may result in less traffic in routing. However, single-point failure may occur if the super peer for a requested service leaves the network. Besides, there may be overhead in searching as there are two layers that need to be searched sequentially, i.e. searching in peer layer and then searching in tree layer. This approach may work well in a small-scaled network however, in a large-scale network with many different types of services that cannot be grouped into a tree will require high traffic and higher depth to achieve a good success rate.

ASAP (Gu, et al., 2007) is a search algorithm for unstructured P2P network that uses Bloom filters across the network enabling nodes to search for services without sending anything other than confirmation messages. Advertisement will be sent by new nodes as they join the network or when any node in the network requests them. Nodes in the network can also choose to only save information on topics that they are interested in. With the help of Bloom filters enables traffic to be reduced during the searching phase. However, a service consumer still has to expand its search radius according to the maximum time-to-live if its nearest neighbours do not have the advertisement requested. Besides, some nodes could keep so many advertisements locally and may not even use it. On the other hand, publishing advertisement is only done one time as new node join causing newer consumer nodes the need to request for advertisement by the means of flooding.

Clustella, an approach proposed by Stefan and Roger (2007) attempts to improve the efficiency of flooding by decomposing the network into different clusters. Each cluster has its own beacon that enables peers in the network to identify other clusters. A peer is elected to become a beacon if there is no existing beacon in the peer's cluster. The beacon is used to ensure the routing table entries of a peer are far from each other but are near to the peer itself. Hence, when routing for a certain key in the network, a message can be forwarded quickly to peers that are far from the local peer. However, a message could be forwarded back and forth to the same cluster which may not be reliable. Besides, Clustella has a system that enables a packet to continue to be routed to its destination even after its time-to-live (TTL) is reached by enabling the packet to be piggybacked on another packet. Although this approach can help to extend the flood coverage without increasing network traffic but the size of the packets that have to piggyback another packet will also increase. A big packet that has to be passed and broadcasted may need to be fragmented into smaller packets which could result in increase in network traffic and reduce throughput.

Search+ is a distributed service discovery scheme by Skjegstad & Johnson, (2009) that uses unstructured P2P for routing. The overall architecture is simply an enhanced version of ASAP. However, instead of broadcasting advertisements to the network like ASAP, new nodes in Search+ are given the option to only subscribe to advertisements they are interested in as they join the network. This will establish subscriptions of advertisements that it is interested in and the new nodes will be informed as new advertisements of their topic of interest comes in. This method is very effective in reducing bandwidth and traffic generated in service searching but flooding is still unavoidable when the node changes its topic of interest. Maintenance process is provided in Search+ where queries will be sent to the network, requesting advertisements from neighbouring nodes but this method is still similar to blind search.

As searching in unstructured P2P systems are usually blind, Anusuya, et al (2010) proposed using an enhanced guided search protocol to model user's common interest pattern by using a probability-theoretic framework that is able to guide the searching in service discovery. However, this approach requires a lot of global information about past events and intensive computing power to calculate the probabilities in order to have an accurate guidance for the peers during service discovery. On the other hand, the author also discussed another approach to improve the searching in unstructured P2P systems through the peers' routing tables. In the event of successful service discovery where a requested service provider has been identified, the sending peer and the peers that the message passed through will update their routing tables to include the identified service provider including the information about the service it can provide. Although this approach can help to guide future discovery that eventually may be able to reduce overall traffic generated in a network, this advantage may become an issue for service provisioning because popular service providers tend to be discovered easily and become more popular, and vice versa for less popular services. This will result in an inefficient and unbalanced service load distribution among those peer nodes which provide those similar service.

Zhou, et al. (2011) proposed each peer in the network using kd-tree to establish a data space for indexing the service descriptions. Then, all nodes will use one-hop replication to share the service indexes with their neighbour nodes. Eventually, when the service indexes in a node reach a threshold, it can promote itself to become super peer. The normal routing protocol is to broadcast the query message to all neighbours of the requesting peer, but the existence of super peer works as a shortcut. If any super peer exists in the network, the query message will be forwarded to that super peer. The experimental results from this approach shows that the number of traffic could be reduced to half when compared to other unstructured approaches. However, the message flooding of using unstructured P2P still would not be totally prevented as the simulation results provided by the author shows that each discovery query requires on average 3625.554 messages, which is still very high compared to structured P2P approach.

Another author (Saleem, et al., 2011) proposed the idea of using autonomous systems (AS) to clusterize the P2P network, and Application Oriented Networking (AON) for inter-AS routing. Although the proposed framework can help to reduce the number of broadcast messages and to improve the scalability of the system even by using unstructured P2P system, it requires a rather complex maintenance scheme for the AON routers as the routers will need to learn the service-classification specific routing. Besides, if a router along the routing path is not AON-enabled, message flooding would not be avoidable for inter-AS service discovery.

2.3 Structured P2P

2.3.1 Overview

Structured P2P systems, or sometimes referred to as Distributed Hash Tables (DHTs), are scalable network infrastructure that supports large-scale distributed systems. Structured P2P systems provide deterministic query search because the neighbourhood links are better defined.

There are many existing structured P2P algorithms available that can be integrated in distributed service discovery. For example, Plaxton, Chord, Tapestry, Pastry, Kademlia, and CAN (Lua, et al., 2005).

Generally, the performance of P2P depends on the size of each node's routing table where the information about the network is stored. Clearly, a node cannot store all details of all other nodes for the algorithm to be scalable. From the literature review conducted on distributed service discovery using structured P2P, many approaches have chosen to use Chord and Pastry.

Chord, a structured P2P algorithm by Stoica, et al., (2001) arranges its identifier space in a circular fashion. Each node uses its own finger table that contains nodes spaced exponentially around the identifier circle. The routing in Chord works by forwarding the query to the node closest to the key. If no such node exists, the query will be forwarded to the node preceding it in the finger table. Chord has a stabilization process that validates the joining and leaving of Chord network to ensure the finger table of each node is well maintained.

On the other hand, Pastry, proposed by Druschel and Rowstron (2001) generates its node identifier randomly as new node joins a network resulting in a uniformly distributed identifier space in the network. The entries in routing tables are chosen based on their locality and are sorted based on their identifiers. The routing in Pastry works by forwarding the query to the node that is numerically closest to the key. Each Pastry node also maintains a neighbourhood set that enables each node to repair their own routing tables when departed node is found.

In conclusion, both Pastry and Chord are fault tolerant and able to achieve logarithmic routing complexity. However, Pastry is better in providing locality awareness in routing when compared with Chord.

2.3.2 Existing service discovery approaches

The following describes various approaches using structured P2P in service discovery.

An approach by Castro, et al. (2002) applied Pastry to implement a design that uses universal P2P overlay for service discovery and for service binding in structured P2P overlay networks. The core proposal here is to group service providers according to the services offered in a sub overlay, and for each of these services, a small list of contact node can be obtained from the universal overlay that enables a node the join the specific service overlay. The strength of this solution is that it allows service consumers to find the specific service overlay more easily, including joining that overlay in order to get the services. However, the cost of maintenance of contact nodes list would be very high because it would requires frequent updates among peers in order to avoid service unreachable due to contact node failure. As each node may offer more than one type of service resulting in several sub-overlay identities, this would complicate the maintenance process.

CompuP2P, proposed by Gupta and Somani (2004) is a scheme that uses structured P2P, specifically Chord (Stoica, et al., 2001) for computing resource discovery and trading. The seller (or service provider) hashes its available compute power (i.e., CPU cycles) as a key, and uses the key to determine and locate the market owner. On the other hand, the buyer (or service consumer) can use the same hash function to find the market owner, where a seller can trade the compute resource with a buyer. However, the service provided in this scheme is only limited to the compute resource and a buyer therefore ought to know the required compute power being the key in order to identify the corresponding market owner. Besides, if a buyer only knows the minimum requirement, or needs a range of compute powers rather than just a specific one, it may need to perform lookup many times in order to find market owners for different specifications, which results in a higher complexity of the approach.

Guo, et al. (2006) introduced DINPeer to identify most powerful nodes, known as the Data-In-Network Nodes (DIN Nodes) and form an inner ring that consist of only DIN Nodes. Multiple DIN Nodes are used to replace a single registry to avoid the single-point failure issue. This approach enables every node in the network to find their nearest DIN Node and join the Steiner tree that each DIN Node maintains. In searching, a requesting node will search from the tree that it is in first. However, if the local area does not have the service that it needs, the query is forwarded to the inner ring that requires each DIN Node in the inner ring to send multicast messages to their children node that may cause high routing traffic in the network. Besides, the issue of single-point failure will still exist if some of the DIN Nodes leave the network. When a DIN Node dies, no new DIN Node is elected. Instead, the author proposed that the children nodes of the failed DIN Node to find other alive DIN Nodes and join their trees. The existing DIN Nodes would be too occupied because service request query that cannot be found in the local area will have to pass through them.

Aneka-Federation proposed by Ranjan (2007) is the first attempt that integrates P2P with cloud based on P2P infrastructure. It provides a decentralised and distributed system which combines enterprise Clouds, overlay networking, and structured P2P techniques to create a scalable wide-area networking of compute nodes for high-throughput computing. The Aneka-Federation integrates numerous small scale Aneka Enterprise Cloud services and nodes that are distributed over multiple control and enterprise domains as parts of a single coordinated resource leasing abstraction. The service discovery and update here are performed by using spatial indices to handle multidimensional queries where the indices are formed by hashing multiple attributes. However, multidimensional query requires users to provide values for all pre-defined attributes, which may not be flexible. Besides, service query may not return any result if the query is too specific at one value where the network may return only a potential service provider to the consumer. If the service query can range from a minimum to a higher requirement, this will increase the complexity of the implementation. Another issue is that the locality may not be well preserved while performing P2P lookup routing because of the way how the indices are mapped.

Chord4S proposed by Qiang, et al. (2008) is a structured P2P based decentralised service discovery that is the closest to this research. It uses Chord to utilize the data distribution and lookup capabilities to discover and distribute services in a decentralised manner. Chord4S improves data availability by distributing service descriptions of functionally equivalent services to different successor nodes that are organized into a virtual segment in the Chord circle. Although using service descriptions to be embedded into the node’s identifiers may promote efficiency in searching for a particular service provider, locality may be a challenge where the service consumers may need to be routed to a service provider located far away when there is a nearer one geographically.

Caron, et al. (2011) proposed using Distributed Lexicographic Placement Table (DLPT) prefix tree for service discovery. The DLPT tree grows dynamically as services are declared where each black node in the tree is labelled by the service name and stores a list of the service providers providing that service. In order to reveal the prefix tree pattern, white nodes are used and are labelled by the greatest common prefix of their children labels. This approach is convenient and easy in searching because each service request query can be routed up to the root of the prefix tree and then down to the service requested, hence supporting range queries. However, any root in the tree that leaves the tree may cause broken parent-children paths hence resulting in searching failure. Each node that built the tree must be in stable state and should not leave the network to avoid this issue.

2.4 Discussion

In this chapter, a brief discussion about the differences between unstructured and structured P2P as well as the distributed service discovery approaches on these two P2P systems are conducted. The service discovery approaches of using unstructured P2P has lower complexity in maintaining the network but high complexity in routing thus not fit for a large scale network. On the other hand, the service discovery approaches on structured P2P discussed have systematic way of mapping the services to peers, enabling service consumers to find the service providers more easily. However, the approaches discussed emphasized more on the discovery success rate. Although the routing complexity is low when using structured P2P, some of the approaches that uses tree for service mapping are still in the risk of single-point failure. Besides that, the approaches that do not use tree may have locality issues in searching.

In the next chapter, the discussion on using unstructured and structured P2P for distributed service discovery will be conducted. Besides, simulation results will also be shown in order to measure the performance of the discussed approaches.

CHAPTER 3

DISTRIBUTED SERVICE DISCOVERY SCHEMES IN P2P NETWORKS

3.1 Introduction

This chapter verifies our arguments regarding the shortcoming of unstructured P2P service discovery approaches by providing some theoretical discussions as well as simulation results as performance evaluation. The focus of this chapter proceeds to discuss about the usage of structured P2P for service discovery. A simulation using structured P2P for service discovery is also carried out to demonstrate its superiority in terms of achieving satisfactory success rate with less traffic generated.

3.1.1 Breadth first search (BFS)

There are many different searching techniques in unstructured P2P. However, most of them employed brute-force search for discovery such as breath first search (Li & Wu, 2005). The breadth first search (BFS) approach is simple, where a request query is forwarded to every neighbour of the sending peer. Then each of these neighbours that receive the request query will check if they have the file or service requested and return the result back to the sending peer. If none of these neighbours has the file or service requested, each of these neighbours will forward the request query to its neighbours as well, until the file or service requested is found.

This search method requires a mechanism in each query to stop routing at a conditional time by using time-to-live (TTL). The TTL can also be represented as the maximum depth, *D* that limits the maximum number of overlay hops of each query message. If the maximum depth is reached during searching and the file or service requested is yet to be found, then the request query will be considered as a failure.

The searching in BFS can be used as the routing protocol in service discovery as the maintenance cost is low and the structure of routing is simple to implement. Besides, as brute force search is used where each peer may receive the service request query, the service discovery success rate may be very high as well.

In order to measure the performance of service discovery in an unstructured P2P network using BFS, simulations are carried out in networks that consist of number of nodes from 1,000 to 10,000 nodes, with increment 1000 nodes. The neighbours of each node are randomly generated in the neighbourhood set and each neighbourhood set could contain 30 entries to 40 entries. During the searching phase, the sending peer will broadcast the query to all nodes inside its neighbourhood set.

The following are the settings used in the simulation:

1. Each node in the network has a unique node identifier (nodeId).
2. Each service type in the network has a unique service identifier (serviceId)
3. The total number of service type in the network is 500 and each node can provide two to three different service types.

4. The total number of request queries generated in the network is 100,000 and each querying node is randomly selected to send the request query message.

Figure 3.1 shows the simulation result of the BFS scheme. As shown in the figure, the success rate of the BFS can reach almost 100% when the network size is 4,000 nodes and above, especially when the depth of searching is 3. As the depth is increased, the search range will keep expanding until it covers all the nodes in the network. Hence, BFS approach can guarantee successful search if the depth or TTL is large enough.

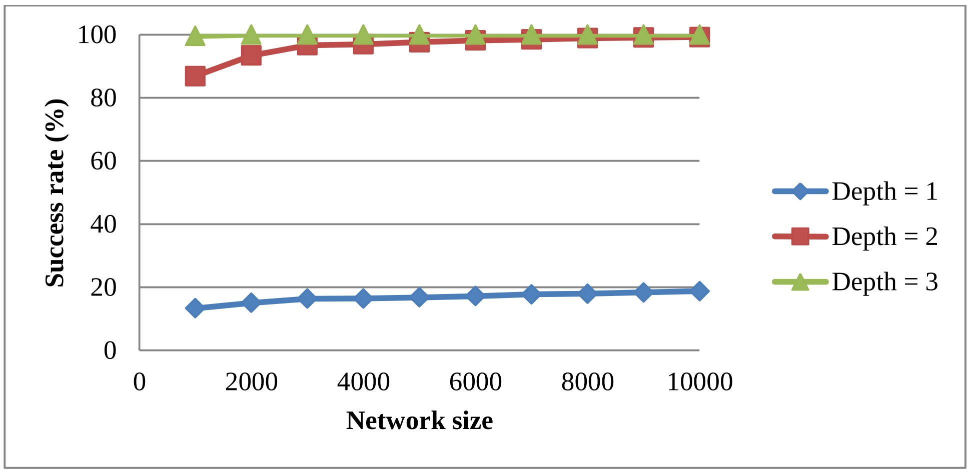


Figure 3.1 Success rate for BFS simulation

The BFS scheme shows that it can produce great results in searching however, the downside of this scheme is that the volume of traffic produced is very high. As shown in Figure 3.2, the average traffic (or messages) generated per query can reach as high as above 40000 messages for a network that consists of only 3000 nodes at *D* = 3. This is also a general drawback of most message flooding searching schemes.

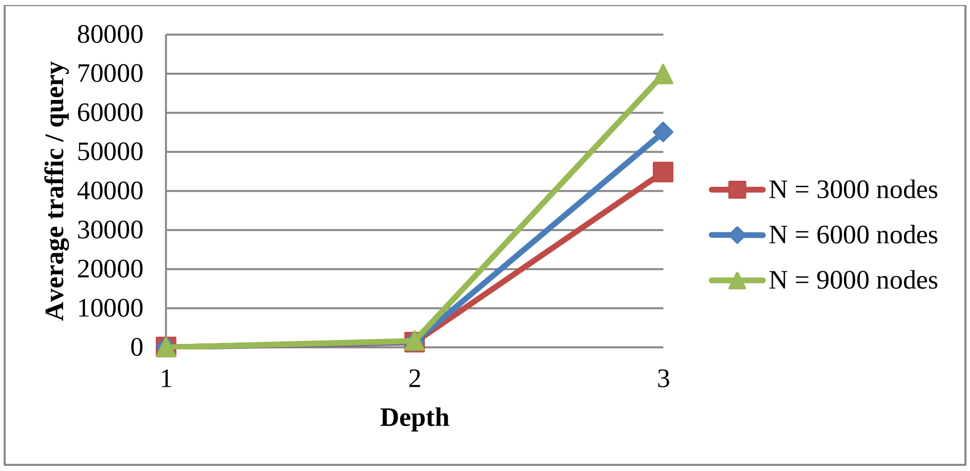


Figure 3.2 Average traffic generated per query

In conclusion, the flooding approach can result in too much traffic generated in the network although high success rate can be achieved. This condition will cause congestion in message routing as the network will be filled with high volume of traffic.

3.1.2 Modified random BFS

In order to address the flooding issue in the BFS scheme, one of the alternatives proposed is the modified random BFS (Li & Wu, 2005). In this approach, the querying node will send query requests to a subset of its neighbour. These neighbours are randomly chosen by the querying node. Each of the neighbour nodes will process the query and forwards the query to a randomly chosen subset of their neighbours until the stopping condition is met.

A simulation is carried out in order to compare the performance of the modified random BFS approach with the BFS approach. Instead of forwarding the request to all neighbours, the simulation is set to randomly select *k* number of neighbours to forward the request message. The simulation results show that the amount of traffic generated by each query is significantly reduced but the overall success rate in searching is not that promising.

Figure 3.3 and Figure 3.4 show the simulation results of the modified random BFS where each peer forwards the request query to 10 randomly selected neighbours. As shown, modified random BFS can reach high success rate when D = 3. However, the searching complexity of this approach is $\mathrm{O}(k^D)$ where D represents depth of searching or TTL and k represents the number of neighbours each node is connected to send a query to. Hence, the average messages generated per query is more than 1000 messages for this depth when $k = 10$. Although the message generated in modified random BFS is significantly reduced when compared to BFS approach, the total messages flooding in the network is still too high.

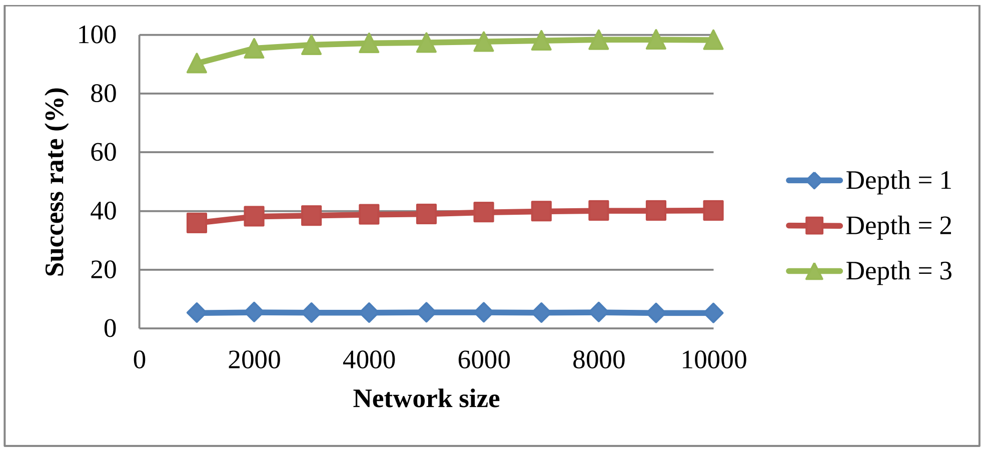


Figure 3.3 Success rate for modified random BFS with *k* = 10

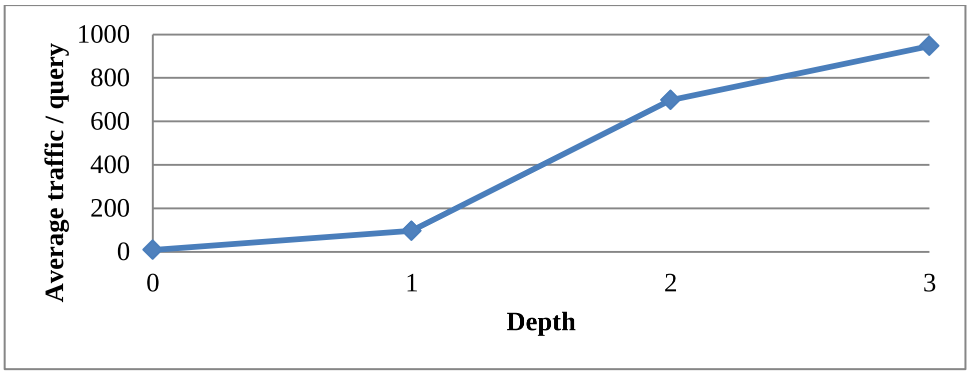


Figure 3.4 Average traffic per query generated in modified random BFS in network of 6000 nodes with *k* = 10

3.1.3 Observation and discussion

Observing the simulation results, the use of brute-force in searching will flood the network causing too much traffic generated although more traffic can produce higher discovery rate. Despite that, even if the size of each message generated in the network is so small that it may seem to have little effect on the traffic flowing in the network, the traffic will still be highly congested if all nodes in the network broadcast service discovery request query.

One of the reasons why searching in unstructured P2P generates high traffic is because only the querying node is active in searching for the files or services in need. The file or service providers would remain passive in the network and waiting for query requests causing high number of traffic generated.

In order to reduce the traffic generated of searching in unstructured P2P, many researchers proposed different replication techniques for file sharing (Sabu & Chandra, 2010). However, it should be noted that only files can be replicated and stored in different nodes. Resources such as compute power, storage, and bandwidth cannot be duplicated because such resources come from physical peripherals.

Although resources cannot be duplicated, the information about resources can be duplicated and shared among nodes to help with the searching. Hence, we proposed a solution in which a new term, named the directory node is introduced in our research work. A directory node can act as a platform for the service providers to advertise their capabilities. Besides, a directory node is also a platform for service consumer to find the services they need.

It should be noted that any nodes in the network can become a directory node if those nodes are given information about a particular resource. This is because all peers in a P2P network are cooperative and equal. Hence, any node can assume three roles in the proposed scheme:

1. **Service providers**:
    - Nodes that can provide the service.
2. **Service consumer**:
    - Nodes that need the service.
3. **Directory node**:
    - Nodes that serve as a platform for service providers to advertise their capabilities and for services consumer to find the information about the service providers who can provide the requested services.

However, even with directory nodes, the flooding approach in unstructured P2P is still unavoidable. For instance, when a service provider has services to offer, it still has to flood the network and advertise to every neighbour node so that the nodes that received the service advertisement request can become the directory node for the service. The service consumer will have to go through the same process as well in service discovery to find any directory nodes. The amount of messages generated from each service discovery query will still be high and may cause traffic congestion in a P2P network.

3.2 Distributed service discovery in structured P2P network

As discussed earlier in this chapter regarding using unstructured P2P for service discovery, the flooding approach used in unstructured P2P results in high volume of traffic in the network. Hence, structured P2P is proposed to reduce the traffic generated from the result of flooding in unstructured P2P.

The reason that structured P2P is chosen in the proposed scheme is because the routing protocol in structured P2P is systematic and well defined. In structured P2P, each data key is mapped to a peer hence enabling discovery of data by using only the key, avoiding the need to flood the network. There are many types of structured P2P systems such as Chord, Pastry, Tapestry, CAN (Content Addressable Network), and Kademlia (Lua, et al., 2005), each with its own routing protocol.

One of the aims of this project is to enable both service provider and service consumer to take part in the distributed service discovery. By allowing service providers to advertise their capabilities to directory nodes may improve the service discovery success rate without generating high volume of traffic during service discovery.

The idea of service advertisement and service discovery here was discussed earlier by Hautakorpi, et al. (2012). In this approach, service providers perform service advertisement by randomly selecting directory nodes to advertise their capabilities. Here, the number of directory nodes is determined based on the probability that requires some global information. The approach in discussion chose Chord proposed by Stoica, et al. (2001) to be used as the routing protocol.

On the other hand, the author proposed using brute force for service discovery. Here, the service consumer divides the Chord overlay into *M* locations' sector head and forwards the service discovery request to each of sector heads. Each of these sector heads then randomly forward the request to another node until TTL runs out.

A simulation is carried out in this research work to test the efficiency of using directory nodes using the approach by Hautakorpi, et al. (2012). As there is no global information to determine how many directory nodes for each service should be planted in the simulator, the simulator will be set to randomly select 10 neighbours of the service provider to become the directory node for the service type.

The following is the settings used in the simulation:

1. Each node has a unique node identifier (nodeId) generated randomly
2. Each service type has a unique service identifier (serviceId) generated randomly.

3. There are 10 regions in the network and each node will be randomly assigned with one region.
4. The total number of service type in the network is 500 and each node can provide two to three different service types.
5. The total number of service request query generated in the network is 100,000 and each querying node is randomly selected to send the request query message.

Figure 3.5 shows the success rate of simulating the distributed service discovery using Chord. Notice that the success rate when *D* = 1 has increased from less than 5% to above 50% when compared with the unstructured approach at section 3.1.2. Furthermore, the performance in terms of success rate has improved in all depths when compared with service discovery using unstructured P2P in section 3.1.1 and section 3.1.2.

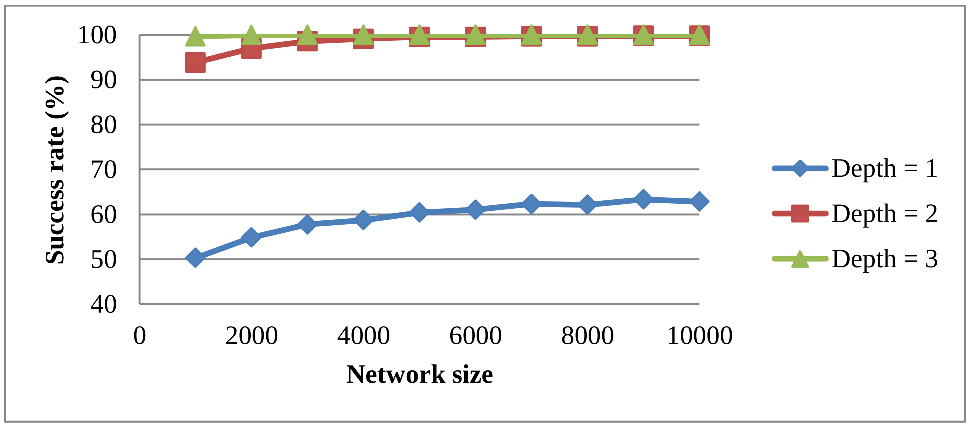


Figure 3.5 Success rate for distributed service discovery using structured P2P system

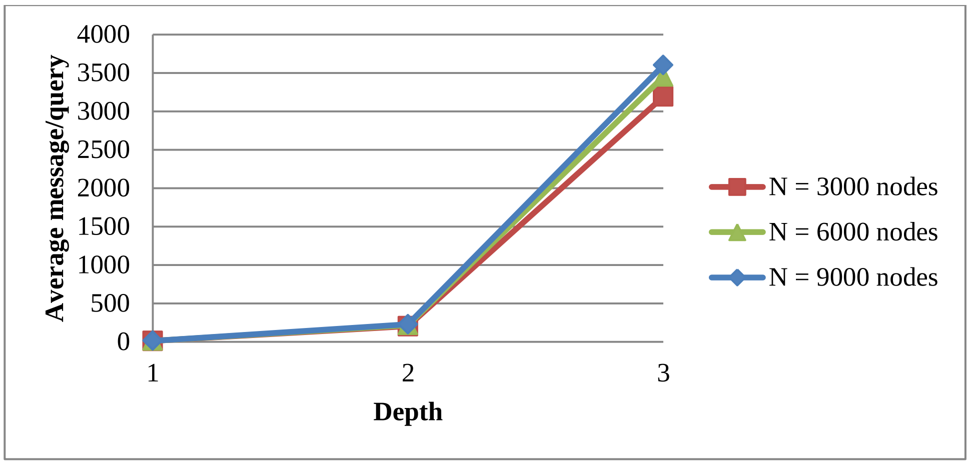


Figure 3.6 Average traffic generated in distributed service discovery using structured P2P

The reason is both service provider and service consumer are active in the distributed service discovery approach using structured P2P. Note that the service providers only choose 10 random nodes from their own neighbourhood to become directory nodes for each service they can provide. However, as the number of nodes in the network is increased, the number of directory nodes will also increase as shown in Figure 3.7. The reason is, each service type will be advertised to 10 different directory nodes according to the service providers' routing list. The service providers have more choice of directory nodes to choose from, preventing overlapping in advertisement requests to the same directory node.

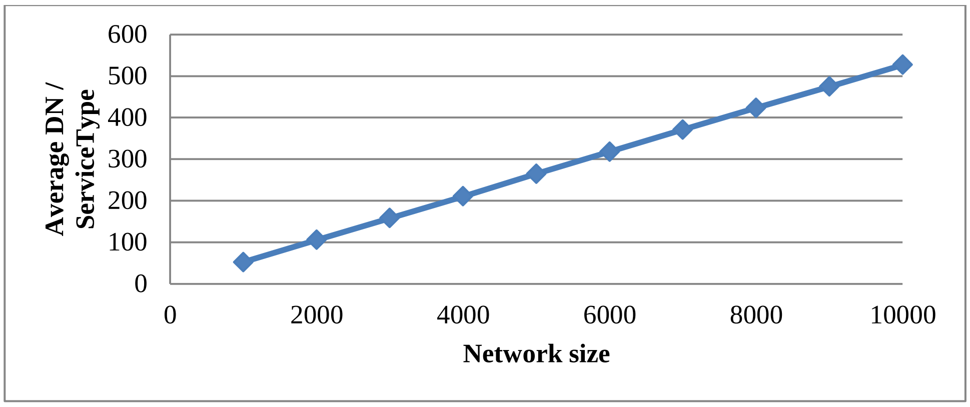


Figure 3.7 Average number of directory nodes per service type

On the other hand, there are exactly 10 regions in the simulated network and each node in the network is randomly labelled with a region of their own. In service discovery, it is better to have a service provider that is near the service consumer to make sure the connection delay and the traffic generated are at minimum for both service provider and service consumer to communicate with each other.

A case is considered as the failure of locality search if it obeys either of the following conditions:

1. Service consumer is unable to find a service provider in its region when both service provider and service consumer are in the same region
2. Service consumer is unable to find directory node that hosts the type of service it needs when both service provider and service consumer are in the same region

The locality search failure percentage in service discovery is also focused in this simulation and the result is shown in Figure 3.8.

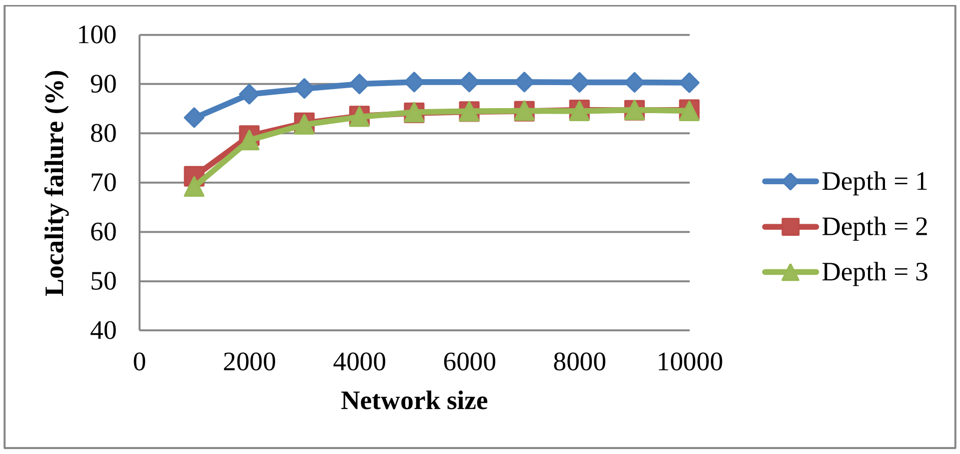


Figure 3.8 Locality search failure of service discovery using structured P2P

Although the success rate of using directory node for service discovery shows improvement when compared with approaches without directory nodes, as shown in Figure 3.8, the locality failure is mostly above 80% for all depths. Due to the structure of Chord's finger table that does not emphasize on locality awareness, when brute force searching is applied on such finger (i.e., routing) table caused most of the service consumers fail to locate service provider that is in their proximity and this happens frequently when the network size is increased. Hence, a better and systematic service searching approach is needed in order to find suitable and nearer service providers for the service consumers.

CHAPTER 4

PREFIX-BASEDADVERTISING AND SEARCHING SCHEME FOR DISTRIBUTED SERVICE DISCOVERY IN STRUCTURED P2P NETWORKS

4.1 Introduction

In this chapter, prefix-based searching for service discovery and service advertisement (PASS) is proposed to improve the overall discovery performance. That is, in the proposed solution, the prefix of an identifier is used as a key for identifying directory nodes and for routing on the underlying P2P network. Directory nodes should not be randomly selected like the approach discussed in section 3.2 because it would require the brute force search for them to be identified, which in turn would create the flood of query traffic. When a directory node can be identified using only the key, the efficiency in searching can be improved more strategically.

Figure 4.1 shows a summary on the service advertisement and service discovery process that is proposed. First, the service provider will advertise one of its services to a directory node. This is done by performing hashing on the service type in order to obtain a service identifier. A key is extracted from the service identifier to search for a directory node. Next, the directory node will add the service provider into a list of service provider. Then when a service consumer is in need of the service, it will hash the service type to obtain a service identifier and extract the key from the service identifier to search for the directory node. The directory node will send a copy of the list of service provider and forwards it back to the service consumer. Finally, the service consumer can use the list to identify service provider and request service from the service provider.

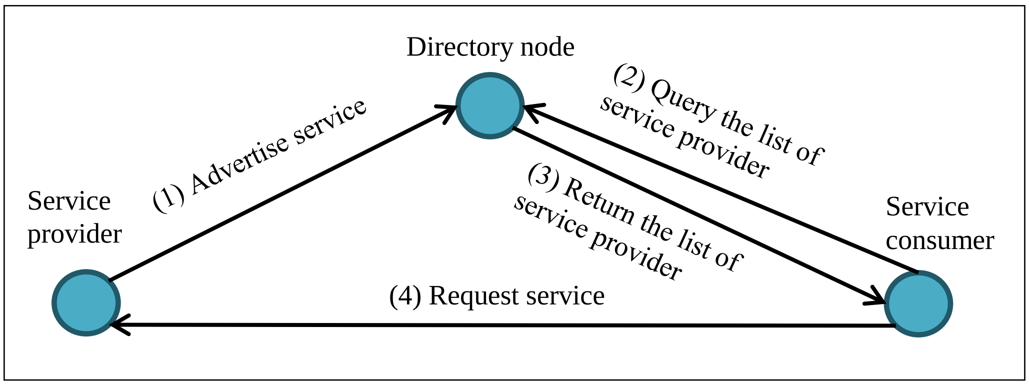


Figure 4.1 Service advertisement and service discovery

One of the focuses of this project is to emphasize on locality awareness in searching for service discovery because it is better for a service consumer to be able to find a service provider in close proximity. This is to ensure that the distance in between service provider and service consumer is as close as possible to avoid delay in delivering the services requested.

Hence, a structured P2P system that is suitable to be integrated with the proposed system must have locality awareness in its routing protocol. The Pastry routing P2P network (Rowston & Druschel, 2001) is one of the good candidates because in Pastry the routing table at each node is constructed according to the proximity to its neighbours.

In Pastry, each node in the network is identified by a randomly generated unique node identifier (nodeId) with length of *n* bits using a hash function. The nodeId can also be generated by hashing the IP address of the node and expressed in n digits, each digit has a radix of B. When given a key, a Pastry node can efficiently route the message to any Pastry node that is numerically closest to the key.

The randomness of nodeId generated and assigned to each node can result in a uniformly distributed Pastry network. Hence, nodes with adjacent nodeIds are diverse geographically and nodes in close proximity have diverse nodeId prefixes. For example, a node with nodeId of 3302 is supposed to be physically far away from node with nodeId of 3301. Besides this, a node with nodeId of 0123 may be in the same neighbourhood as a node with nodeId of 3012.

Each Pastry node maintains three states as follows:

i. Leaf set
    - Consist of peer nodes with adjacent nodeIds.

ii. Routing table
    - Consist of peer nodes that are in close proximity.

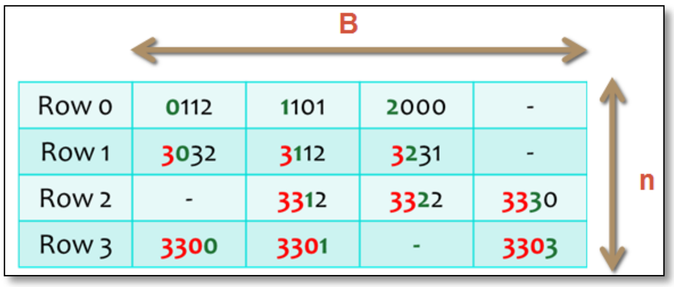
iii. Neighbourhood set
    - Consist of other nodes in close proximity but not listed in the routing table.

Each Pastry node maintains L nodes in its own leaf set. Note that $L/2$ entries are numerically closest smaller than the local nodeId whereas $L/2$ entries are numerically closest larger than the local nodeId. The size of routing table consists of $log_B N \times (B-1)$ entries where N represents the number of nodes in the network.

In Pastry, when presented a message with a numeric key, a node will use the key to search from its routing table in order to forward the message to the next hop. Since all nodes shown in the routing table are physically close to the node, based on the construction principle of routing table in Pastry, this enables the searching to start from its close proximity.

The Pastry routing process requires leaf set and routing table. Given a message, the node first checks to see if the key is within the range of nodeIds covered by its leaf set. If such node exists, then it is the nodeId that is numerically closest to the key and the message will be forwarded to that node. The routing table is used if the key is not covered by the leaf set. The message is forwarded to the node that shares a common prefix with the key by at least one more digit. In cases where no such node exists, the message is forwarded to the node that shares a prefix with the key at least as long as the local node and is numerically closer to the key than the current node.

The node entries in Pastry routing table is arranged according to the prefixes of nodeIds. The nodeId in row p column q has the same first digits with that of the local node, and the $p + 1^{st}$ bit is q, where $0 \leq p \leq log_2 B - 1$, and $0 \leq q \leq B - 1$. For example, given a Pastry network that is assigned with 16-bit node identifier space and is identified by a sequence of digits with base, B where B = 4. The routing table can be expressed as shown in Figure 4.2 where the first row of a Pastry node routing table contains nodeIds that have a distinct first digit. The distinct value is taken from the set$\{0, 1, 2, 3\}$. The second row of a Pastry node routing table contains nodeIds that share the first digit prefix with the Pastry nodeId but different in the second digit. A simpler explanation is, nodes in row 0 share 0 prefix with the nodeId, nodes in row 1 share only 1 digit prefix with the nodeId, nodes in row 2 share 2 digits prefix with the nodeId, and so forth.



Row 0	0112	1101	2000	-
Row 1	3032	3112	3231	-
Row 2	-	3312	3322	3330
Row 3	3300	3301	-	3303

Figure 4.2 Example of routing table state for Pastry node with nodeId = 3302, *B* = 4, and *n* = 4 digits

When a new node N joins a Pastry network, it has to go through node A that is already in the network. Node A is known as the contact node of node N. The joining process continues as node N performs lookup using its own identifier as the key. As Pastry routing will bring the lookup message to the node that is numerically closest to the key, hence the information of each node along the path from node A to the targeted destination will be used to help node N builds its own routing table.

For example, given the join request of node N has passed through node A, B, C and finally reaching the node Z whose nodeId is numerically closest to node N. The leaf set of node N can be constructed based on the leaf set of node Z. As node A is usually in the proximity of node N, hence the neighbourhood set of node A is suitable for node N.

If node N does not share any common prefix with node A, then entries in row zero of node A routing table can be used to construct row zero of node N routing table as row zero of the routing tables are not dependent on one’s nodeId. Next, row one of node N routing table can be obtained from row one of node B routing table, given that both N and B share one digit common prefix in their nodeId. Similarly, row two of node N routing table can be obtained from row two of node C routing table if both node N and C share two digit common prefix in their nodeId.

4.2 Service advertisement and service discovery

This sub-section discusses the in-depth of service advertisement and service discovery using prefix based routing.

4.2.1 Service advertisement

In the prefix based routing scheme, the key is generated by hashing the service type a service provider can provide. The hashed service type will return the serviceId that will be used as the key for routing. In service advertisement, searching for a directory node only requires the first m bits of the serviceId, where $log_2 B \leq m \leq n$. Note that any nodes that share the same m prefix bits with the key are eligible to become a directory node.

The following are the steps for service advertisement:

(1) Service provider hashes the service type to get the serviceId.

(2) The first m bits of serviceId are extracted and used as the key.

(3) The service provider sends a service advertisement message using Pastry routing to search for any directory nodes that share the same prefix of m bits as the key.

(4) The directory node that receives this service advertisement message will add the information of the service provider and capability of the

service provider into a list of service provider hosted by the directory node.

(5) The directory node then forwards the service advertisement message to all nodes from its routing table whose nodeId also share the same prefix of *m* bits as the key and those nodes that receive this message will also add the information of service provider into the list of service provider.

Figure 4.3 shows an example of service advertisement. *Step 1* shows node A, the service provider hashes the service type that it can provide to obtain a serviceId, say in this example, serviceId of 1230. Then the first *m* bits of the serviceId are extracted to become the key. At *step 2*, Pastry routing using the key is shown as node A forwards the service advertisement request to node B whose nodeId is numerically closest to the key according to node A's routing table. At *step 3*, node B forwards the service advertisement request to node D because node D has a nodeId that is numerically closest to the key and that it also shares the same prefix with the key. Finally, node D becomes the directory node for the service type of 1230 and the information about the service provider, node A is added into the list of service type 1230 as shown in the figure. On the other hand, node D is also the directory node for service type 1201 as well because they share the same prefix of 2 digits as the key. The service advertisement continues as shown in the figure where the directory node D further forwards the service advertisement request to all nodes in its routing table that share the same prefix key as highlighted in blue.

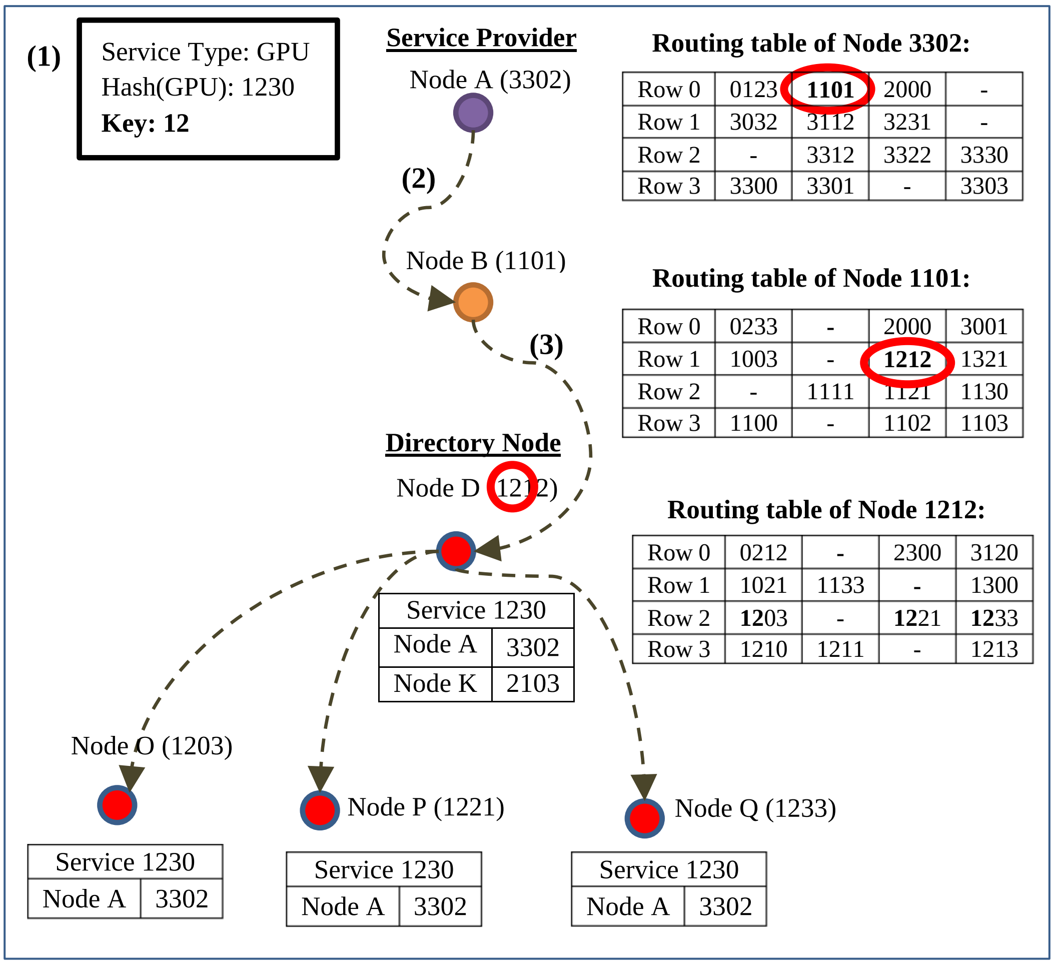

(1)
Service Type: GPU
Hash(GPU): 1230
Key: 12
Service Provider
Node A (3302)
(2)
Node B (1101)
(3)
Directory Node
Node D (1212)
Routing table of Node 3302:
Row 0 | 0123 | 1101 | 2000 | -
Row 1 | 3032 | 3112 | 3231 | -
Row 2 | - | 3312 | 3322 | 3330
Row 3 | 3300 | 3301 | - | 3303
Routing table of Node 1101:
Row 0 | 0233 | - | 2000 | 3001
Row 1 | 1003 | - | 1212 | 1321
Row 2 | - | 1111 | 1121 | 1130
Row 3 | 1100 | - | 1102 | 1103
Routing table of Node 1212:
Row 0 | 0212 | - | 2300 | 3120
Row 1 | 1021 | 1133 | - | 1300
Row 2 | 1203 | - | 1221 | 1233
Row 3 | 1210 | 1211 | - | 1213
Service 1230
Node A | 3302
Node K | 2103
Node O (1203)
Node P (1221)
Node Q (1233)
Service 1230
Node A | 3302
Service 1230
Node A | 3302
Service 1230
Node A | 3302

Figure 4.3 Service advertisement example where *B* = 4, *n* = 8 bits (4 digits), and *m* = 4 bits (2 digits)

4.2.2 Service discovery

The overall concept of service discovery is almost similar with service advertisement. The service discovery starts with a service consumer who is in need of a particular service. Then the service consumer hashes the service type that it needs to get the serviceId and then extract the first *m* bits of the serviceId to be the key.

The following are the steps for service discovery:

(1) Service consumer hashes the service type to get the serviceId.

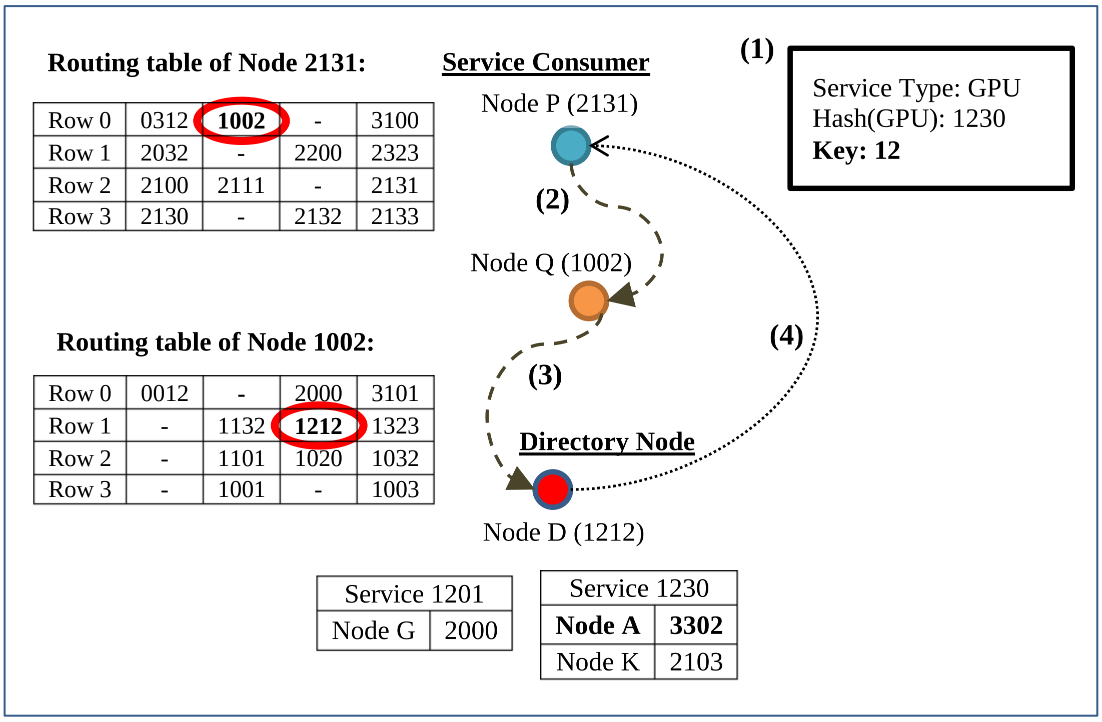
(2) The first *m* bits of serviceId are extracted and used as the key.

(3) The service consumer sends a service discovery message using Pastry routing to search for any directory nodes that share the same prefix of *m* bits as the key.

(4) The directory node that receives this service discovery message will send a copy of the service provider list to the service consumer.

(5) If the directory node does not have the list of service provider requested, the directory node forwards the service discovery request to all nodes in its routing table whose nodeId share the same prefix of *m* bits as the key. These nodes that received the service discovery request will forward a copy of the service provider list to the service consumer.

An example of service discovery is illustrated in Figure 4.4. At *step 1*, the service consumer, node P hashes the service type that it needs to get a serviceId, say in this example, serviceId of 1230. Then, the key is extracted and is used for routing at *step 2* where the service consumer forwards the service discovery query to node Q whose nodeId is 1102 because node Q is numerically closest to the key. When node Q receives the service discovery request, it continues to forward the service discovery request to node D whose nodeId is numerically closest to the key from node Q's routing table of at *step 3*. Finally, the service discovery message arrives at node D whose nodeId shares the same 2 digit prefix with the key, which also indicate that node D is the directory node for the service type 1230.



Routing table of Node 2131:

Row 0	0312	**1002**	-	3100
Row 1	2032	-	2200	2323
Row 2	2100	2111	-	2131
Row 3	2130	-	2132	2133

Routing table of Node 1002:

Row 0	0012	-	2000	3101
Row 1	-	1132	**1212**	1323
Row 2	-	1101	1020	1032
Row 3	-	1001	-	1003

Service Type: GPU
Hash(GPU): 1230
Key: 12

Service 1201	
Node G	2000

Service 1230	
Node A	**3302**
Node K	2103

Figure 4.4 Service discovery example where *B* = 4, *n* = 8 bits (4 digits), and *m* = 4 bits (2 digits)

As shown in Figure 4.4, node D is currently the directory node for both serviceId of 1201 and serviceId 1230. At *step 4*, since the requested service type is 1230, hence node D will make a copy for the service list 1230 that contains both node A and node K back to the service consumer, node P. Note that, if the directory node D does not have the list of service provider requested, the directory node can forward the service discovery request to all nodes in its routing table that share the same 2 digit prefix with the key. These nodes that received the service discovery request will forward a copy of the service provider list to the service consumer if they have the list.

4.3 The selection of *m*

The selection of *m* bits as the prefix key will affect the number of directory nodes in the network. Although more directory nodes in the network may increase the success rate, also other factors have to be analysed before determining what should be the value of *m*.

4.3.1 Smaller *m*

A smaller *m* can result in more directory nodes in the network. For example, when the value of *m* is set to 0, any node in the network is eligible to become the directory node of any service type. This is typically the brute force advertisement because the service providers can advertise their capabilities to any nodes in the network. Hence, smaller *m* enables more choices to map between services and directory nodes.

Since smaller *m* can result in directory nodes to be closer to the service providers, the travelling path to locate a directory node is shorter. However, a small *m* may cause the service providers and service consumer to be unable to meet at a common directory node. This event is illustrated in Figure 4.5.

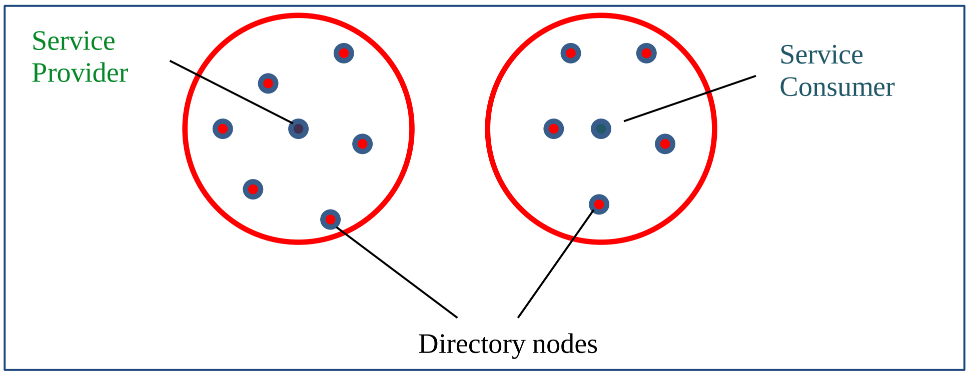


Figure 4.5 Impact of small *m*

4.3.2 Larger *m*

Larger *m* may result in smaller number of directory nodes in the network. This is because there will be fewer choices to map between services and directory nodes in the network. Besides, larger *m* may cause the services to be mapped to directory nodes that are far from the service provider. Thus a directory node may not be located in the close proximity of service provider. However, if *m* is sufficiently large, it would be easier for service provider and service consumer to meet at a common directory node. Figure 4.6 illustrates this example where a common directory node is found.

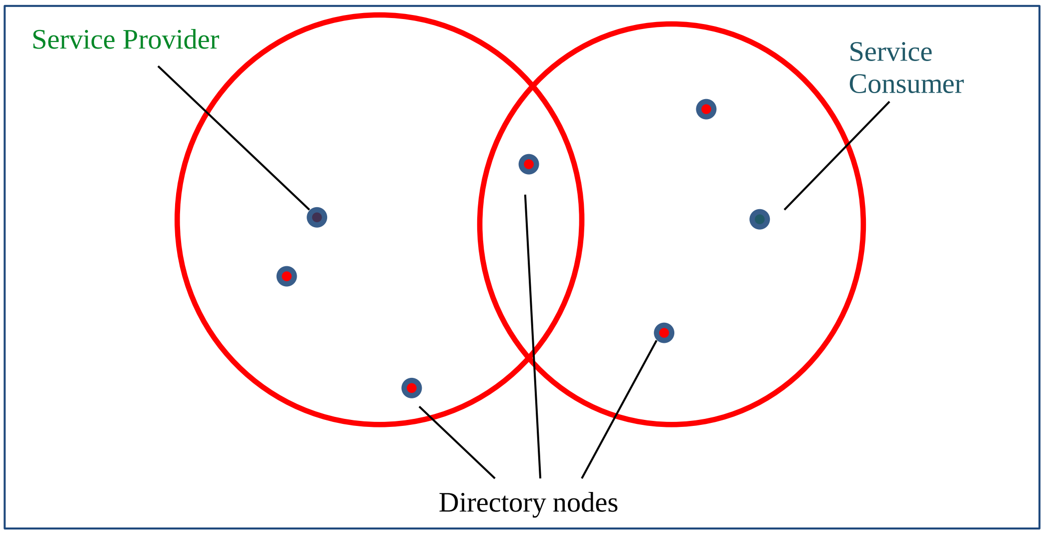


Figure 4.6 Impact of large *m*

4.4 Performance measure

The service discovery success rate of the proposed scheme is bounded by two factors:

1. **Success rate in identifying a directory node**

   The success rate in identifying a directory node shown in Figure 4.7 is higher when the value of *m* is small and the success rate will start to decrease as the value of *m* increases. This phenomenon has been explained in the previous sub-section 4.3.

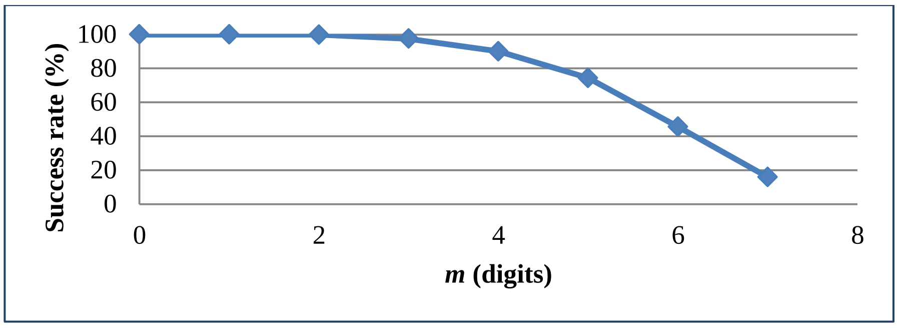


Figure 4.7 Success rate in identifying a directory node

2. **Probability that a directory node contains the required list of service providers**

   There could be many nodes in the network that can become the directory node for a particular service type as long as the directory nodes share the same prefix as the key. However, not all of the potential directory nodes are chosen by the service providers to advertise their services. Hence, directory nodes that are found by service consumers may or may not contain the required list of service providers. Figure 4.8 shows the probability that a directory node contains the required list of service provider increases as the value of *m* increases. This shows that when the value of *m* is small, it is harder for service provider and service consumer to meet at the common directory node.

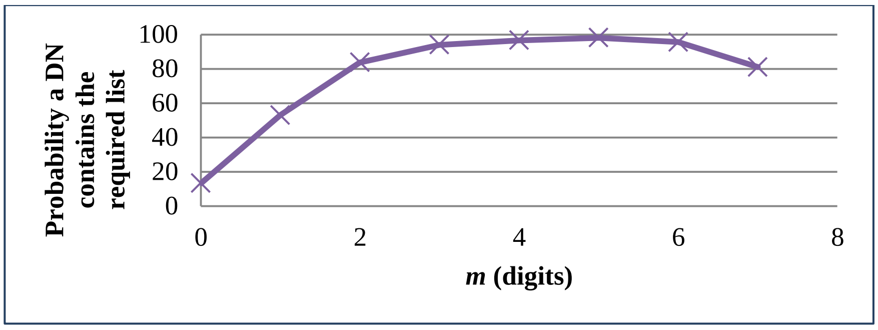


Figure 4.8 Probability that a directory node contains the required list of service providers

The combination of these two factors will yield the service discovery success rate shown in Figure 4.9. This shows that there is an optimal point of *m* where $0 \le m \le n$.

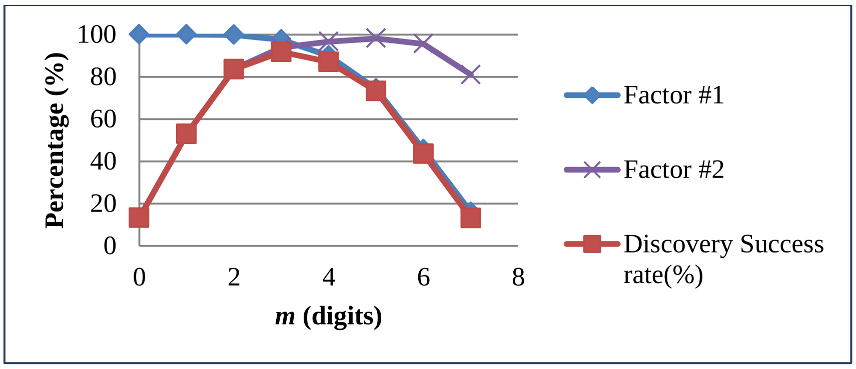


Figure 4.9 Service discovery success rate

4.5 The prefix-based advertising and searching scheme simulations

In order to test the performance of the proposed scheme (PASS), simulations are carried out in a Pastry network that consists of 6000 active nodes. The node identifier address field used in the simulation is 16 bits. It is assumed that there are 500 types of services and their unique serviceIds are randomly generated. Each node in the network can provide two or three service types and the serviceIds are randomly chosen from the pool of 500 serviceIds. There are in total 10 regions and each node is randomly assigned with one region. In order to measure the latency between nodes in the simulation, the latency between each node is generated according to the region they are assigned to. The following table shows the latency range between nodes:

Table 4.1 Latency range between nodes

Type	Latency
Contact node	1-5 ms
Same region	6-20 ms
Different region	100-200 ms

The simulation starts with service advertisement. Each service provider advertises the services they can provide to directory nodes. For service discovery request, service consumer is randomly chosen to perform service discovery. The service consumers are set to randomly choose a serviceId as the requested service. In the simulation, 100,000 of service discovery requests will be generated.

Two simulations with different settings are conducted to measure the performance of the proposed scheme in a large node identifier space. In the first simulation, known as Simulation-I, the value of its base is set to 4 whereas in the second simulation, known as Simulation-II will have the value of its base set to 16.

4.5.1 Simulation-I results and discussion

The specific setting used in this experiment is that the node identifier space is 16 bits and is represented in 8 digits, where each digit is presented with 2 bits. Besides that, the base that is used in the simulation is 4 (B = 4) hence, the routing table size of each Pastry node consist of 4 columns and 8 rows, giving each node a maximum number of 24 neighbours which is around 0.4% of the network information.

Figure 4.10 shows the influence of *m* value to the performance of PASS in terms of service advertisement success rate and service discovery success rate. The figure shows that as the value of *m* increase, it is harder for the service provider to find directory nodes that share the same prefix as the key hence causing the success rate in advertisement to decrease.

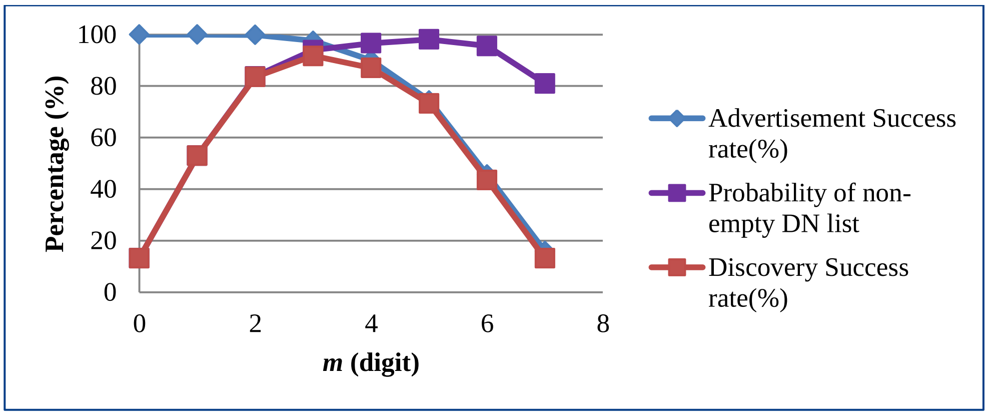


Figure 4.10: Simulation-I result

Figure 4.10 shows as the value of *m* increases, the value of the probability of non-empty directory node lists also increases. This is because the service advertisement by service providers starts from a smaller distance to a larger distance as *m* increases. From the results, it seems that most of the service providers and service consumers are able to meet at common directory nodes when *m* = 3, implying that the optimal value of *m* in this experiment is 3 digits.

Finally, Figure 4.10 also shows that the service discovery success rate is bounded by the service advertisement success rate and the probability of non-empty directory node lists. The figure shows that the highest discovery success rate is 91.7%.

Figure 4.11 shows the performance of PASS in terms of latency. The figure demonstrates that as *m* increases, both average latency from service consumer to directory node and average latency from service provider to directory node also increase. This is because the range of service advertisement and service discovery also increases with *m*. On the other hand, the average latency from service consumer to service provider is less than 64 ms. This shows that most service consumers are able to locate a nearby service provider.

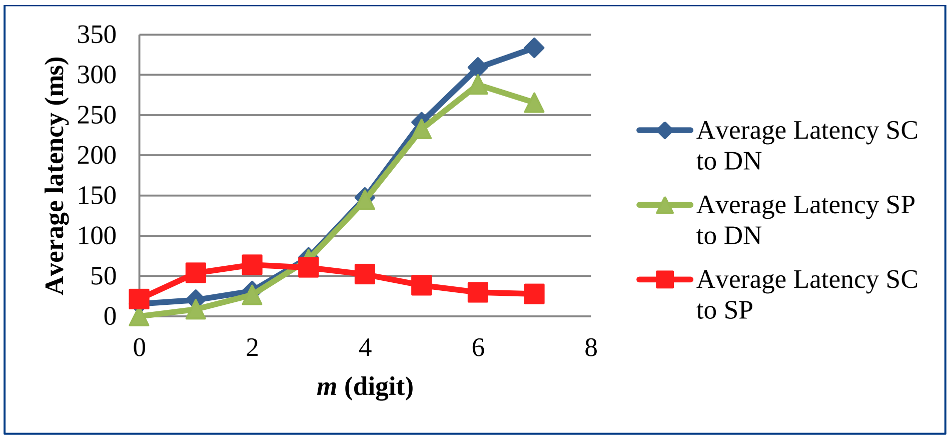


Figure 4.11 Simulation-I: Average latency of prefix-based service discovery

Figure 4.12 shows the locality failure of prefix-based searching in the proposed scheme. When *m* = 3, the service discovery records the highest success rate at 91.7% but the locality failure at this point is 43.4%. This means that there are around 43% of the successful service discovery cases where the service consumers are unable to find a nearby service provider, even it exists in the region.

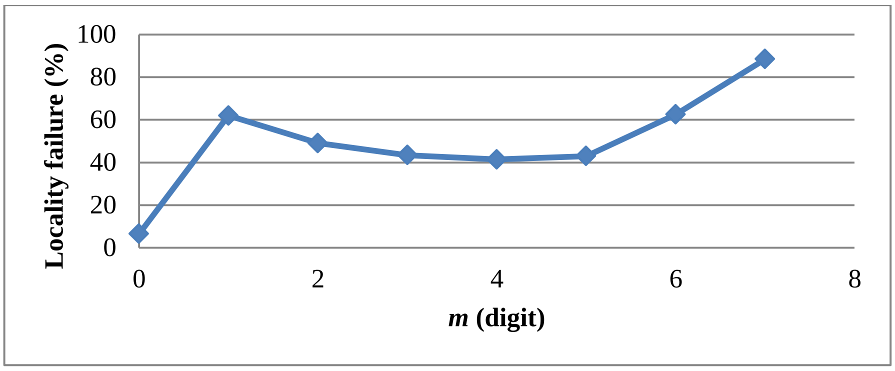


Figure 4.12 Simulation-I: Locality failure of prefix-based service discovery

Furthermore, at m = 0, the locality search failure is the lowest when compared with other values of m. This is because both service providers and service consumer will tend to advertise and search from their own region. Although the success rate of service discovery for m = 0 is low, this shows that whenever a service consumer found a directory node to get the service provider that it needs, the service providers found will be nearby.

However, the locality search failure slowly decreasing from m = 1 to m = 4 which means that service providers and service consumers are able to gradually meet at the common directory node and the optimal point is at m = 4. The locality search failure starts to increase after m = 4 because the service consumer would tend to find service providers that are far from it as the radius of service advertisement and service discovery becoming bigger.

Even so, the prefix-based service discovery approach has much lower percentage in locality search failure compared with the distributed service discovery scheme in section 3.2. This means that the proposed approach, PASS has achieved the objective of locality awareness.

4.5.2 Simulation-I with only 0.1% of service providers

In this sub-section, the performance of PASS in terms of effectiveness is evaluated by limiting the number of available service providers in the network. In this simulation, we test whether rare services can be located by the proposed approach or not.

The simulation is carried out by inducing only 6 service providers for each service type resulting in only 0.1% of service providers are made available in a network of 6000 nodes. The setting used in this experiment consists of 16 bits of node identifier space, represented in 8 digits where each digit is presented with 2 bits. The base, *B* is set to 4 and there are 6000 number of active nodes simulated in the network. The assignment of each serviceId to service providers is done by randomly choosing six nodes from the network and each service provider can only be assigned with a maximum number of 3 serviceId. The simulation will induce 100,000 service discovery requests and each request is performed by randomly selecting service consumers from the network.

Figure 4.13 shows the simulation results in terms of service advertisement and service discovery success rate. The simulation with only 0.1% of service providers available in the network can achieve 70.14% of discovery success rate at $m = 3$ digits. Besides, the discovery success rate is again bounded by the advertisement success rate and the probability of non-empty directory node list as shown in the figure.

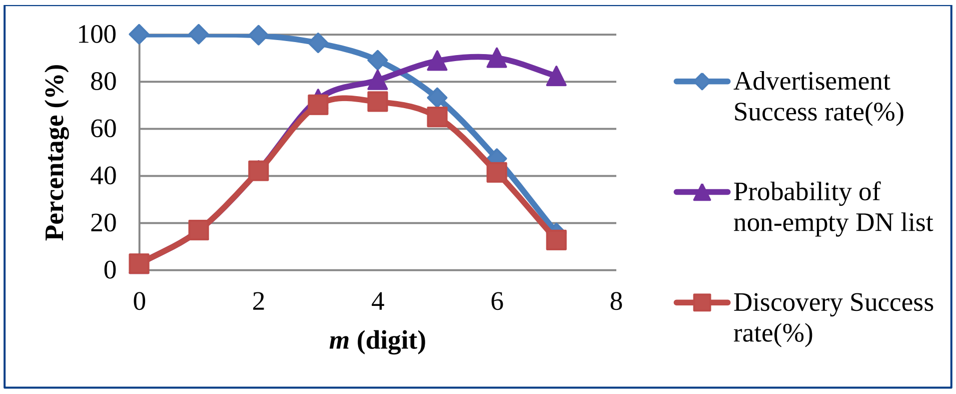


Figure 4.13 Simulation-I result with 0.1% of service providers

Figure 4.14 shows that the average latency from service consumer to service provider remains under 100 ms for most of the time except when $m = 3$. This shows that in most of the successful discovery cases, the service consumers are able to locate a nearby service provider even though there are only 0.1% of service providers available in the network.

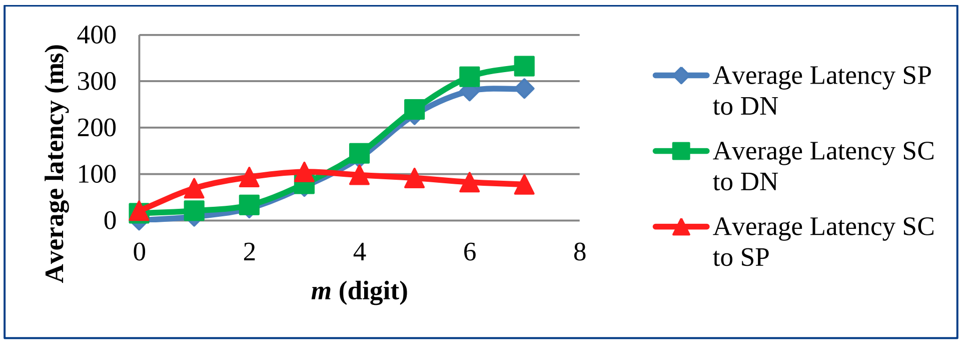


Figure 4.14 Average latency for 0.1% of service provider simulation-I

The above simulation results shows that highest service discovery rate is achieved when $m = 3$. Figure 4.15 shows discovery success rate increases when the number of service providers for each service is increased when $m = 3$. Furthermore, Figure 4.16 shows that the locality failure rate is between 40%

and 60% where the locality failure rate decreases when the number of service provider for each type of service is increased.

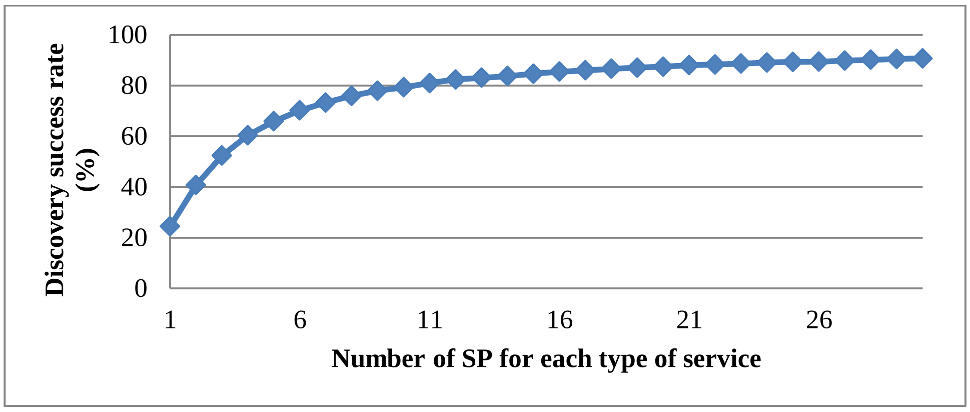


Figure 4.15 Simulation-I: Service discovery success rate when *m* = 3 and *N* = 6000

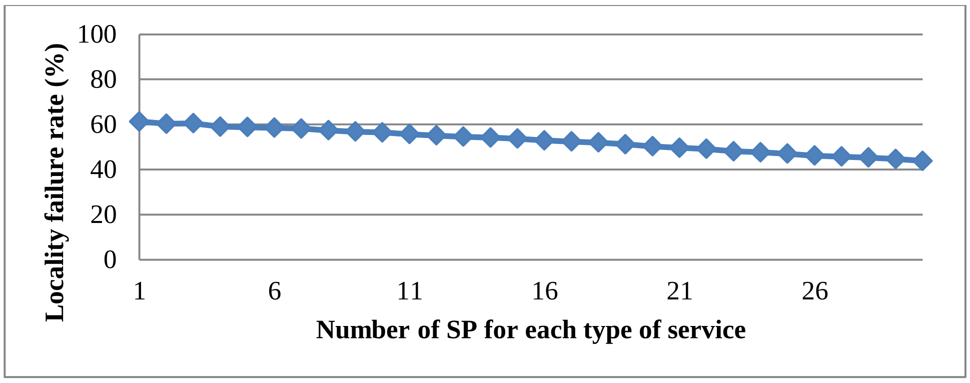


Figure 4.16 Simulation-I: Locality failure rate when *m* = 3 and *N* = 6000

4.5.3 Simulation-II results and discussion

The setting in this simulation is almost the same as Simulation-I, which is conducted in a network of 6000 nodes. The differences are the base, *B* that is used in this section is 16 (*B* = 16), and the node identifier is represented in 4 digits. For example, given the length of node address space is 16 bits and is represented in 4 digits where each digit is equal to 4 bits. The Pastry routing table for each node in this simulation consists of 16 columns and 4 rows. This means that the maximum entries in a routing table are 60 entries, which is around 1% of the network information.

Figure 4.17 shows the results from the experiment. The highest service discovery success rate here is able to reach 99.05% which is higher than the experiment in Simulation-I. This shows that the settings must be defined carefully in order to achieve high service discovery success rate.

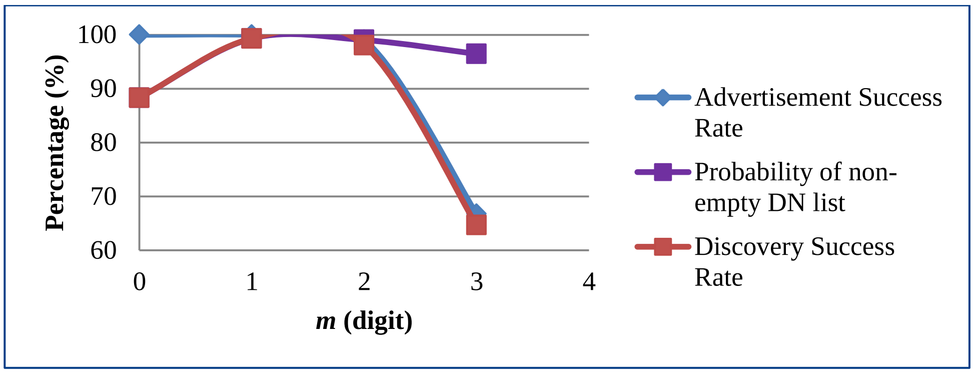


Figure 4.17 Simulation-II results

Besides that, Figure 4.18 shows that the average latency from both service consumer and service provider to directory node is less than 50 ms. This shows that the average latency has decreased nearly half from Simulation-I, which means that the settings of parameters *B* and *m* can affect the performance of PASS.

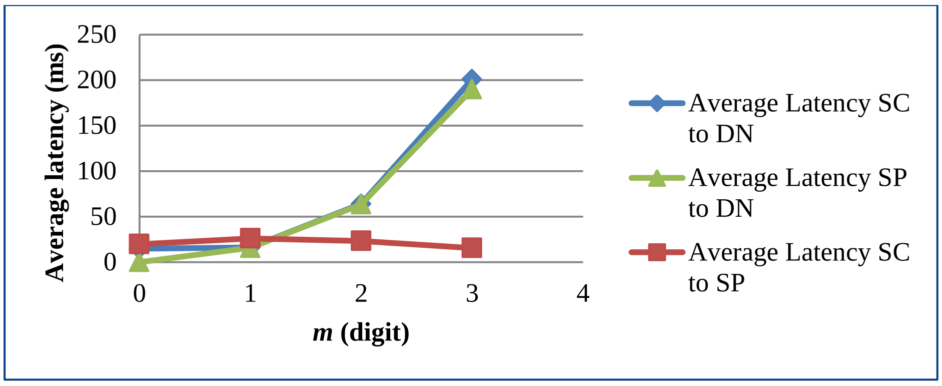


Figure 4.18 Simulation-II: Average latency of prefix-based service discovery

Figure 4.19 shows at *m* = 1, the locality failure is at 12.51% when the successful service discovery rate is at 92.96% as shown in Figure 4.17. Compared with Simulation-I, the locality failure at the highest service discovery rate has dropped from 43.4% to 12.51%.

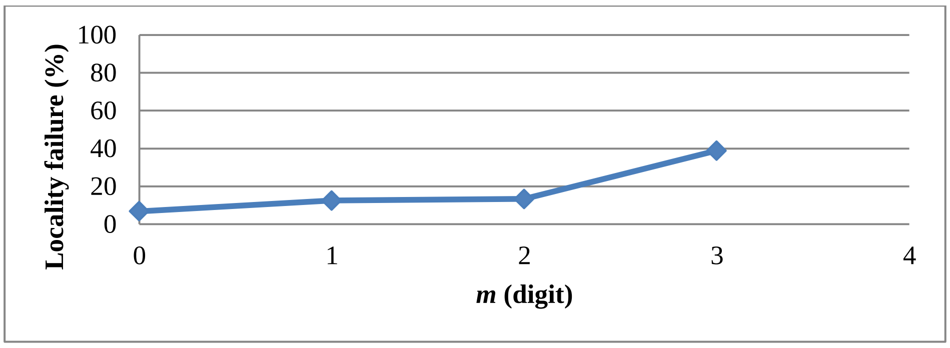


Figure 4.19 Simulation-II: Locality failure of prefix-based service discovery

4.5.4 Simulation-II with only 0.1% of service providers

Using the same settings in as previous sub-section 4.5.3, another simulation is conducted using only 6 service providers for each service type in the network of 6000 active nodes yields the following results:

Figure 4.20 below shows that even with 0.1% of the service providers are available, PASS can still reach 92.96% of successful discovery rate at *m* = 1. This shows that the proposed solution is able to locate rare services with high success rate.

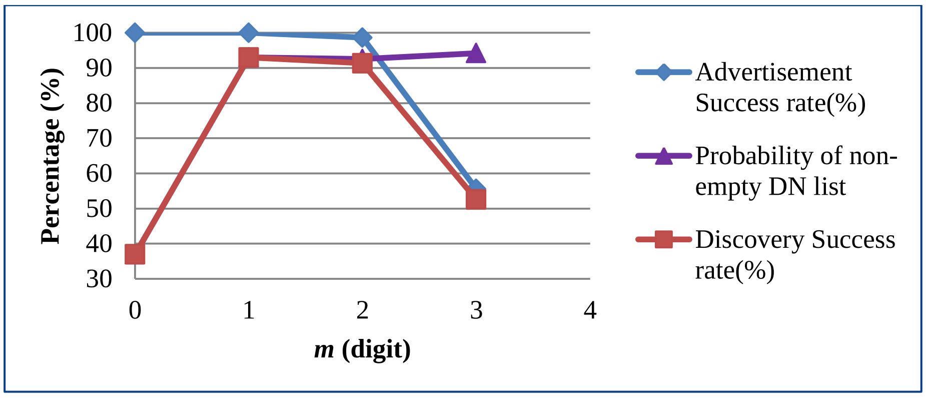


Figure 4.20 Simulation-II with 0.1% of service providers

Figure 4.21 shows that even with 0.1% of service providers, average latency from service consumer to service provider is 83 ms while the average latency from both service providers and service consumers to directory node is less than 20 ms. This shows that in most of the successful service discovery cases, the service consumers are able to locate a nearby service provider even though there are only 0.1% of service providers available in the network.

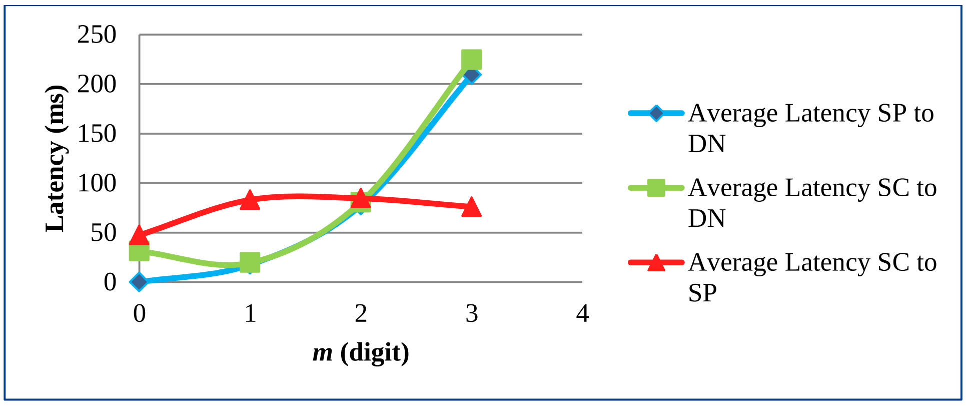


Figure 4.21 Simulation-II: Average latency for 0.1% of service provider

As shown in all the results above, when the prefix key for service discovery and advertisement, *m* is equal to 1, the service discovery success rate is at its highest. The following Figure 4.22 shows the discovery success rate increases when the number of service providers for each service is increased when *m* = 1. Furthermore, Figure 4.23 shows that the locality failure rate is below 20%. This means that the locality awareness of PASS is preserved.

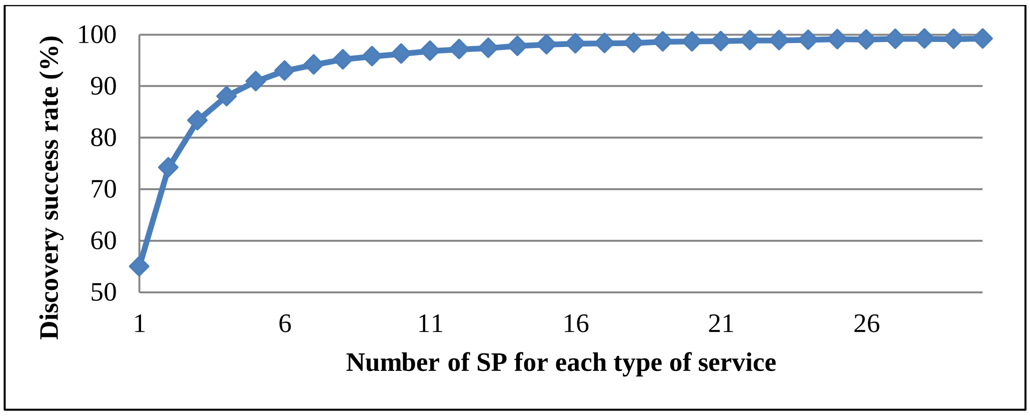


Figure 4.22 Simulation-II: Service discovery success rate when *m* = 1 and *N* = 6000

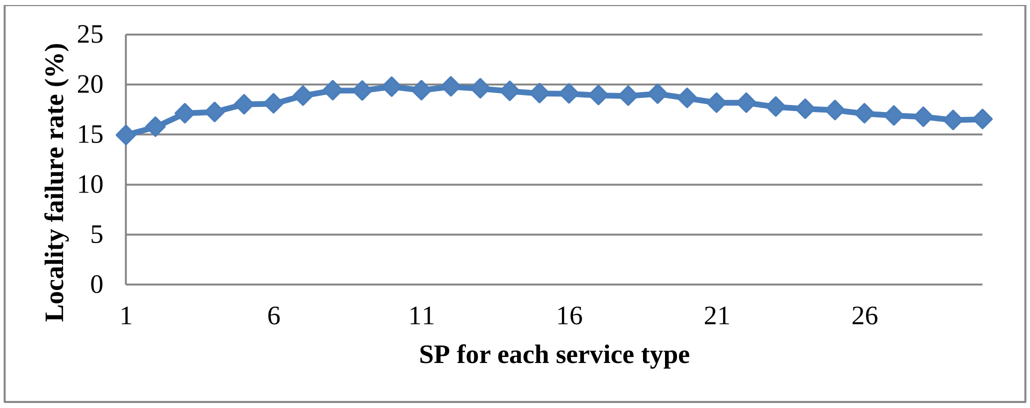


Figure 4.23 Simulation-II: Locality failure rate when *m* = 1 and *N* = 6000

In conclusion, the prefix-based advertising and searching scheme (PASS) shows superior performance when compared with the approaches discussed in the previous chapter. In this chapter, we have proved that PASS is able to provide locality awareness in searching with lower volume of traffic in the network and can maintain high service discovery success rate. Besides that, the simulation of PASS in a network that consists of 0.1% of service providers further proved the effectiveness of PASS in locating rare services as 92.9% of service discovery success rate is achieved.

CHAPTER 5

CUMULATIVE PREFIX-BASED ADVERTISING AND SEARCHING SCHEME FOR DISTRIBUTED SERVICE DISCOVERY IN STRUCTURED P2P NETWORKS

5.1 Introduction

From the simulation study, PASS for distributed service discovery proposed in Chapter 4 has satisfactory performance in all aspects as compared with the existing schemes. However, the scheme can be further improved by slightly modifying the algorithm service advertising and searching. For example, instead of searching only for directory nodes of which the nodeIds share the same prefix of m bits with the serviceId, the performance can be enhanced by enabling the search cumulatively from the nodes sharing 0 prefix bits incrementally to m prefix bits. That would greatly increase the number of directory nodes along the path to the destination nodes and thus increasing the chances of service capabilities to be found. In this chapter, we introduce a cumulative prefix-based advertising and searching scheme (CPASS).

The following sub-sections describe service advertisement and service discovery in CPASS. Next, the simulation results of CPASS and the comparison between PASS and CPASS are shown and discussed.

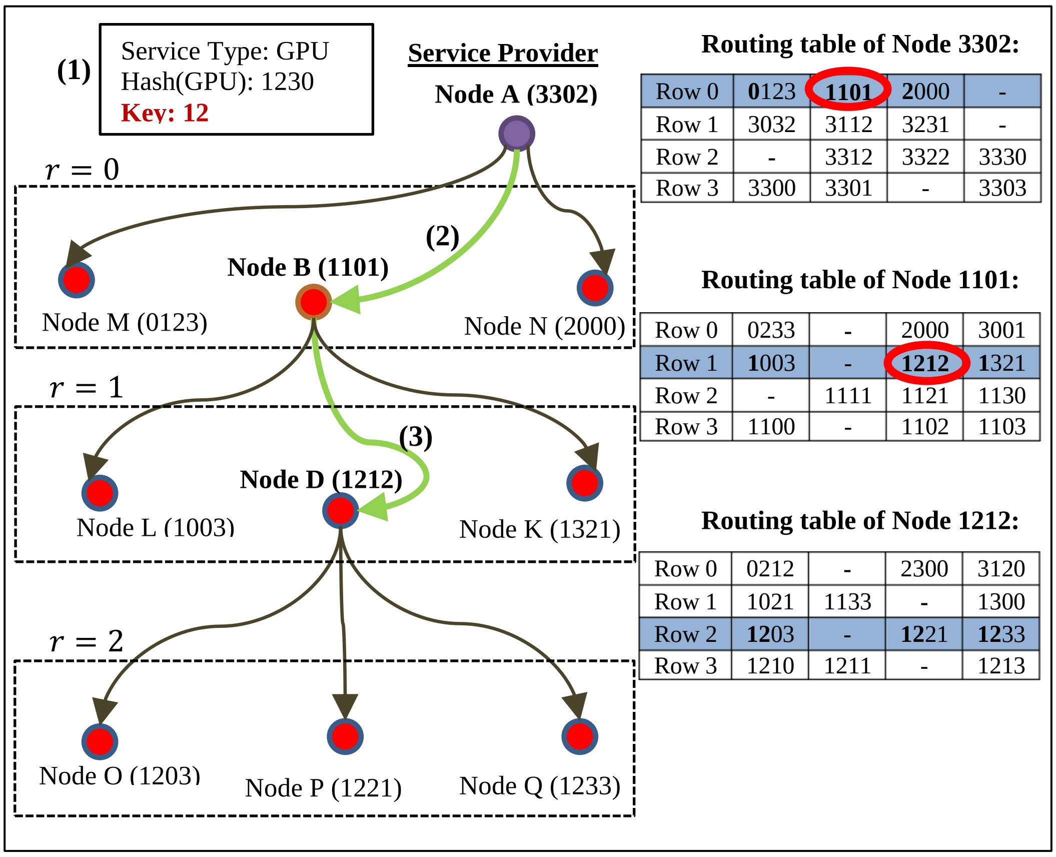
5.1.1 Service advertisement

The steps taken in service advertisement are almost similar to the steps in PASS. A new variable, r is introduced in CPASS where $0 \le r \le m$. Here, r will act as a running variable in both service advertisement and service discovery. In order to provide a better explanation, the term main-branch node is introduced. In Pastry, when presented a message with a numeric key, a node will use the key to search from its routing table in order to forward the message to the next node until the message reaches its destination. Each node along the path is known as the main-branch node. A level-*r* main-branch node shares the same *r* prefix bits with the key.

Given *m* = 2 and the variable *r* is initialised with 0, Figure 5.1 illustrates an example of service advertisement by the service provider where the main-branch directory nodes are node A, B and D. The numbers of bits in the node identifier space are presented in digits in the example (i.e., 2 bits in 1 digit).

As shown in Figure 5.1, the service advertisement starts with the service provider, node A hashes the service type that it can provide at *step 1* and the key 12 is extracted from the serviceId 1230. The main-branch nodes A, B, and D are shown in the figure and these nodes will be responsible to do the service advertisement. The service provider (node A) is known as the level-0 main branch node. Hence, it will become the directory node for the service it can provide. Besides, the all routing table entries in row-0 of node A, as highlighted in blue, will also become the directory node for the service 1230 as they currently share zero digit prefix with the key. When proceeding to the next main-branch node, the value of *r* in digit is incremented by 1.

At *step 2*, using Pastry routing, the next main branch node is node B, whose nodeId is 1101 because it is numerically closest to the key according to node A's routing table. The current variable of *r* is 1, as node B shares 1 digit prefix as the key. Thus, node B will forward the service advertisement request to all nodes of row 1 in its routing table and these nodes will also become the directory node for service 1230. When proceeding to the next main-branch node, the value of r will be incremented with 1 again, producing r = 2, as shown at *step 3* in the figure.



Routing table of Node 3302:

Row 0	0123	1101	2000	-
Row 1	3032	3112	3231	-
Row 2	-	3312	3322	3330
Row 3	3300	3301	-	3303

Routing table of Node 1101:

Row 0	0233	-	2000	3001
Row 1	1003	-	1212	1321
Row 2	-	1111	1121	1130
Row 3	1100	-	1102	1103

Routing table of Node 1212:

Row 0	0212	-	2300	3120
Row 1	1021	1133	-	1300
Row 2	1203	-	1221	1233
Row 3	1210	1211	-	1213

Figure 5.1 Cumulative prefix-based service advertisement

Note that the current variable is r = 2 at the main-branch node D (1212), hence the service provider has to advertise service 1230 to every node that shares r digit prefix as the key. Shown in the routing table of Node D, every node in row 2 is eligible to become the directory node for service 1230 because they also share 2 digit prefix with the key. The service advertisement stops now because the value of *r* has been incremented until it is equal to the value of *m*.

The following describes the algorithm for service advertisement in CPASS:

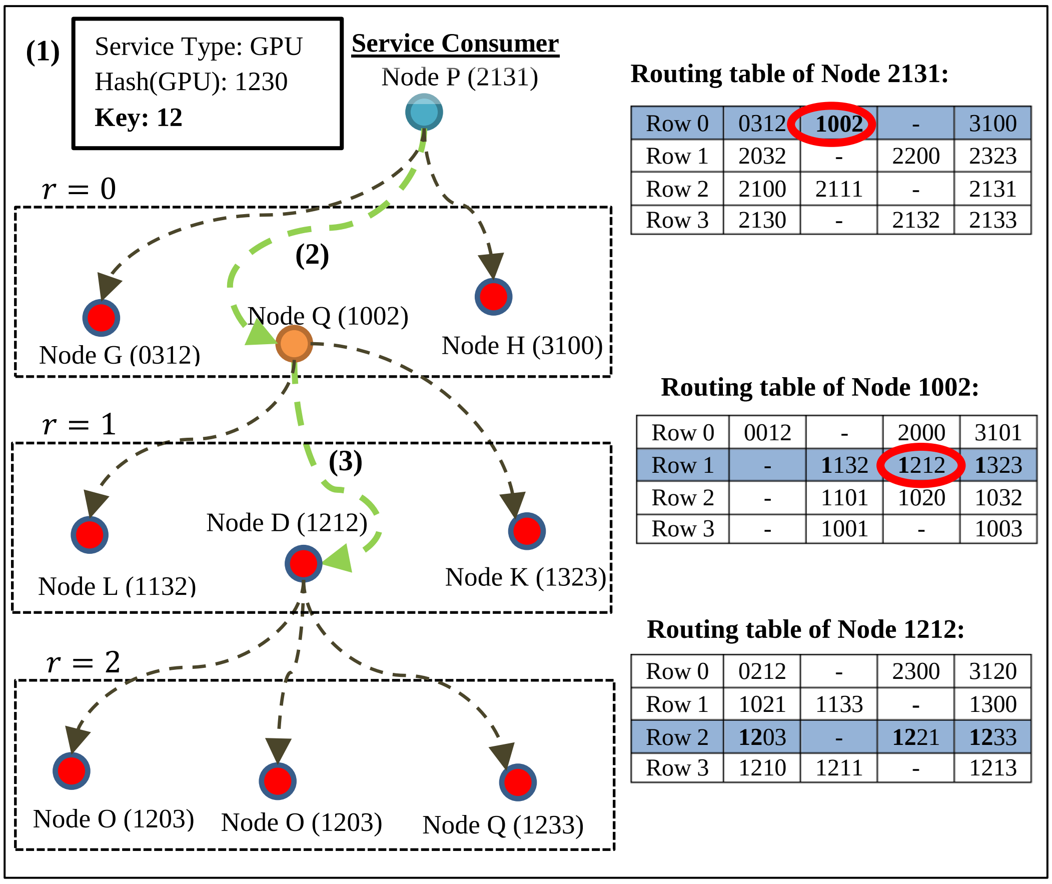
1. Service provider (SP) hashes the service type it can provide to generate a serviceId and then extract the first *m* bits of serviceId to be the key.
2. Service provider performs lookup search for any directory nodes of which the nodeIds share the same prefix of *m* bits with the serviceId. Note that the path from service provider to the node sharing the same prefix of *m* bits with the serviceId is referred to as the main-branch of advertisement. All nodes along this path are called the main-branch nodes, and the service provider itself is defined as the level-0 main-branch node. Besides, all the main-branch nodes help the service provider to do advertisement.
3. A running variable, *r* is set with an initial value of 0 where $0 \leq r \leq m$.
4. If a service advertisement request from a service provider reaches a main-branch directory node who shares at least *r* bits prefix with the key, the information of the service provider will be added into a service provider list in that particular directory node. Note that if the directory node is not found, then the service advertisement stops and this particular service advertisement request is consider failed and shall not proceed to the next step.

5. The main-branch directory node will forward the service advertisement request message to nodes in the *r-th* row of its routing table where all nodes in the *r*-th row share the same *r* bits prefix with the key.
6. The ***r***-th row directory nodes that receive the service advertisement request query from the main-branch directory node will add the information of the service provider to their own list of service provider.
7. If $r \leq m$, increment the value of *r* by 1 and repeat step 4, 5, and 6. Stop the service advertisement request if the value of *r* exceeds *m*.

5.1.2 Service discovery

Given $m = 2$ and the variable *r* is initialised with 0, Figure 5.2 illustrates an example of service discovery by the service consumer:

The service discovery starts with the service consumer node P hashes the service type that it can provide at Step *1* and the key 12 is extracted from the serviceId 1230. The main-branch nodes, P, Q, and D are shown in Figure 5.2 and these nodes will be responsible to help the service consumer to do service discovery. As the service consumer, node P is known as the level-0 main branch node, hence it will check its own list of service provider for the service it needs. Besides, node P will also forward the service discovery message to all routing table entries in row-0 of node P, highlighted in blue, for the service 1230 as they currently share 0 digit prefix as the key. If any of these directory nodes have the list of service providers requested, the list of service provider will be forwarded back to the service consumer node P and the service discovery stops here without proceeding to Step *2*.



Routing table of Node 2131:

Row 0	0312	1002	-	3100
Row 1	2032	-	2200	2323
Row 2	2100	2111	-	2131
Row 3	2130	-	2132	2133

Routing table of Node 1002:

Row 0	0012	-	2000	3101
Row 1	-	1132	1212	1323
Row 2	-	1101	1020	1032
Row 3	-	1001	-	1003

Routing table of Node 1212:

Row 0	0212	-	2300	3120
Row 1	1021	1133	-	1300
Row 2	1203	-	1221	1233
Row 3	1210	1211	-	1213

Figure 5.2 Cumulative prefix-based service discovery

However, if none of the directory nodes in level-0 has the list of service providers requested, the service discovery request will be forwarded to the next main-branch node, with an incremented value of *r* as shown at Step *2* in Figure 5.2. As node Q receives the service discovery request, it forwards the request to all level-1 directory nodes in its routing table, as highlighted in blue in the figure. If any of these directory nodes has the list of service provider requested, the list will be forwarded to the service consumer and the service discovery shall stop here without proceeding to Step *3*.

Note that each time the service discovery proceeds from one main-branch directory node to the next main-branch directory node, the value of *r* must be incremented by 1. The service discovery shall continue to proceed until the value of *r* is equal to the value of *m* or at any phase where the list of service provider is found.

The following describes the algorithm for service discovery in the cumulative scheme:

1. When a service consumer (SC) is in need of a specific service, it hashes the service type in need to generate the serviceId by using a hashing algorithm and then extract the first *m* bits of serviceId to be the key.

2. Service consumer performs lookup search for any directory nodes that shares the same prefix of *m* bits with the serviceId. Note that the path from service consumer to the node sharing the same prefix of *m* bits with the key is referred to as the main-branch of discovery. All nodes along this path are called the main-branch nodes, and the service consumer itself is defined as the level-0 main-branch node. Similar to service advertisement, all the main-branch nodes help the service consumer to do service discovery.

3. A running variable, ***r*** is set with an initial value of 0 where $0 \leq r \leq m$.

4. If a service discovery request from a service consumer reaches a main-branch directory node who shares at least *r* bits prefix with the key, the list of service providers will be retrieved from the main-branch directory node and forwarded back to the service consumer. Note that if the directory node is not found, then the service discovery request is considered failed and shall not proceed to the next step.

5. If the directory node does not have the list of service provider requested, the main-branch directory node will forward the service discovery request to nodes in the *r-th* row of its routing table where all nodes in the *r*-th row shares the same prefix bits as the key.

6. The *r*-th row directory nodes that receive the service discovery request query from the first directory node will forward the list of service providers back to the service consumer.

7. If none of these directory nodes have the list of service provider requested by the service consumer and $r \leq m$, then increment the value of ***r*** by 1 and repeat step 4, 5, 6, and 7. Note that if the value of *r* is larger than *m*, and the list of service provider is not found, then the service discovery is considered failed.

5.2 Simulation results and discussion

Simulations are carried out to test the performance of cumulative prefix-based service advertisement and searching scheme (CPASS). The settings in the simulation consist of 16 bits of node identifier address space, represented in 4 digits. The base, *B* is 16 and the other settings will be similar to the simulation settings in 4.5.3 except the network size will vary from 1000 nodes to 10000 nodes but the focus is on network with size 6000 nodes. The reason is, given the node identifier space is 16 bits where there are 2^{16}, or 65536 unique node identifiers that can be assigned to each node before collision in assignment of node identifiers take place. Thus, in a full network that consist of 65536 nodes with each node has a unique node identifier, 6000 nodes is almost 10% of the maximum network size.

Note that our proposed schemes can actually be implemented on both Pastry and Chord. However, as discussed in the literature review, although Chord is also a popular structured P2P approach for resource sharing, it does not provide locality awareness. Hence, two simulations on CPASS are conducted where Pastry will be used in the first simulation and Chord will be used in the second simulation in order to compare the performance of CPASS on the two P2P protocols. Note that both simulations on Chord and Pastry have the same settings as described in section 4.5. Both simulations have the base of the node address identifier space set to 16, and the node identifier is represented in 4 digits.

5.2.1 Simulation on Pastry network

The bounding first factor discussed in PASS (section 4.4) is not applicable here because every service advertisement should be successful considering the service provider is the directory node for the service type that it can provide as well as all row-0 nodes from its routing table, unless there is no entry at all in the routing table of the service provider, which cannot be true since the provider already joined the network. Due to this, the service discovery success rate in CPASS will definitely outperform PASS described in Chapter 4.

Figure 5.3 shows the simulation conducted in networks that consist of numbers of nodes from 1,000 to 10,000 nodes, with increment 1000 nodes. From the figure, it is shown that higher success rate is achieved when the value of *m* is more than one and when the network size increases.

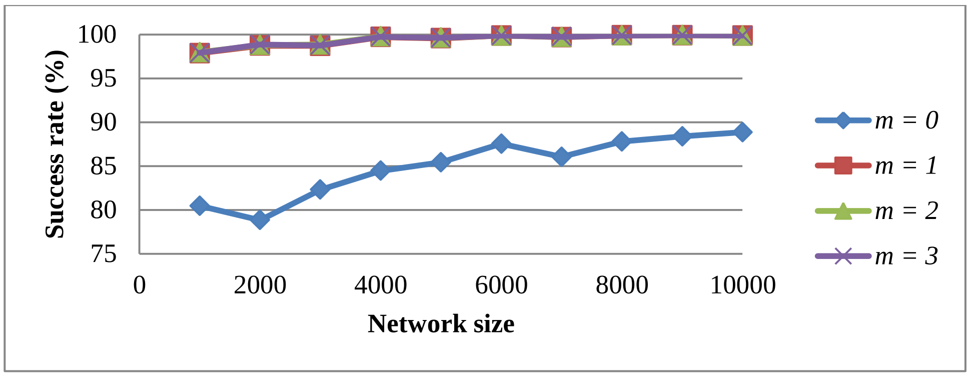


Figure 5.3 Service discovery success rate in CPASS on Pastry network

The following simulation results focus on the network service discovery success rates with respect to different values of *m* in the network that consists of 6000 nodes as this represents 10% of the entire network.

As shown in Figure 5.4, the service discovery success rate in CPASS shows some improvement at all digit of *m*. The comparison Table 5.1 shows that the service discovery rate can reach as high as 99% in both PASS and CPASS but CPASS shows that the success rate is more stable when the value of *m* is increased.

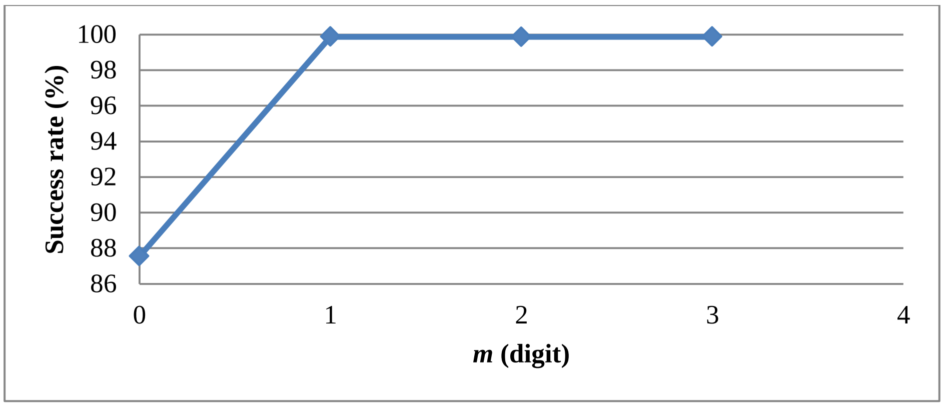


Figure 5.4 Service discovery success rate in network size of 6000 nodes on Pastry network

Table 5.1 Comparison of discovery success rate between prefix-based scheme (PASS) and cumulative prefix-based scheme (CPASS) on Pastry network

m	Prefix-based advertising and searching scheme	Cumulative prefix-based advertising and searching scheme
0	86.38 %	87.54 %
1	99.56 %	99.87 %
2	98.70 %	99.86 %
3	59.07 %	99.88 %

On the other hand, Figure 5.5 shows the average traffic in terms of the number of query messages generated per service discovery request in CPASS. This figure shows the significant improvement of this scheme when compared with the distributed scheme in section 3.2.

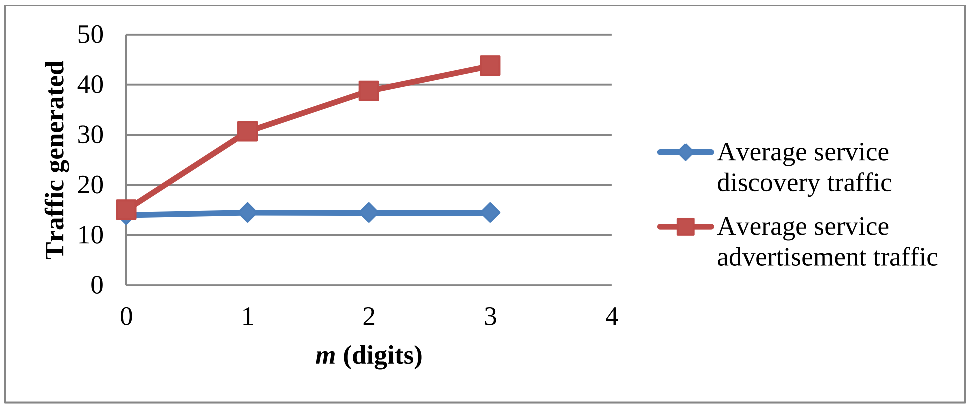


Figure 5.5 Traffic generated in service discovery of cumulative prefix-based scheme on Pastry network

Furthermore, Table 5.2 shows the comparison of both schemes traffic generated in network of 6000 nodes. The table also shows that there is no need to flood the network as using the cumulative prefix-based scheme can achieve 99% of discovery success rate. When the value of *m* increases, the search radius and success rate will also increase but it will not increase the traffic generated in the network. However when compared with the distributed service discovery scheme, as the search radius (or depth) increases, the traffic generated will increase exponentially. Even so, the only trade-off of CPASS is that the traffic (or messages) generated in service advertisement is slightly higher than the distributed service discovery in structured P2P scheme using Chord discussed in section 3.2.

Table 5.2 Comparison of average traffic generated per query between distributed service discovery scheme and cumulative prefix-based scheme on Pastry network

Distributed service discovery in structured P2P	Cumulative prefix-based advertising and searching scheme
12.85 (Depth = 1)	13.98 (*m* = 0)
218.50 (Depth = 2)	14.47 (*m* = 1)
3448.81 (Depth = 3)	14.42 (*m* = 2)
-	14.42 (*m* = 3)

Figure 5.6 shows that the locality failure has significantly decreased when compared to the prefix-based searching scheme in Chapter 4. This means that the current cumulative scheme gives higher probability of enabling the service consumer to discover nearby service providers.

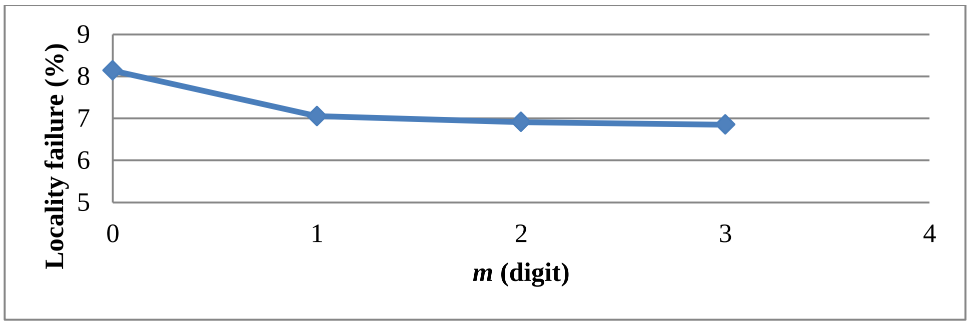


Figure 5.6 Locality search failure of prefix-based cumulative scheme on Pastry network

Figure 5.7 shows the average latency from service consumer to directory node and the average latency from service consumer to service provider. As explained in Table 4.1, the latency generated between nodes according to the node's region where two nodes in the same region should have 6 ms to 20 ms latency, the average latency from service consumer to service provider is below 20 ms. This means that the service consumer is able to find service providers that exist in the same region as shown in Figure 5.7. Hence, the locality of service discovery is preserved, or even enhanced, in this cumulative scheme.

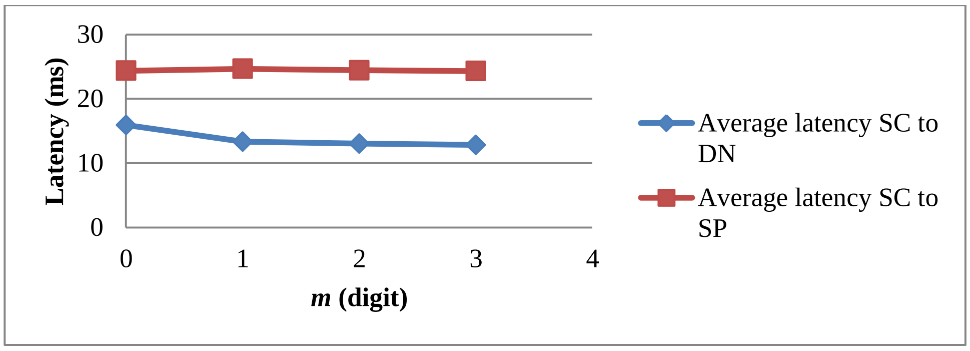


Figure 5.7 Average latency of cumulative scheme on Pastry network

5.2.2 Simulation on Chord network

5.2.2.1 Prefix-based cumulative service advertisement and discovery searching on Chord network

This sub-section briefly describes Chord routing and how the prefix-based advertising and searching scheme (CPASS) is implemented on Chord system.

As the simulation on Chord will only use Chord's finger table to do routing, hence the structure of a Chord's finger table is focused here. Each Chord node has a pointer pointing to a successor node and a predecessor node, hence Chord network is assumed to be constructed on a circular identifier space (El-Ansary & Haridi, 2005). Furthermore, each Chord node keeps a set of pointers of node called the finger table and the size of finger table is equal to the node identifier length, M in bits. The set of pointers are chosen by positioning the node itself at the start of the identifier space and find fill up finger table entries such that $F_i = Successor(u + 2^{i-1}), where\ 1 \leq i \leq M$ and u represents the node identifier.

For example, given M = 8 bits and the following shows the finger table entries for Chord node with the identifier of 5, where u = 5. The Chord network consists of 10 nodes with identifiers of 4, 5, 9, 40, 66, 78, 99, 130, and 240.

Table 5.3 Chord finger table example for Chord with node identifier of 5, with M = 8

F_i	$Successor(u + 2^{i-1})$
F_1	$Successor(6)$ = 9
F_2	$Successor(7)$ = 9
F_3	$Successor(9)$ = 9
F_4	$Successor(13)$ = 40
F_5	$Successor(21)$ = 40
F_6	$Successor(37)$ = 40
F_7	$Successor(69)$ = 78
F_8	$Successor(133)$ = 240

When a Chord node needs to route to a specific target, it first checks its finger table for any entries that is closest preceding to the key and forwards the message to that node entry. For instance, if node 5 has a message with the key 27, the node will select node 9 to send the message because node 9 has a Chord identifier that immediately precedes the key 27.

The service advertisement using Chord is the same as service advertisement algorithm using Pastry in section 5.1.1. The only difference is in Pastry, routing table is used whereas in Chord, finger table is used. The algorithm for service discovery stated in section 5.1.2 can also be applied on Chord.

For example, the algorithm of service advertisement discussed in section 5.1.1 is to forward the service advertisement query to all nodes in row-*r* because those nodes shares *r* prefix with the key. Here, the finger table entries are not arranged according to prefix. Hence, the advertisement query will be forwarded to any node entry that shares the first *r* digits with the key.

5.2.2.2 Simulation results and discussion

The Chord finger table has at most 16 entries as the size of finger table depends on the bit length of the Chord's node identifier address space.

Shown in Figure 5.8 and Figure 5.9, both service advertisement and service discovery are performed using brute force hence the lower success rate at $m = 0$. The reason is Chord's finger table which consist of only at most 16 entries, causing the lower chances in achieving successful discovery. Besides, the routing table size for Pastry in the previous simulation (section 5.2.1) is bigger than Chord where Pastry has at most 60 entries. Hence $m = 0$ has lower success rate in discovery compared with the same scheme on Pastry network.

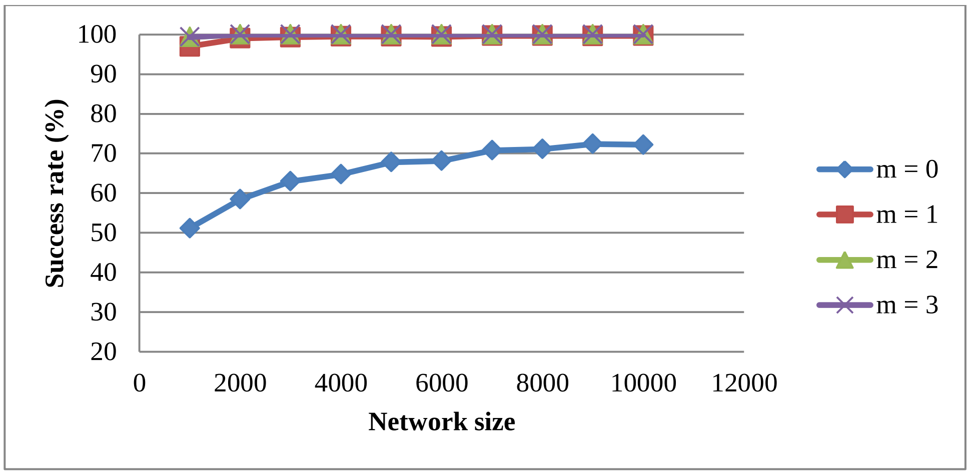


Figure 5.8 Service discovery success rate of CPASS on Chord network

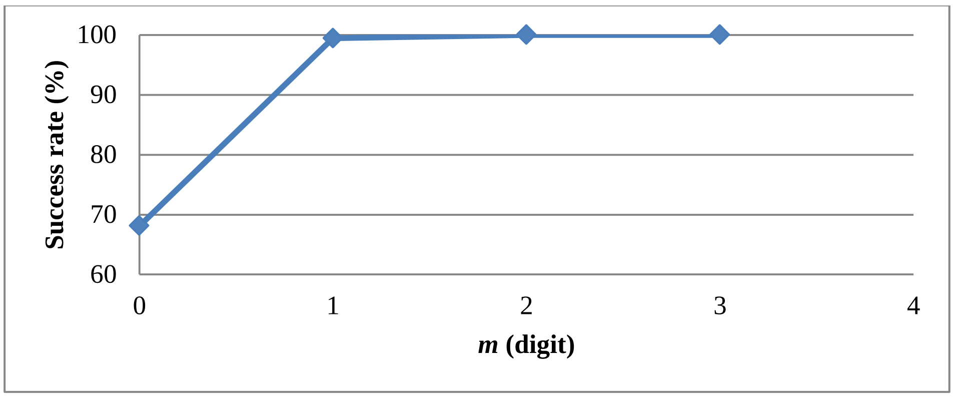


Figure 5.9 Service discovery success rate in network size of 6000 nodes on Chord network

On the other hand, the success rate for other values of *m* records higher success rate in discovery when compared to Pastry. This is because the links between Chord nodes are perfectly constructed and whatever key used to do the routing will send the message to the successor of the key, unless hop limit is specified in the system.

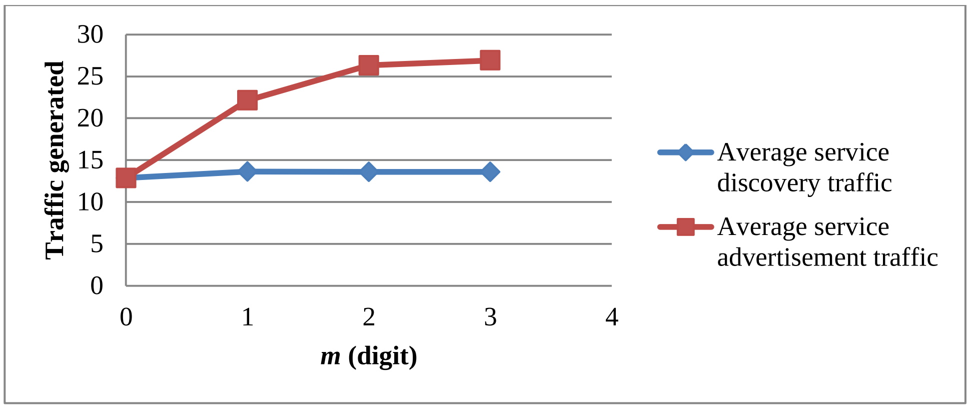


Figure 5.10 Average traffic generated in service discovery of CPASS on Chord network

The traffic generated for both service discovery and service advertisement on Chord network is slightly lower than the traffic generated on Pastry network. This is because Chord's finger table is not structured according to prefixes like Pastry's routing table thus the number of entries that shares the same prefix in Chord's finger table are lesser than Pastry's. Hence the traffic generated is also lesser than Pastry.

Besides that, the number of directory nodes for each service type are lower when compared with Pastry because in most cases of service discovery and service advertisement, the service provider or service consumer tend to find the same directory node when the same key is used for routing. Due to this the success rate on Chord is higher than Pastry.

Although with higher success rate, the locality search failure is high on Chord network. As shown in Figure 5.11, the locality failure is at the highest at 88% when *m* = 0. Besides that, the locality failure is still around 72% for other values of *m*. This means that Chord system is unable to preserve locality when routing for a certain node.

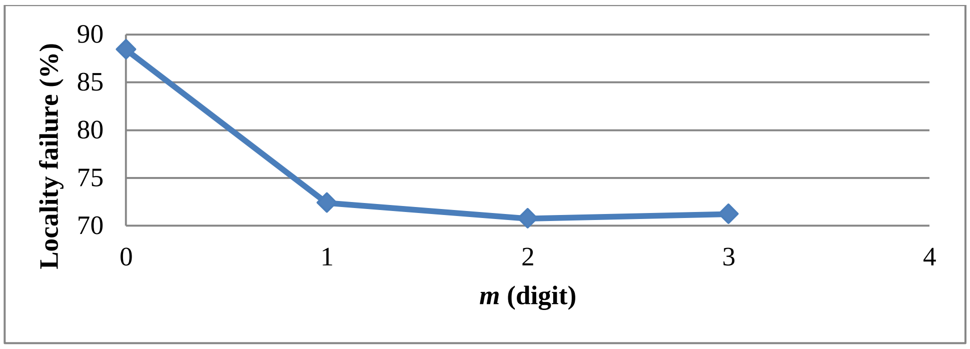


Figure 5.11 Locality search failure of cumulative prefix-based scheme on Chord network

Figure 5.12 shows that the average latency from service consumer to service provider is always above 100 ms. This means that almost all the cases of successful discovery, the service consumers are only able to contact service providers that are not in the same region. Besides, the average latency from service consumer to directory node is also higher when compared with the same approach running on Pastry network.

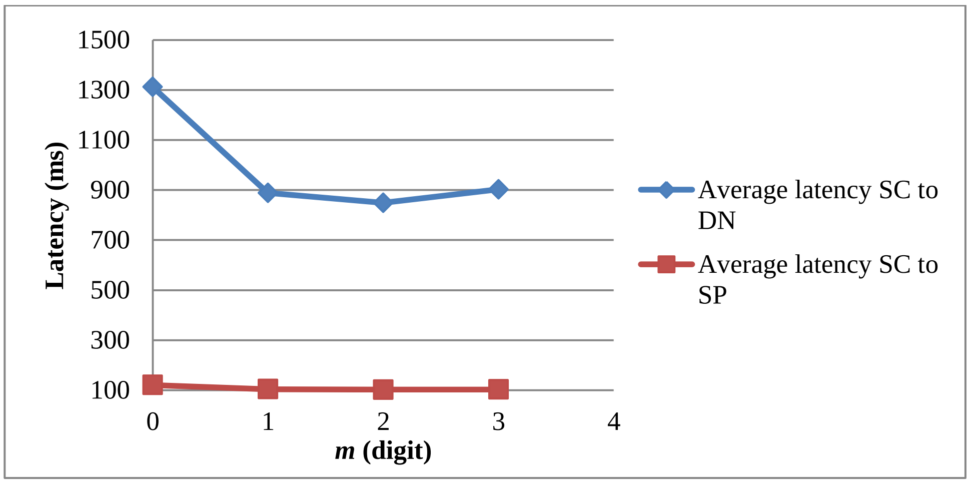


Figure 5.12 Average latency of cumulative prefix-based scheme on Chord network

In conclusion, when the same searching algorithm CPASS is applied on Chord and Pastry, CPASS on Chord shows slightly better result in service discovery success rate than that of CPASS on Pastry, but both actually can achieve 99% of service discovery success rate as shown in Table 5.4. Both simulations of CPASS on Pastry and Chord have significant improvement when compare against PASS on Pastry when the prefix key *m* increased as shown in Table 5.5.

Table 5.4 Service discovery success rate of CPASS on Pastry and Chord

Network Size	**Service discovery success rate of CPASS (%)**							
	***m* = 0**		***m* = 1**		***m* = 2**		***m* = 3**	
	Pastry	**Chord**	**Pastry**	**Chord**	**Pastry**	**Chord**	**Pastry**	**Chord**
3000	82.30	62.95	98.70	99.29	98.85	100.00	98.76	100.00
6000	87.54	68.13	99.87	99.43	99.86	100.00	99.88	100.00
9000	88.38	72.40	99.91	99.65	99.92	100.00	99.93	100.00

Table 5.5 Service discovery success rate of PASS on Pastry

Network Size	**Service discovery success rate of PASS (%)**			
	***m* = 0**	***m* = 1**	***m* = 2**	***m* = 3**
3000	81.64	98.91	96.01	34.33
6000	88.33	99.31	98.06	64.68
9000	88.94	99.43	98.31	67.82

Although CPASS on Chord gives better success rate but CPASS on Pastry gives much better locality awareness when compared with CPASS on Chord. This can be seen in Table 5.6 where the locality failure of CPASS on Pastry is much lower than CPASS on Chord. However, when comparing locality awareness, CPASS is better than PASS as shown in Table 5.7 where higher value of *m* results in lower locality failure in CPASS.

Table 5.6 Locality failure success rate of CPASS on Pastry and Chord

Network Size	Locality failure rate of CPASS (%)							
	***m* = 0**		***m* = 1**		***m* = 2**		***m* = 3**	
	Pastry	**Chord**	**Pastry**	**Chord**	**Pastry**	**Chord**	**Pastry**	**Chord**
3000	10.86	87.75	8.93	69.41	8.78	67.76	8.81	68.34
6000	8.14	88.43	7.05	72.40	6.91	70.77	6.85	71.23
9000	7.87	87.60	7.23	73.89	6.82	72.24	7.03	72.58

Table 5.7 Locality failure rate of PASS on Pastry

Network Size	Locality failure rate of PASS (%)			
	***m* = 0**	***m* = 1**	***m* = 2**	***m* = 3**
3000	9.30	18.94	18.41	68.06
6000	6.85	12.51	13.34	38.86
9000	6.29	12.23	13.14	35.92

In the next chapter, the resiliency of CPASS on Pastry is tested.

CHAPTER 6

THE RESILLIENCY OF CUMULATIVE PREFIX-BASED ADVERTISING AND SEARCHING SCHEME

This chapter describes the resiliency of the cumulative prefix-based service advertisement and service discovery scheme (CPASS) by performing simulation where nodes are set to leave the network. In the following sub-chapters, the performance of CPASS will be tested and discussed in the event of 10% nodes encountered failure (or departed from the network) after the routing tables have been set up for all nodes. Next, the routing tables of the remaining active nodes will be repaired and the results of both simulations are compared. It should be noted that the resiliency of prefix-based service advertisement and service discovery scheme (PASS) is not tested because the performance of CPASS has already proved to outperform PASS in the previous chapter.

6.1 The resiliency simulation

In this simulation, 10% of the active nodes are randomly chosen to leave the network. It should be noted that these leaving nodes are considered failed and will not inform the remaining active nodes in the network about their departure. Hence, the node identifiers of these departed nodes will still exist in the remaining active nodes' routing tables. In the case where a departed node is encountered during the Pastry routing process, the routing will cease and should not be able to carry on hence will result in a failed search.

Figure 6.1 shows the simulation of running CPASS on Pastry in a network that consist of numbers of nodes from 1,000 to 10,000 nodes with increment 1000 nodes. The simulation settings are the same as described in section 5.2. The difference here is that 10% of the active nodes are set to depart from the network. For example, in a network that consists of 6000 nodes, 600 randomly chosen nodes are set to leave the network. As shown in Figure 6.1, the cumulative prefix-based scheme shows that even when 10% of the nodes have left the network, good success rate is still achievable. Although the success rate shows declination when compared with the simulation shown in section 5.2.1 however this is expected due to the existence of node identifiers of failed nodes in the remaining active nodes' routing tables.

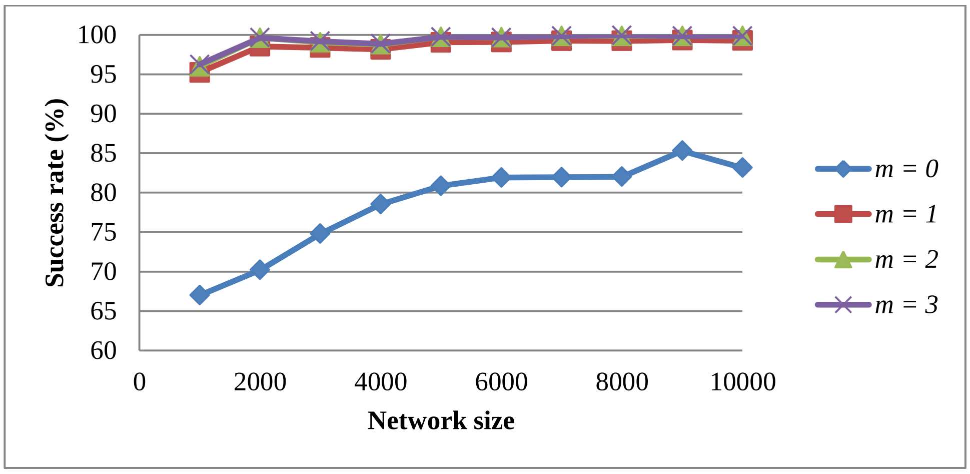


Figure 6.1 Service discovery success rate for resiliency test in a Pastry network

Figure 6.2 shows that the success rate has also declined when compared with the simulation shown in Figure 5.4 in section 5.2.1. Although at the beginning where *m* = 0, the success rate has dropped from 88% to 82% but as *m* increases, the service discovery success rate gradually goes back to a higher rate which is comparable with the result by the cumulative prefix-based scheme (CPASS).

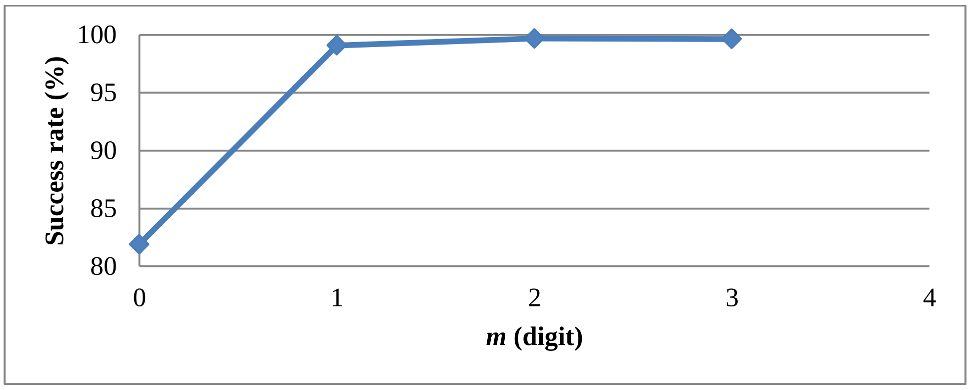


Figure 6.2 Success rate in a network that consist of 6000 nodes after 10% of the nodes departed

The traffic generated in this resiliency test in a 6000 nodes network is almost the same as in the normal network. This shows that the proposed scheme is able to withhold against node failure even when 10% of the network population have failed.

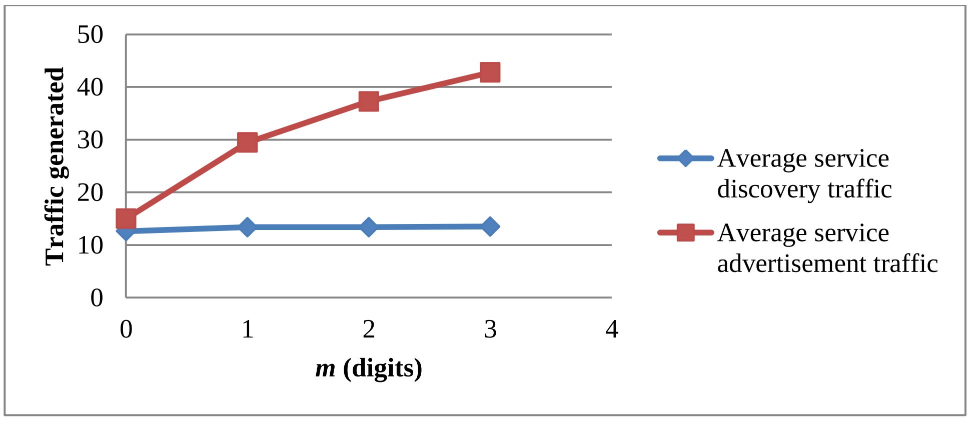


Figure 6.3 Traffic generated in a network that consist of 6000 nodes after 10% of the nodes departed

Overall, the low locality failure shown in Figure 6.4 indicates that most of the successful service discovery cases are able to locate a nearby service provider as well.

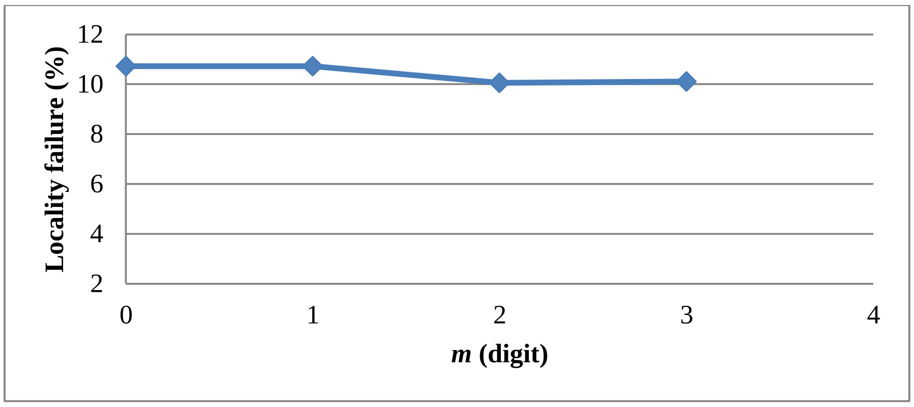


Figure 6.4 Locality search failure in a network that consist of 6000 nodes after 10% of the nodes departed

Figure 6.5 shows that the average latency in successful service discovery queries from service consumer to service provider are between 10 ms to 20 ms. This means that the majority of the service consumers are able to locate service providers in their own proximity. However, when compared with the average latency shown at Figure 5.7 in section 5.2.1, a rise in latency occurs. This is because the time taken to locate a directory node has become longer due to the failed node identifier entries in the routing tables of the remaining active nodes. Besides, the average latency from service consumer to service provider also increase as the value of *m* increases. The declining number of active node entries in the service consumer's routing table has forced the service consumer to widen its search radius.

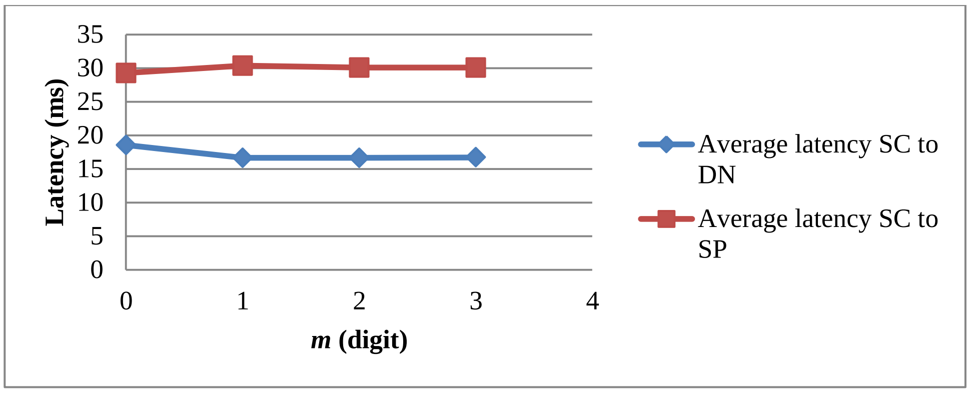


Figure 6.5 Average latency in a network that consist of 6000 nodes after 10% of the nodes departed

In conclusion, the resiliency test shows that even with 10% of nodes have departed from the network, the proposed cumulative scheme is still able to perform well by achieving high success rate, i.e., 99% when m = 3. However, this has caused the increase in latency between service consumer and service provider as a result of forcing the service consumer to expand its search radius. Hence, in order to reduce such effect, repairing the routing tables of remaining active nodes by replacing the departed nodes identifiers with active nodes identifiers is important in the real network.

6.2 Repairing the Pastry routing table

The Pastry routing protocol comes with routing table repairing system that enables each node to repair its routing table when departed or failed node is identified during the occasional node checking process. However, the original Pastry's process of repairing the routing table requires the neighbourhood set maintained by each node. The neighbourhood set consist of nodes that are in close proximity but not listed in the routing table.

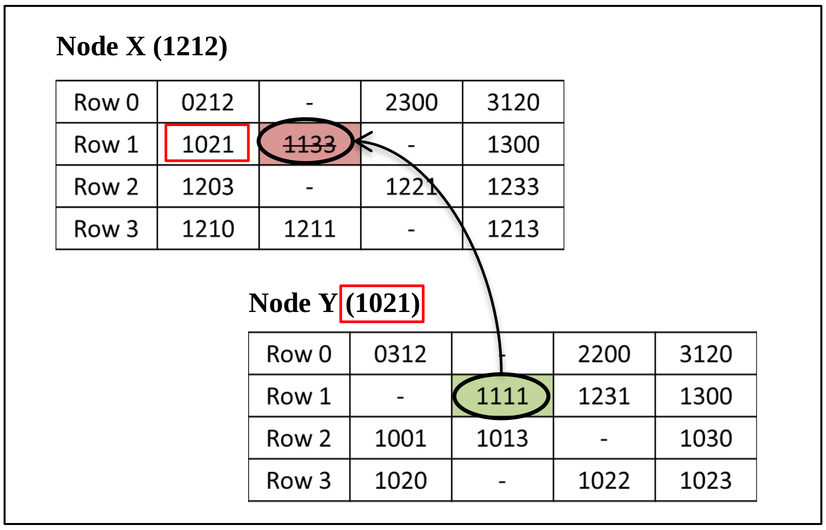
As the neighbourhood set is not configured in the simulation system, an alternative way of repairing the routing table is performed. The following describes the steps performed by each node for repairing routing table.

1. Identify the failed node from the routing table.
2. Query the first active node that is in the same row as the failed node.
3. Request routing table from the active node and use the routing table entries from the active node to replace the failed node.
4. If the failed node is not appropriate to be replaced by the node entry in the retrieved routing table, then request routing table from the next active node in the same row as the failed node.
5. After the failed node identifier is replaced by the active node identifier, the active node will send copies of relevant service lists to the replaced node.

Given node X whose nodeId is 1212 and has a failed node entry whose nodeId is 1133 in its routing table as shown in Figure 6.6. In order to replace the failed node entry, node 1212 sends a request to node Y whose nodeId is 1021 for its routing table because node Y is the first active node that is in the same row as the failed node 1133. When node X receives a copy of node Y's routing table, it finds a suitable replacement for 1133. Then the entry 1133 is replaced by the entry 1111 retrieved from node Y's routing table.

Note that the replacement of failed node will be equipped with service lists that are relevant to it. For example, node 1111 will receive service lists with serviceIds that share the same prefix of *m* bits with node 1111 from node X.

This is a step to enable the replacement node to become a directory node and resume its responsibilities of providing information about service providers. Although the replacement might already become a directory node but it may not contain as much information about service provider as the failed node that it replaced. Thus, this step may help to ensure high success discovery rate is still achievable and the average latency is lowered.



Node X (1212)

Row 0	0212	-	2300	3120
Row 1	1021	~~1133~~	-	1300
Row 2	1203	-	1221	1233
Row 3	1210	1211	-	1213

Node Y (1021)

Row 0	0312	-	2200	3120
Row 1	-	1111	1231	1300
Row 2	1001	1013	-	1030
Row 3	1020	-	1022	1023

Figure 6.6 Example of routing table repairing process

The following describes the simulation results and discussions. As shown in Figure 6.7, the service discovery success rate at *m* = 0 has shown 10% improvement after repairing the routing table. However, the success rate also slowly increased (as the network size increased) to be at the same rate even without repairing procedure. This may be caused by the completeness of routing table entries in higher network size and 10% of departed nodes in the network did not affect much on the service discovery process.

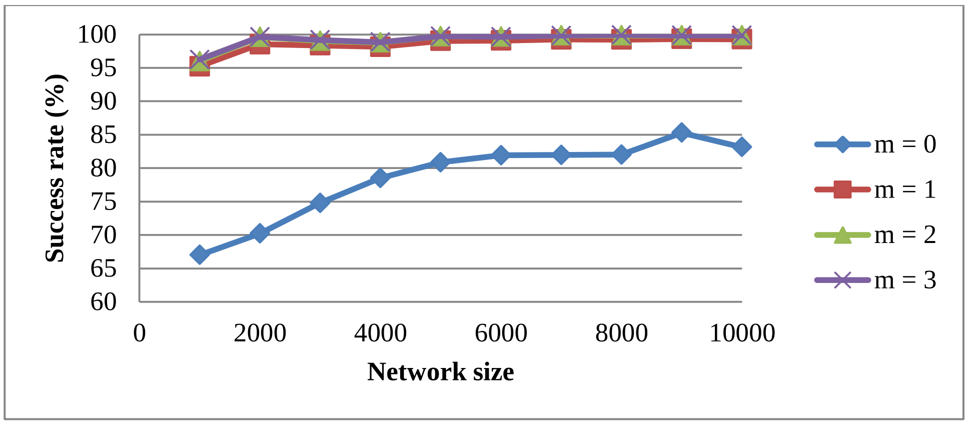


Figure 6.7 Service discovery success rate after the repairing procedure

Figure 6.8 shows the service discovery success rate after the routing table repairing process, where the success rate slowly increases to 99% as the value of *m* increases.

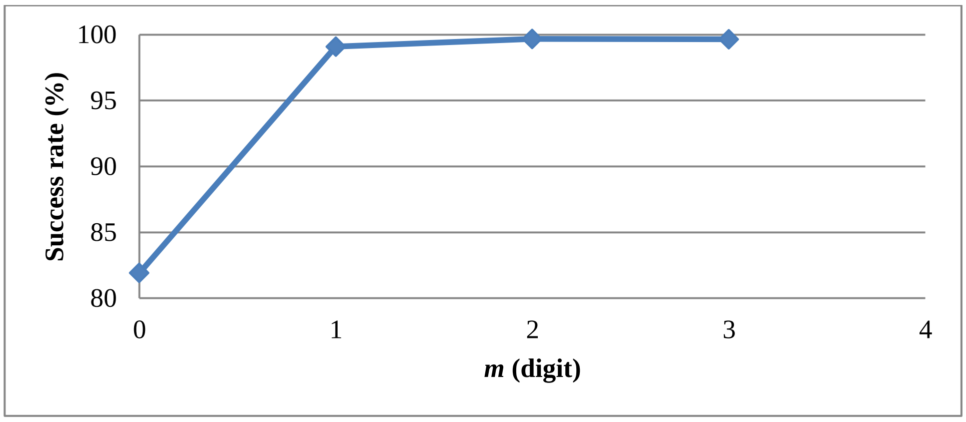


Figure 6.8 Success rate in a network that consist of 6000 nodes after repairing process

According to Figure 6.9, the average traffic generated at *m* = 0 is slightly lower than *m* = 1, 2, and 3. As most of the successful service discovery cases occurred at *m* = 0 hence the traffic generated is low at first. However as the search radius expands, the traffic generated also increased.

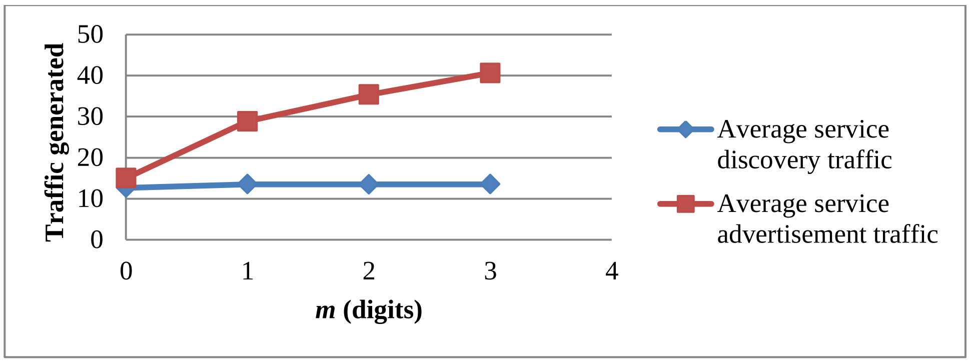


Figure 6.9 Traffic generated in a network that consists of 6000 nodes after repairing process

The locality search failure in this simulation as shown in Figure 6.10 has gotten higher after the routing repairing process is conducted. This is the result of the repairing procedure done to the routing tables as the replacements of failed nodes are chosen from a neighbour's neighbour. Although the service discovery success rate is still high, the locality search failure has shown the effects of repairing the routing table. Furthermore, repairing the routing table has also caused the average latency to increase as shown in Figure 6.11.

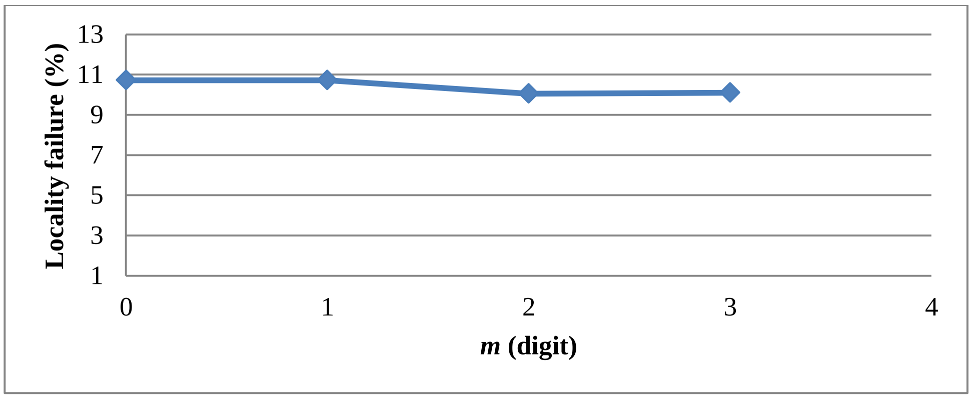


Figure 6.10 Locality search failure in a network that consist of 6000 nodes after repairing process

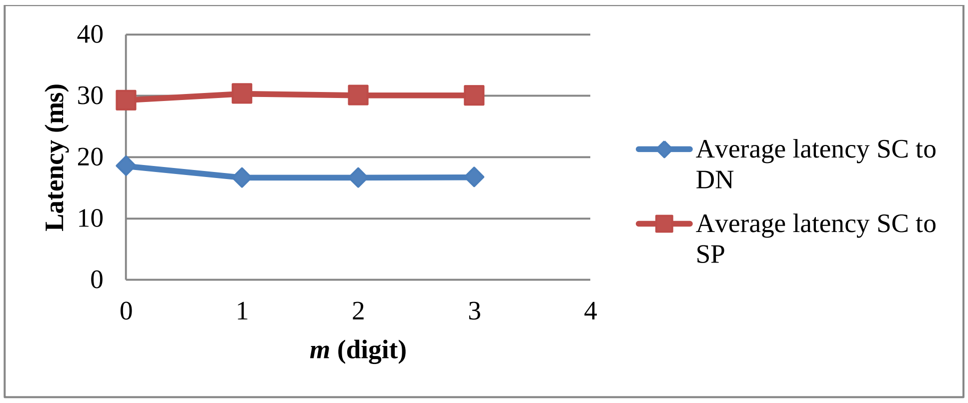


Figure 6.11 Average latency in a network that consist of 6000 nodes after repairing process

6.3 Discussion

This chapter describes the performance of the cumulative service discovery scheme in a dynamic network. Even with 10% of the nodes in the network departed, the simulation result in section 6.1 has shown that 99% of service discovery success rate is achievable. Table 6.1 compares the results of service discovery success rate before any of the nodes in the network are set to fail, after 10% of nodes are set to fail, and after repairing the routing tables. The resiliency test simulation and has shown that nodes leaving the network have little effect on the success rate. On the other hand, Table 6.2 shows that the average service discovery traffic generated per query is almost the same before and after the repairing process.

Table 6.1 Service discovery success rate in a network of 6000 nodes

m	**Before resiliency test**	**Resiliency test with 10% of failed node**	**Resiliency test after routing table repairing process**
0	87.54 %	81.92 %	81.92 %
1	99.87 %	99.09 %	99.10 %
2	99.86 %	99.67 %	99.68 %
3	99.88 %	99.64 %	99.65 %

Even after repairing the routing tables by replacing the failed nodeId entries with active nodeId entries, there is only small increase in the service discovery success rate and the average traffic generated shows no changes.

Table 6.2 Average service discovery traffic generated in a network of 6000 nodes

m	**Before resiliency test**	**Resiliency test with 10% of failed node**	**Resiliency test after routing table repairing process**
0	15.93	12.63	12.63
1	13.31	13.38	13.38
2	13.02	13.39	13.39
3	12.83	13.51	13.51

The existence of departed nodes in the network has forced the service consumers to expand search radius causing higher average latency between the service provider and service consumer as shown in Table 6.3 and Table 6.4. However, the average traffic generated in service discovery still maintained the same in both simulations. The increase of latency between service consumer and directory node could be caused by the routing table repairing process where the failed nodes are replaced with active nodes that are much farther than the local node. Even so, the average latency between service consumer and service provider has slightly improved.

Table 6.3 Average latency generated from service consumer to directory node in a network of 6000 nodes

m	**Before resiliency test**	**Resiliency test with 10% of failed node**	**Resiliency test after routing table repairing process**
0	15.93 ms	18.55 ms	18.55 ms
1	13.31 ms	16.64 ms	16.72 ms
2	13.02 ms	16.64 ms	16.65 ms
3	12.83 ms	16.72 ms	16.73 ms

Table 6.4 Average latency generated from service consumer to service provider in a network of 6000 nodes

m	Before resiliency test	Resiliency test with 10% failed node	Resiliency test after routing table repairing process
0	24.35 ms	29.26 ms	29.26 ms
1	24.65 ms	30.35 ms	30.34 ms
2	24.43 ms	30.08 ms	30.04 ms
3	24.33 ms	30.07 ms	30.10 ms

In conclusion, the resiliency test has shown that CPASS is able to achieve 99% service discovery success rate even when 10% of the nodes have failed to work. Besides, the average traffic generated per query and the locality search failure maintained low. Furthermore, the simulation experiments have shown that both PASS and CPASS rely on the underlying P2P routing protocol to achieve good performance in terms of service discovery success rate, locality awareness, and others. Thus, the performance of PASS and CPASS could inherit the limitations of the routing protocol used.

CHAPTER 7

CONCLUSION

This research has studied about resource sharing in a large scale decentralised network. The conventional approaches are often centralised and subject to the single-point failure risk. This issue leads to a distributed approach in service discovery using P2P system.

This dissertation has presented some existing approaches of distributed service discovery schemes and introduced new distributed service discovery schemes and its simulation study. Besides that, this research has also introduced a new term, named the directory node that act as a platform for service advertisement and service discovery by peer nodes.

The finding of the simulation studies has shown that the existing approaches of using unstructured P2P and structured P2P can achieve high success rate but either can result in (1) high traffic generated as brute force technique is usually applied, or (2) cannot provide locality awareness while perform searching for a service provider.

In order to tackle the above two issues, we have proposed two Prefix-based Advertising and Searching Schemes, namely PASS and CPASS, based on the Pastry P2P architecture. Through simulation, we showed that both PASS and CPASS are able to achieve 99% success rate with only 1% of active nodes in the network. Furthermore, when compared with other existing approaches, the proposed schemes, especially CPASS have superior performance as they are able to maintain locality awareness with locality success rate of more than 90% and deterministic routing with log order complexity using Pastry as the underlying routing protocol. The simulation studies have also shown that the proposed schemes are able to achieve high success rate without generating high number of traffic in the network.

This dissertation also compares the performance of using two most popular structured P2P system i.e., Pastry and Chord. The simulation result has revealed that although the Chord routing protocol is able to achieve higher service discovery success rate, Pastry is better in providing locality awareness.

In addition, resiliency test has also been conducted in order to measure the resiliency of CPASS. The simulation result has shown that even with 10% of active nodes having left the network, 99% of service discovery success rate is still achievable. This shows that the proposed schemes are able to withstand the dynamicity of a peer-to-peer network.

One issue that comes with the proposed framework is when a requesting peer receives a list of potential providers that can deliver the same service, which provider it will choose to minimize the cost in terms of delay, bandwidth, charge, and etc. Besides, security issues are yet to be addressed in the proposed scheme such as phishing where the directory node may return a list of malicious addresses to the service consumer. On the other hand, the maintenance of the proposed scheme has to be carefully planned to avoid the risk of returning outdated results. Hence, future work may include (1) simulating both proposed schemes (i.e., PASS and CPASS) in a large Pastry network with 128 bits of identifier space, (2) address the issue to select the best service provider from the list of potential providers, and (3) implement both proposed schemes on similar structured P2P protocol that can provide locality awareness such as Kademlia and Tapestry.

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