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Short Description:
In this report, a two coupled networks model as a simplified version of the DBE is presented. The upper layer is the business network layer and the lower layer is P2P FADA network layer. How the performance of the P2P network depends on the network topology and dynamics of the network is investigated. Through discrete event simulation, the effects of different evolutionary principles inspired by random graph and scale-free networks on the performance of the P2P network are illustrated. Furthermore, several rules to design a resilient and efficient P2P network are addressed.

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Network Topology From Combining Graph-theoretic And System Requirements

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Chapter 1

Introduction

1.1 Background

In the European economy, Small and Medium sized Enterprises (SMEs) are playing a very important role, by contributing a considerable share of GDP and providing new jobs and new business ideas and so on. However, most of the SMEs are far behind the stage to use the Internet technology as a business tool. The obstacles include lack of resources, skilled employees, adaptable technology to SMEs, and also lack of awareness of potential benefits[1].

1.2 Introduction to Digital Business Ecosystem

In order to be always competitive in the global market, SMEs need some easy to use technology to avoid the ever increasing gap of using between them and large size enterprises. Therefore the idea of a digital business ecosystem (DBE) is issued. The aim of the DBE is to develop an open source distributed digital software environment that can support the deployment, retrieval and composition of services so that it can help SMEs to cooperate with other SMEs to produce components and applications adapted to local business needs.

Traditionally, an ecosystem is defined as a biological community of interaction organisms and their physical environment. Like the individuals as plants or animals in a nature

ecosystem, enterprises have to form associations and clusters in order to flourish. As a consequence, the notion from biology, ecosystem, is widely used to describe the increasingly interrelated nature of enterprises as competing and evolving organisms in a business environment. In this business ecosystem, customers obtain goods and services of value. In the meanwhile, they also co-evolve their capabilities, their role, and tend to align themselves with future directions. The innovative thought of the DBE relies on developing an Information and Communication Technology (ICT) technology-based ecosystem, where software components, applications, services, knowledge, business models, training modules etc are regarded as "digital species" interacting with each other in a "digital environment". These species can evolve in the way that, services can combine with other services to produce more new and innovative services, more adaptive species can reproduce while less adaptive species die out from the system based on laws of market selection.

1.3 Introduction to network topology (S7)

1.3.1 Objective

SMEs as users of the DBE are in different physical locations, thus the communication between them will be implemented as in a distributed computing system, called nervous system. The platform of the DBE will be built on a decentralized peer-to-peer architecture due to its advantages such as self organization, load-balancing, fault tolerance. Moreover, the integrated P2P architecture has to be flexible enough to fulfil the requirements of all DBE services built on it.

In this project, Federated Advanced Directory Architecture (FADA) is an important component in the "nervous system". It is used for clients to find and download service proxies based on corresponding unique identifiers, which have been registered with FADA by service providers. This technology has been applied to networks in the tourism sector. Moreover, FADA network uses the mathematical tool Kalman filter, to model the network delay for lease renewal so that it can overcome the limitation of its ancestor, Jini

technology which can only be used in some low-latency networks such as in LAN, due to without taking variable net latency for lease renewal into account. During the system's operation, the network topology is assumed to be dynamic, constantly changing over time with node joining in and leaving out. Thus, it is a challenging research problem for us to investigate how the performance and network resilience of the FADA network within the DBE depends on the network topology and dynamics. On the other hand, in deliverable provided by UBHAM [2], how different topologies affect the time taken to solve the set-cover problem and effects on diversity maintained in SMEs are discussed.

1.3.2 Our approach

We build up a two coupled networks model as a simplified version of the DBE, consisting of a business network layer where business process between different SMEs happen and a P2P communication layer supporting the communication in the DBE, where FADA is applied. Through discrete event simulation, we investigate the effects of different evolutionary principles inspired by random graph and scale-free networks on the performance of the FADA network. We find several rules to design a resilient and efficient FADA network.

1.4 Organisation of the report

The rest of this report is organized as follows.

Chapter 2 In this chapter, we provide some background information about the P2P network and literature review on topologies of complex network which are applicable to our research.

Chapter 3 We present the two coupled networks model in details.

Chapter 4 We explain detains of simulations on the model will be and discuss simulations results.

Chapter 5 We finalize with conclusions of the work and the direction of future work.

Chapter 2

Background and Related work

2.1 Studies on Topology of Peer-to-peer Network

Recently, Peer-to-peer (P2P) networks have attracted significant attention in both academia and industry due to the widely usage of P2P systems today. Besides the benefit of sharing huge amounts of data, P2P networks present advantages including adaption, self-organization, load-balancing and fault tolerance. However, despite of these strengths, there are still several challenges for the systems to consider for more widely usage, which are primarily aspects of scalability and efficient search. Many works have focus on how to achieve both scalability and functionality of the P2P systems. In [3] ,[4], they study the topologies and protocols of the systems and users' behavior and evaluate the performance and to investigate possible improvements of better scaling etc. Efficient search techniques such as CAN [5], Chord [6], Pastry [7], Tapestry [8], Yappers [9] and Grapes [10] can offer fast lookups and still keep the systems scalable. Moreover, different routing algorithms have also been widely studied to improve performance, e.g in [11], presenting a cost effective broadcast algorithm for fully decentralized P2P networks, implemented on a scale-free topology, based on Barabási and Albert's model in [12]. Nevertheless, we have to notice that the work mentioned above, as the studies of topologies, efficient search techniques and routing algorithms perform well for the systems in a well-behaved fashion that they are intended for and of a certain degree of topology, where their analytical

and empirical studies base on. But, we need to be aware that topology itself has significant impact on the performance, network resilience, scalability, and communication cost. How topology affects the results of studies on P2P networks is an important open problem.

Appropriate models of the topological structure of a network are essential for the analysis and development of it. Many researchers have made significant effort in developing topology generators for e.g Internet simulations. Waxman introduced one of the most commonly used method in [13] for graph generation, where the probability of an edge between two nodes relates to the Euclidean distance between the two nodes. Due to several serious drawbacks of the Waxman model for generating Internet topology, some modified methods such as [14] have been proposed. In [15], Zegura *et al.* evaluated different graph generation methods by a comprehensive set of metrics that characterize the graphs produced. However, these methods have not yet been scaled to apply to much larger size networks. In [16], Paxson and Floyd stated that the difficulty of modelling and simulating the Internet is because the Internet is heterogeneous and changes constantly so that we do not know how to simulate its behaviors.

Therefore, in order to provide an appropriate topological model of the FADA P2P network in the DBE, we combine graph-theoretic and system requirements to derive rules for designing a robust and efficient FADA network. We introduce two dominating network topologies of complex networks which are relative to our work in the following section.

2.2 Topologies of Complex Networks

The network of FADA nodes working together is a complex network. There are some research studies on computer network that relate to the field of statistical physics and complex networks, e.g in [17]. Moreover, a lot of studies on complex networks illuminated how specific topologies or connectivity patterns are based on the construction and growth of such networks.

Complex networks are usually regarded as graphs for topological analysis. Therefore, we regard FADA network as a undirected graph where nodes represent FADA nodes, and edges correspond to virtual connections between the nodes. For the purpose of better understanding of our work, we firstly introduce some graph-theoretic properties of topology that are used in the report.

Degree distribution

The number of edges connected to a vertex is called the *degree* of the vertex. In a network, vertices always have different degree. The node degrees is characterized by a distribution function $P(k)$, which is the probability that a randomly chosen node has exactly k connections.

Average path length

The average path length is the average of the shortest path lengths from each node to every other nodes. Small average path length leads to better responsiveness. In the DBE, it determines how fast requests propagate throughout the FADA network. Based on the complex network theory, there are currently random graph, small-world and scale-free networks as options for network topologies.

2.2.1 Random Graph

The random graph was introduced by Erdös Rènyi as an early effort to model complex networks in [18], in which edges are distributed randomly and the presence or absence of any edge between two nodes in the network is dependent on a fixed connection probability p. We abbreviate it to ER random graph in the following sections in this report. The degree distribution of a ER random graph has been found to follow a Poisson distribution:

$$P(k) = \binom{n}{k} p^k (1-p)^{N-k} \simeq \frac{z^k e^{-z}}{k!}, \quad k \geq 0.$$

Here k represents nodes having exactly k edges, n is the total number of edges and N is the number of nodes in the network. Moreover, the average path length of a random

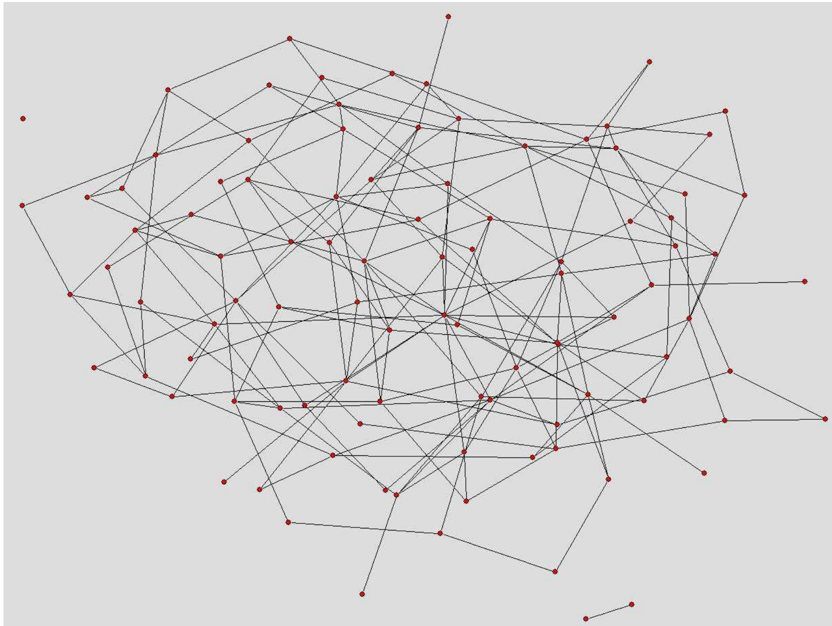


Figure 2.1: An example of random graph: a snapshot of the FADA network of $N = 100$ nodes, by using random graph model setup with connectivity probability $p = 0.04$.

graph has been found to scale with the number of nodes: $\ell \sim \frac{\ln N}{\ln <K>}$.

Numerous networks, particularly in epidemiology studies, have been viewed and analyzed as random graphs. However, random graphs fail in describing the structural properties of some real-world networks.

2.2.2 Scale-free Network

Recently, some real-world networks, such as networks of movie actor collaboration [19][12], science collaboration [20], WWW [21][22] and Internet [23], have been found to have a degree distribution that follows a power-law with different exponents: $P(k) \sim k^{-r}$, which deviates from poisson distribution of random graph. The power-law distribution means that a very few network nodes were far more connected than other nodes. It indicates the networks can self-organize to a scale-free state, where the highly connected "hub" nodes strongly affect the structure and dynamics of the networks. Moreover, the average path

length of a scale-free network has been found to increases approximately logarithmically with the number of nodes N. Furthermore, it has also been observed that ℓ of a scale-free network is smaller than a random graph with the same network size and average degree.

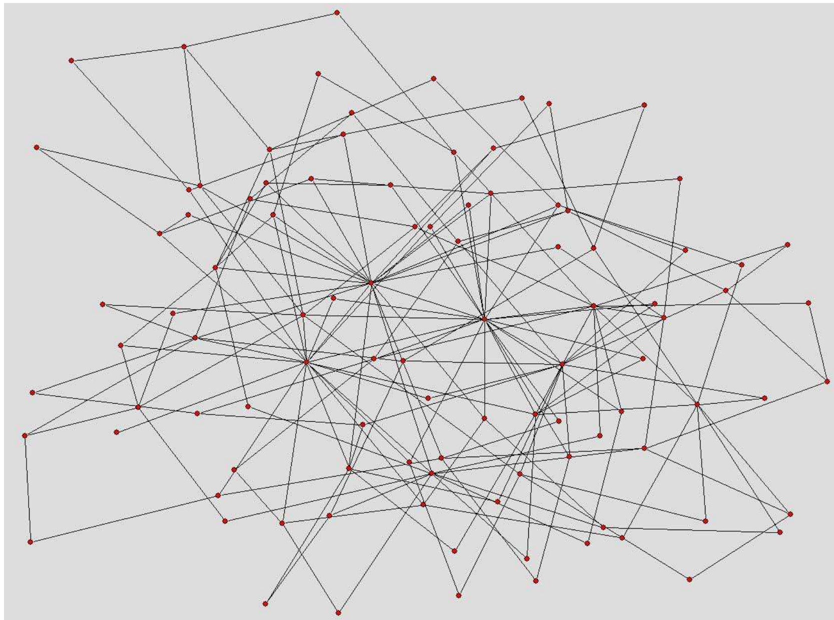


Figure 2.2: An example of scale-free network: a snapshot of the FADA network of $N = 100$ **nodes, by using scale-free model setup, started with two nodes.**

In 1999, Barabàsi and Albert presented in [12] that the origin of this scale-free behavior was found to be the consequence of two mechanisms:

1. Growth of nodes: at each time step, a new node is added, with some edges connecting to nodes already present in the network.

2. Preferential attachment to well connected nodes: the probability of a new node connecting to a node depends on the degree of node i. In other words, a new node is more likely to connect to nodes that are highly connected.

However, by evaluation, we find that all these network topologies have their own advantages with respect to different aspects. For example the ER random graph is more robust to attack than a scale-free topology, while it is less robust to random failure. Thus we can not use one of them directly to construct our network. Nevertheless, in this report,

we show that it is useful to apply their evolution principles to build up the network of the DBE and set up the rules for communication of SMEs using the system. Through discrete event simulation and analysis, we find out what effects of different evolution principles on the properties of system are significant.

Chapter 3

Review of the work

3.1 Scope of the work

The concept of DBE is actually based on the idea that the behavior of self-organization and evolution in biological systems can be also exhibited by software systems. The structure of the DBE is as follows. SME clients submit their service descriptions to the DBE (each SME has a specific service ecosystem, consisting of a pool of services). DBE servers aggregate and recombine these services into service chains and form complex services. Based on the feedback from users, successful service chains cross-over and mutate while useless service chains die. Thus, when SME consumers request services to the DBE, they can obtain the most suitable service chain description according to their requirements and invoke the services at the SME providers' end.

3.2 Communication in the DBE by FADA

In the DBE, different providers who offered services have different physical locations and may be built on disparate platforms, so it is difficult to develop a shared architecture for them. A proposed solution to the communication in the DBE is SUN Microsystems' Federated Advanced Directory Architecture (FADA). It is the enhanced technology of the Jini Networking Technology, which is portable and able to adapt to dynamic network conditions rapidly, making it a good solution for linking virtually any service or device on

any platform without having to re-engineer legacy applications and services. Furthermore, FADA is designed as a peer-to-peer dynamic distributed system in which different lookup servers (FADA nodes) work together to provide lookup server function from any entry point of the FADA system and access services through the network.

Differently from the Jini Network technology, which works over LAN, the FADA network is designed to work over WAN, such as Internet. This requirement is achieved using the following implementation [24]: 1) In LAN, each computer can reach any other computer. However, this is not always true in the Internet due to the firewall. Therefore, in FADA, each node uses one and only one fixed port for communications so that network administrators can easily select a free port and give it to the FADA node that will lie behind the firewall. 2) FADA does not use broadcast or multi-cast mechanisms which can not be used in the Internet to discover available services, but uses a flooding algorithm. 3) FADA uses HTTP as the basic communication channel, which means that clients of the FADA can be in a firewalled network, as long as they have access to the Internet via HTTP.

This FADA network can be viewed as an undirected graph where nodes represent FADA nodes, and edges correspond to virtual connections between the nodes. Several topologies for the FADA network have been considered, such as trees. However, due to some drawbacks of these topologies that are difficult to overcome, the topology of the FADA network is chosen to be not fixed and unknown in advance. But, by applying the FADA network on the communication of DBE, it is challenging to investigate how the performance of the P2P communication network is affected by the ecosystem dynamics and evolution principles.

3.3 Two coupled networks model

We present our two coupled networks model as the simplified version of the DBE in the Fig.3.1 below.

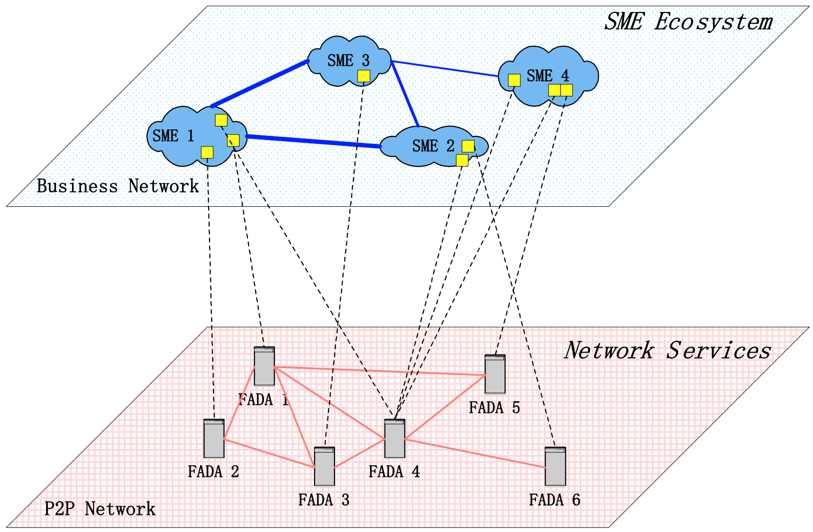


Figure 3.1: Global view of the work

The upper layer is called the business network layer, in which SMEs interact with each other for service exchange and migration. SMEs in different physical locations have been clustered according to their region. We can regard the business network layer as an undirected graph, in which vertices represent individual SMEs and edges correspond to open connections between the SMEs. The lower layer is called the P2P communication layer, based on the FADA network as described above. The interactions between these two layers are shown in the Fig.3.2.

The details of the communication process in Fig.3.2 are illustrated as follows.

1. Once a service provider wants to publish a service, it writes a service proxy which can communicate with the real service and registers the proxy in at least one FADA node.

2. When an SME, as a service consumer joins the system, it sends a lookup request

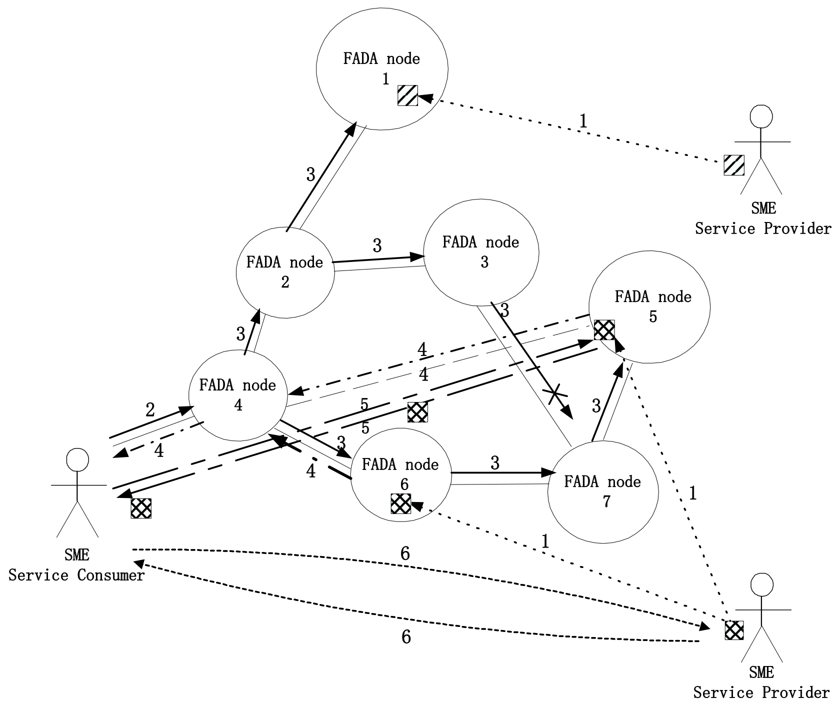


Figure 3.2: Communications in the DBE.

containing information such as price and functionality of a specific service, to a FADA node which is called an initiator node of the request.

3. The initiator node makes a lookup in its own data and uses a flooding algorithm to propagate the request to its neighbors, and its neighbors' neighbors, limited by the number of hops away from the initiator.

4. FADA nodes who find matches return these proxies to the initiator via a direct call instead of passing through previous nodes, which allows a fast response and results in a new connection in the network.

5. Service consumers select the best solution among the matches and contact the FADA node which contains the selected proxy, and downloads the proxy from it.

6. By using this proxy, the service consumer can communicate with the service provider for the real service.

SMEs join in and leave the system frequently as in other P2P networks. Some SMEs interact with the system as service consumers and also providers (executing actions 1-6

above). On the other hand, some SMEs who do not have IT infrastructure use the system as service consumers only (not able to execute action 1).

3.4 Search algorithm in the FADA P2P network

Recently, efficient algorithms for searching in graphs have obtained a lot of interests. In [25], Kleinberg studied search algorithms in a two-dimensional lattice, where a number of "long range" links are added in, controlled by an exponent which is related to the lattice distance between two nodes. He found that the delivery time to forward a message between a random source and target in a network is in a polylogarithmic relationship with the size of the network only when the exponent equals 2. But due to the ad hoc fashion of a P2P network, there is no global information about the position of the target node as is the scenario in Kleinberg's method. To simply locate files, Napster[1] uses a central server that contains an index of all the files every node is sharing when they join the network. However, this method leads to an unwanted situation because the central server becomes a single point of failure. Therefore, instead of having a central sever, Gnutella and Freenet forward queries to one's neighbors until the target is found. They have been found having power-law degree distributions. Furthermore, Adamic *et al.* in [26] introduced several search strategies in power-law networks and compared the search cost in each. They found that by using random walk search in power-law networks, the search cost s, defined as the number of steps to approximately reveal an entire graph, scales sublinearly with the size of the network N: $s \sim N^{3(1-\frac{2}{\tau})}$, where τ is the exponent of a power-law distribution. Moreover, they found search by visiting highest nodes in sequence gained a better scaling, which is $s \sim N^{2-\frac{4}{\tau}}$.

Differently, in the FADA P2P communication network of our model, we use the flooding algorithm described in step 3) above for searching. A lookup request is sent to an initiator node and forwarded to the initiator's neighbors' and its neighbors' neighbors and so on. In order to avoid cycles during propagation of the request, each request is associated

[1] Napster was shut down by leagal attacks from the music industry for non-technical reasons.

with an universal identifier. These request IDs are stored in a temporary registry in every FADA node. If an identifier has been found in the registry in a FADA node, meaning the request has already reached the node, then the request is dropped automatically without any further action. Requests IDs are deleted from the temporary registry after a certain amount of time. During the flooding process, new connections are generated between the nodes which contain the requested file and the initiator node. The reason for having this behavior is that we think in the real world, there are several FADA nodes which can be discovered more easily than others and clients of the FADA network usually use these nodes to perform lookup operations initially. Therefore, it is an ideal situation to have shortest connections between them.

Our analysis on the performance and dynamic behavior of the system described above allows us to investigate possible rules to design a topology for the P2P communication network in the DBE that is resilient against failure of nodes, adapts well with behavior of the evolutionary self-organizing system and is efficient in obtaining more required services and similar networks.

Chapter 4

Model description

In this chaper, we describe the details of our simulation and the evaluation methodology.

The simulation procedure consists of two main stages which are 1) Initialization stage and 2) Evolving stage.

In the *initialization stage*, we statically construct our model in the following way:

- Firstly, we setup the FADA network by using the Random graph model or Barabasi and Albert.
- Assume the number of SMEs in the network is $numSMEs = 1000$. Among these SMEs, several SMEs are randomly selected to initially register their services proxies in FADA nodes. The amount of these selected SMEs is set to be $iniSMEreg = 20$. The number of FADA nodes that are used to register a specific service proxy in is $numReg = 3$.

Network topology of a P2P network is always dynamic and changing constantly because nodes continuously enter and exit the system. New nodes can join in and existing nodes can leave at any time. Therefore, we model the two coupled networks evolve over time as in an *evolving stage* as follows:

- The rate of new SME joining the network is set to be 1 SME/time step. FADA nodes have been assigned limited space so that the overload of registries on a single node can be avoided. Each of the new joining SMEs registers its proxies in $numReg = 3$ randomly selected FADA nodes, whose available space is large enough to store the proxy.

- At each time step, we assume $numRequest = 10$ requests are sent to the system looking for specific services.

- According to the request information (e.g service type, initiator, radius of request), FADA nodes work together to look for the request by using the flooding algorithm. The request can reach other FADA nodes which are $numHops = 5$ hops away from the initiator.

- We assume a linear relationship between the size of the business network and the FADA network. Due to the rate of new joining SMEs being set to be 1, at each time step, one new FADA node is generated to serve the system accordingly.

Up to this stage, nodes in the P2P communication network contain the following information.

- **ID**: an identifier of a FADA node.

- **Neighbors**: a list of nodes that connect to a FADA node which can therefore be contacted and cooperated with.

- **regServiceType**: descriptions of registered services interfaces to be searched for.

- **proxyID**: an identifier of a proxy to be searched for and returned.

- **proxyLeaseTime**: an indicator of the remaining time that a proxy can be registered in a FADA node.

- **requestID**: identifier of a request.

In our simulation, there are three important aspects, which are setup, registration and new connections for new joining nodes. Following the discussion on the current topologies

of complex graphs in section 2.2, we apply the different evolution principles of random graph and scale-free network to investigate the effects of the different mechanisms on the system performance, such as network resilience, efficiency and reachability of requests.

Our studies are through discrete event simulation, summarized by different cases in the table 4.1 below.

Table 4.1: Different mechanisms used in setup, registration and new connections from new nodes

Case No.	Setup	Registration	New connections from new nodes
1	SF	Preferential	Preferential
2	SF	Preferential	Random
3	SF	Random	Preferential
4	SF	Random	Random
5	RG	Preferential	Preferential
6	RG	Preferential	Random
7	RG	Random	Preferential
8	RG	Random	Random

The objective of the ***setup*** process is to construct a network with $N = 100$ nodes in the initialization stage. *SF* represents the scale-free model. In this case, the network starts with $N = 2$ isolated nodes. At each time step, one new FADA node joins in with $m = 2$ new edges connecting to other FADA nodes, each of which preferentially attaches to a node i with degree k_i, with the probability $k_i/\sum_j k_j$ indicating that nodes with high degree attract more new connections. *RG* represents the random graph model that is used, where $N = 100$ initially isolated nodes make connections according to the connectivity probability p. In order to obtain a fair level of comparison, the p has been chosen to be $p = 0.04$ so that after the setup procedure, the total number of edges generated by using *RG* equalling to $p\,N(N-1)/2$, is approximately the same as in *SF*.

Registrations of service interface proxies in a certain amount of FADA nodes by SMEs happen in both the initialization stage and the evolving stage. ***New connections for new joining nodes*** are only considered when the network enters its evolving stage. *Pref-*

erential mechanism in ***registration*** means proxies are more likely registered in nodes with high degree. On the other hand, *random* means registering proxies in randomly selected nodes. The explanation of the two mechanisms for ***new connections for new joining nodes*** are similar as in the ***setup*** process.

The connectivity of the FADA P2P network can be represented by a $N \times N$ *adjacency matrix* C. The value of an element C_{ij} is either one or zero. The connections between FADA nodes have to be symmetric. Thus, if node i is in node j's neighbor list and node j is also in node i's neighbor list, then $c_{i,j} = c_{j,i} = 1$, or vice versa. This variable is used in the simulations to evaluate the degree distribution and network resilience in the following section.

Chapter 5

Simulation results

In this section, we show the simulation results on degree distribution, network resilience, availability and efficiency, when the network evolves to $N = 600$. We observed that 600 nodes in the network is a large enough size to ensure that the results are substantially the same if the simulations are re-run, while still keeping the simulations feasible.

5.1 Degree distribution

In this section, we study the degree distribution of the FADA network by plotting the probability of nodes having degree k as a function of k. Fig.5.1 and Fig.5.2 show the results of the FADA network by using scale-free model setup and ER random graph model setup respectively, where (a) to (g) refers to different cases, case 1 to 8 as presented in table 4.1 accordingly.

Power laws have been found in many different fields where networks are applied, comprehensively presented in [27]. We are interested in determining whether the FADA network with its evolution behavior falls into this category. We find that the degree distribution of the FADA network roughly follows a straight line on a log-log scale, and most of the nodes have only a few links while only some so-called ‘hub’ nodes have many links. This behavior is similar to the power-law distribution observed in other people’s work. By comparing

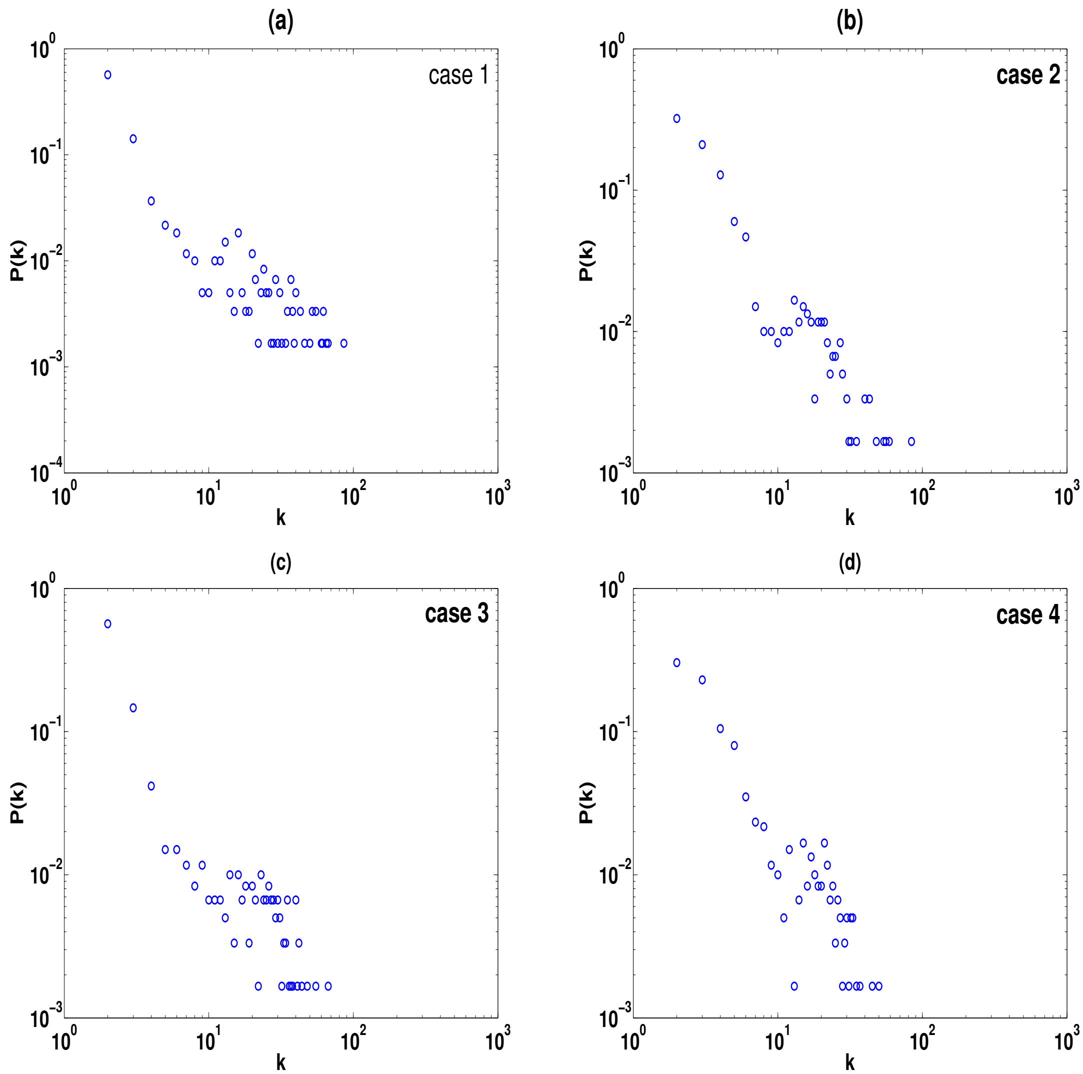


Figure 5.1: Degree distribution of FADA network under scale-free model setup, with network size of N=600. Referring to table 4.1, case 1: preferential registration and preferential new connections for new nodes; case 2: preferential registration and random new connections for new nodes; case 3: random registration and preferential new connections for new nodes; case 4: random registration and random new connections for new nodes.

results in (a) to (h), we can see that no matter what mechanisms in the evolution of the network have been used, the degree distributions under different settings are very similar to each other. One of the reasons is that in our model, the nodes that join the system earlier have always more chances to get more links. However, in the FADA network, a "fat tail" of its degree distribution has been found. We think this "fat tail" occurs because of the randomness due to the links generated during the lookup process by using the flooding

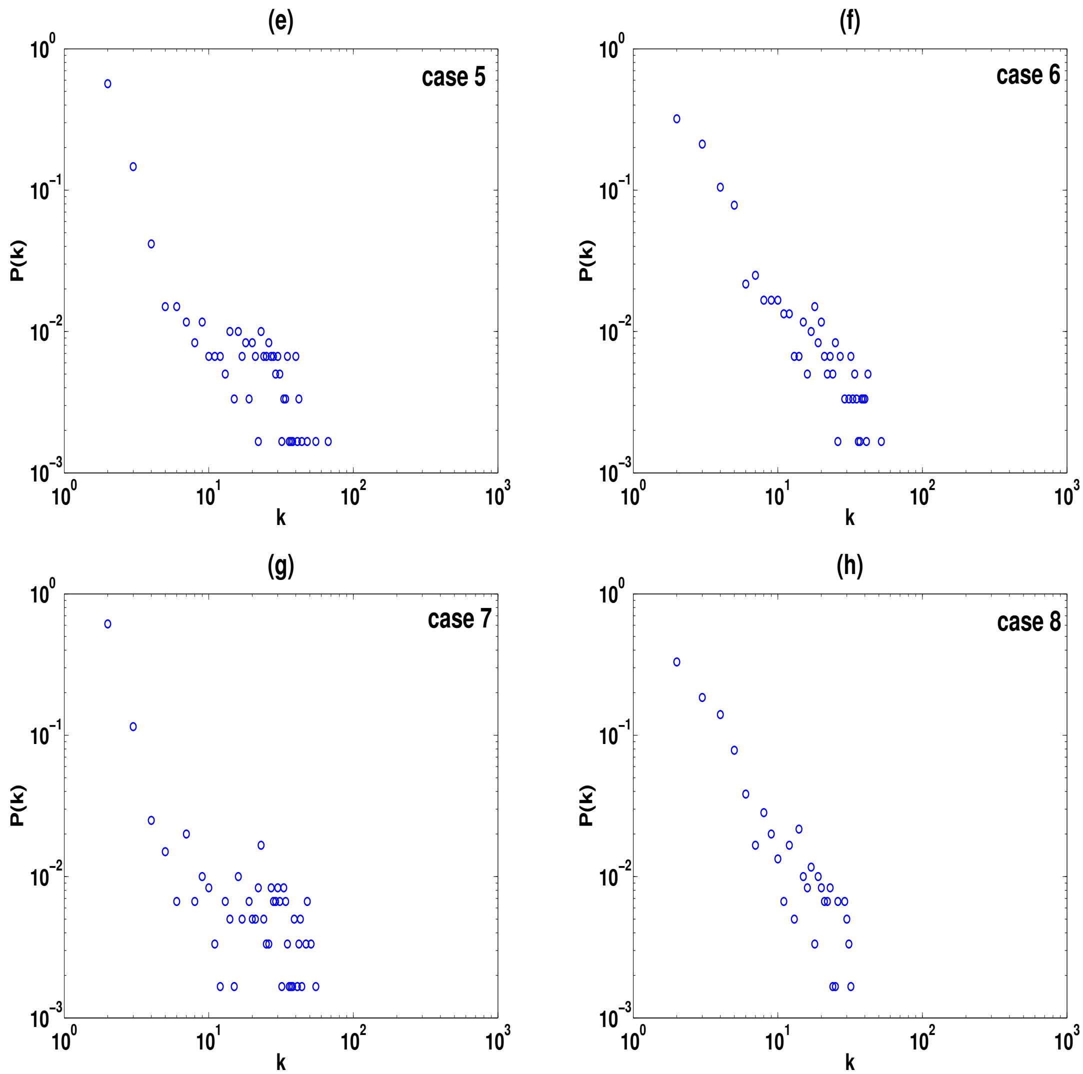


Figure 5.2: Degree distribution of FADA network under ER random graph model setup, with network size of N=600. Referring to table 4.1, case 5: preferential registration and preferential new connections for new nodes; case 6: preferential registration and random new connections for new nodes; case 7: random registration and preferential new connections for new nodes; case 8: random registration and random new connections for new nodes.

algorithm.

5.2 Average number of links

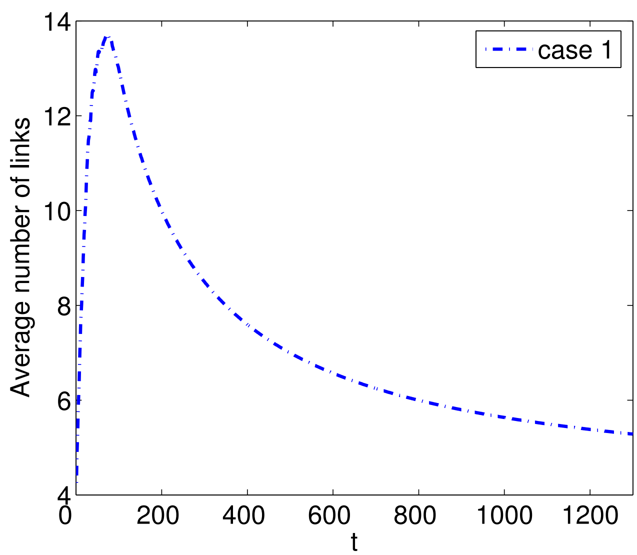
In order to study the average number of links of FADA nodes in the network, we firstly denote the number of links connected to node i by E_i, thus the average number of links

for the whole network E can be calculated as follows:

$$E = \frac{1}{N} \sum_i E_i. \tag{5.1}$$

Here N is the size of the network. We plot E versus time in Fig.5.4. We firstly show the simulation result of E of the network evolves to $N = 1400$ under one specific set of settings. As the simulation consumes lots of resources and takes a long time, it is not feasible to be continued after it evolves to $N = 1400$. In Fig. 5.3, we notice that E tends to converge to

Figure 5.3: Average degree of the FADA network when it evolves to $N = 1400$ nodes, under the setting of case 1: preferential registration and preferential new connections for new nodes;

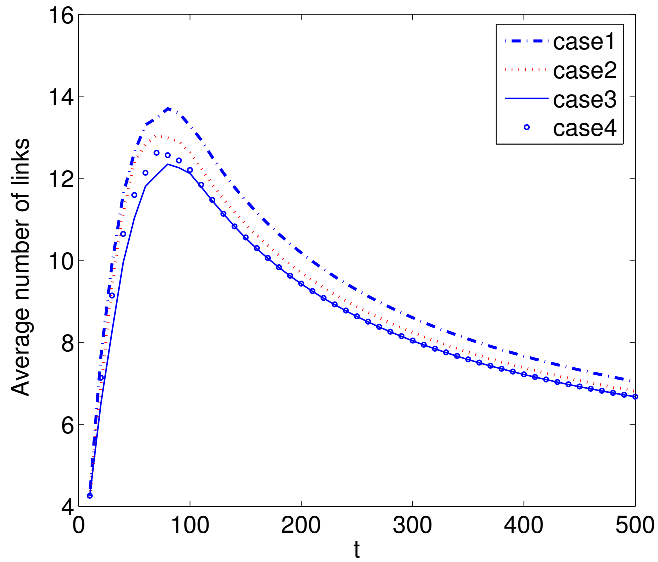


some limit. However, although the change of E is decreasing as time evolves, we still can not claim the exact convergence value from the result. Despite of this, we conjecture that when the time goes to infinity, E will converge to the initial value of E at $t = 1$. Because as time elapses, new nodes join in with a fixed number of new connections as and there is no extra connections generated during lookup procedure after $E = 200$, as the size of the network grows, the average degree of nodes should be getting close to the number of connections that a new node brings in the network when it joins.

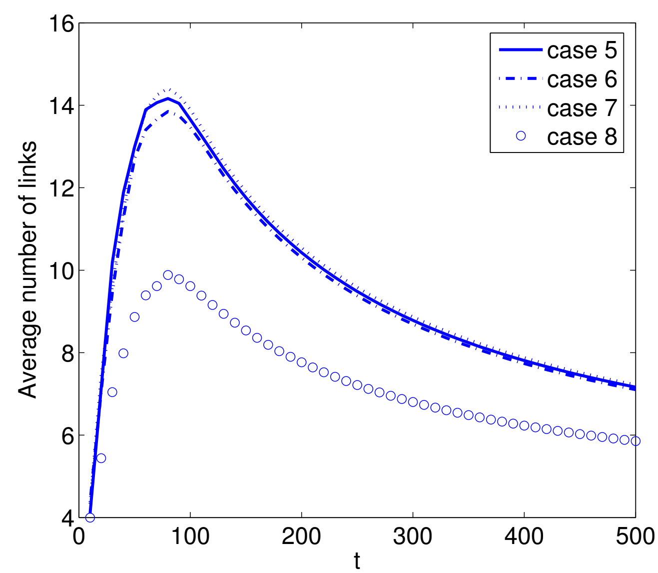
As we have already shown and discussed the result of E of the network when it evolves

to $N = 1400$ in one case as above, by considering consumption of resources and time, it is not necessary to run the experiments so long for all the cases. The simulations for investigating E under different cases of settings ran for 500 time steps and the number of nodes in the network evolves from $N = 100$ nodes in the initial setup stage to $N = 600$ nodes in the evolving stage. Although, the experiments probably stop too soon to confirm the convergence for all cases, results are able to show the effects of different settings on the E of the network which are interesting to investigate. Curves in Fig.5.4 (a) and (b) correspond to network under SF setup and RG setup respectively.

It is shown that in the FADA network under all settings in case 1 to case 8, the average number of links of nodes increases steeply as time elapses until at approximately $t = 100$, E starts to decrease exponentially. We find the reason of this phenomenon is that when $t <= 100$, FADA network can find proxies to request, so new connections have been made between FADA nodes during lookup procedure. Thus, the average number of links increases before $t == 100$. On the other hand, when $t > 100$, the DBE system fail rate of answering a request is nearly 100% so that there is no new connections to appear between FADA nodes during the lookup procedure (this is discussed in detail in section 5.5). As time elapses, new nodes join in the network constantly. However, they make connections to only a few existing nodes. As a result, as the size of the network increases, the average number of links per node decreases after $t = 100$.



(a) By scale-free model setup: case 1: preferential registration and preferential new connections for new nodes; case 2: preferential registration and random new connections for new nodes; case 3: random registration and preferential new connections for new nodes; case 4: random registration and random new connections for new nodes.



(b) By ER random graph model setup: case 5: preferential registration and preferential new connections for new nodes; case 6: preferential registration and random new connections for new nodes; case 7: random registration and preferential new connections for new nodes; case 8: random registration and random new connections for new nodes.

Figure 5.4: Average number of links per node in the FADA network under different settings referring to case 1 to 8 in table 4.1, with network size of N=600.

5.3 Average path length

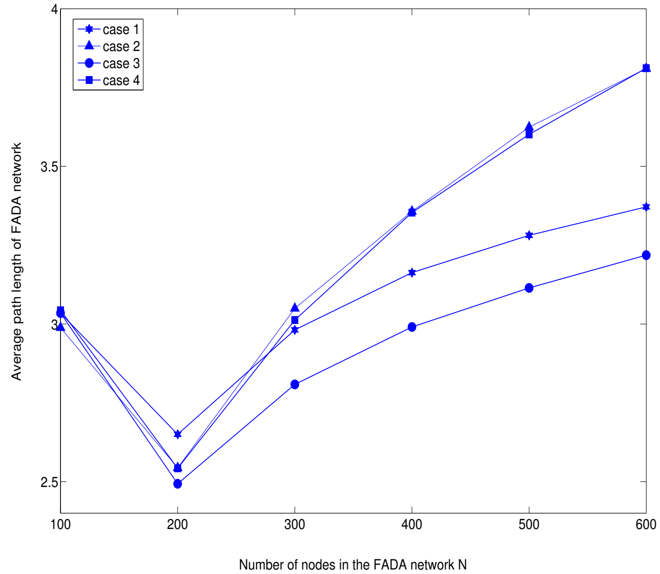
In this section, we study the average path length ℓ of FADA network. Average path length is an important topological property of a network, as discussed in section 2.2. There is no closed formula to compute it yet. But it is widely accepted that this ℓ follows some scaling form as a function of a network model's parameters, e.g. size of network N, connection probability p and so on.

In our simulation, we use the Dijkstra algorithm to compute the shortest path length ℓ_{ij} between any two nodes: node i and node j. From this we can obtain the average path length for the whole network as:

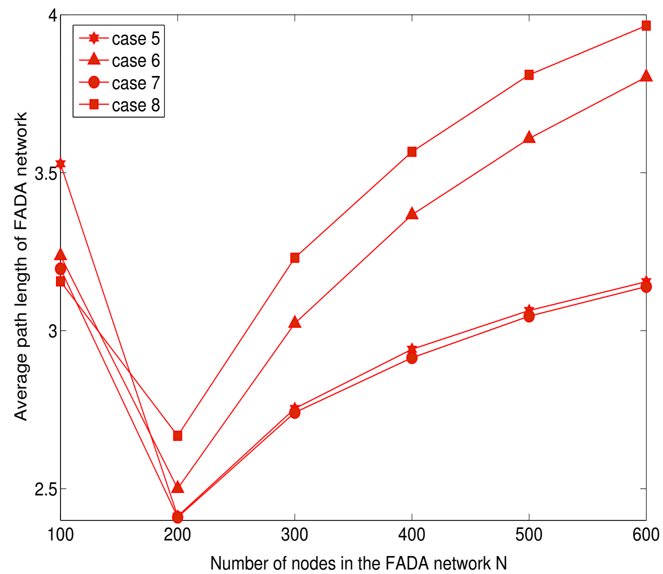
$$\ell = \frac{1}{N^2} \sum_i \sum_j \ell_{ij}, \tag{5.2}$$

where $i, j = 1, 2, \ldots, N$. By observation, we find that when the network grows up to 600 nodes, the number of edges in the network becomes very large so that the computation of shortest path is a computationally intensive process. Therefore, we present the results of average path length of network of size up to 600 nodes here only. While we believe that, based on the results, we can also deduce the average path length of network when it evolves further. We plot the ℓ versus the size of the network N in Fig.5.5. Curves in (a) and (b) correspond to the FADA network using SF model setup and ER random graph model setup respectively.

It is shown that as the FADA network evolves, the average path length decreases until it evolves to $N = 200$ (corresponding to $t = 100$), ℓ start to increase monotonically. The critical point $t = 100$ happens for the average path length as the same as for the average number of links studied in the section above. We consider the reason is the same as discussed in section.5.2. When $t <= 100$, the average number of connections in the network increases, so the distance between any two nodes is shorter. On the other hand, when $t > 100$, the average number of connections decreases. Consequently, the distance between any two nodes is longer.



(a) By scale-free model setup: case 1: preferential registration and preferential new connections for new nodes; case 2: preferential registration and random new connections for new nodes; case 3: random registration and preferential new connections for new nodes; case 4: random registration and random new connections for new nodes.



(b) By ER random graph model setup: case 5: preferential registration and preferential new connections for new nodes; case 6: preferential registration and random new connections for new nodes; case 7: random registration and preferential new connections for new nodes; case 8: random registration and random new connections for new nodes.

Figure 5.5: Average path length in the FADA network under different settings referring to cases in table 4.1, with network size of N=600.

Moreover, by comparing curves in Fig. 5.5 (a) and (b), we find that the values of ℓ of networks by using random new connections for new joining FADA nodes in case 2 and case 4 in Fig. 5.5 (a), and case 6 and 8 in Fig. 5.5 (b) are bigger than other cases. Particularly, the ℓ of network under settings of case 8 is the largest among all cases. As in a network, the shorter the average path length, the better performance of finding requested proxies. Therefore, we can conclude that the FADA network by using random new connections for new joining nodes results in worst performance with longest average path length.

5.4 Network resilience

In order to address the resilience of a network with different topologies, we investigate the impact of random failures and attacks on the network structure. The network fragmentation process under failures and attacks is studied by plotting the relative size of the largest cluster S as the function of f, the percentage of removed nodes. The quantity S is calculated by

$$S = \frac{size\ of\ the\ largest\ cluster}{initial\ size\ of\ the\ network}. \tag{5.3}$$

The metric S has been considered as an interesting metric in [28] to show the maximum number of nodes that can communicate with each other. In addition, we also study the average size of the isolated clusters $\langle s \rangle$ as a function of f. We use the depth-first search algorithm to locate components in different clusters to calculate S and $\langle s \rangle$. The random failures of nodes are simulated by removing randomly selected nodes from the system, while attacks to the system are simulated by removing the most highly connected nodes. Links connecting to these removed nodes are cut off from the network without rewiring. Fig. 5.6 and Fig. 5.7 show the results on the network resilience under different cases by using scale-free model setup as and ER random graph model setup respectively, summarized in table 4.1.

Firstly, we discuss the results on the network under attacks. We find that the relative

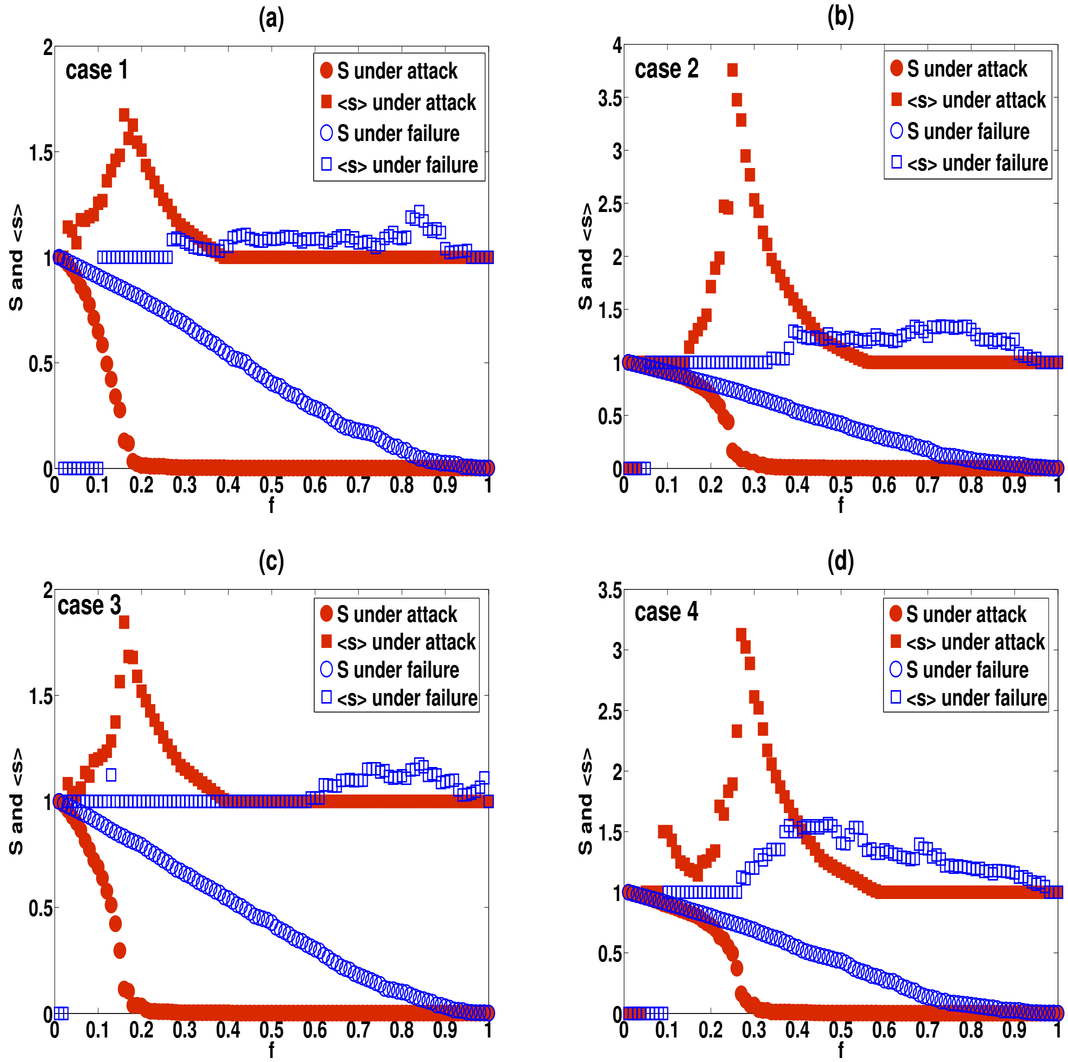


Figure 5.6: Network resilience of FADA network with network size of $N = 600$ under attacks and random failures, by scale-free model setup. Referring to table 4.1, case 1: preferential registration and preferential new connections for new nodes; case 2: preferential registration and random new connections for new nodes; case 3: random registration and preferential new connections for new nodes; case 4: random registration and random new connections for new nodes.

sizes of the largest cluster S under attacks, presented by filled circles in Fig. 5.6 and Fig .5.7, display the threshold-like behavior for all the settings, which has been observed in [29][28]. We can see that when we increase the fraction of removed nodes, S decreases steeply. Until $f > f_c$, we have $S \simeq 0$, indicating the network is seriously fragmented when the main cluster breaks into small pieces so that even the largest cluster contains only a few number of nodes. On the other hand, the average size of isolated clusters (presented

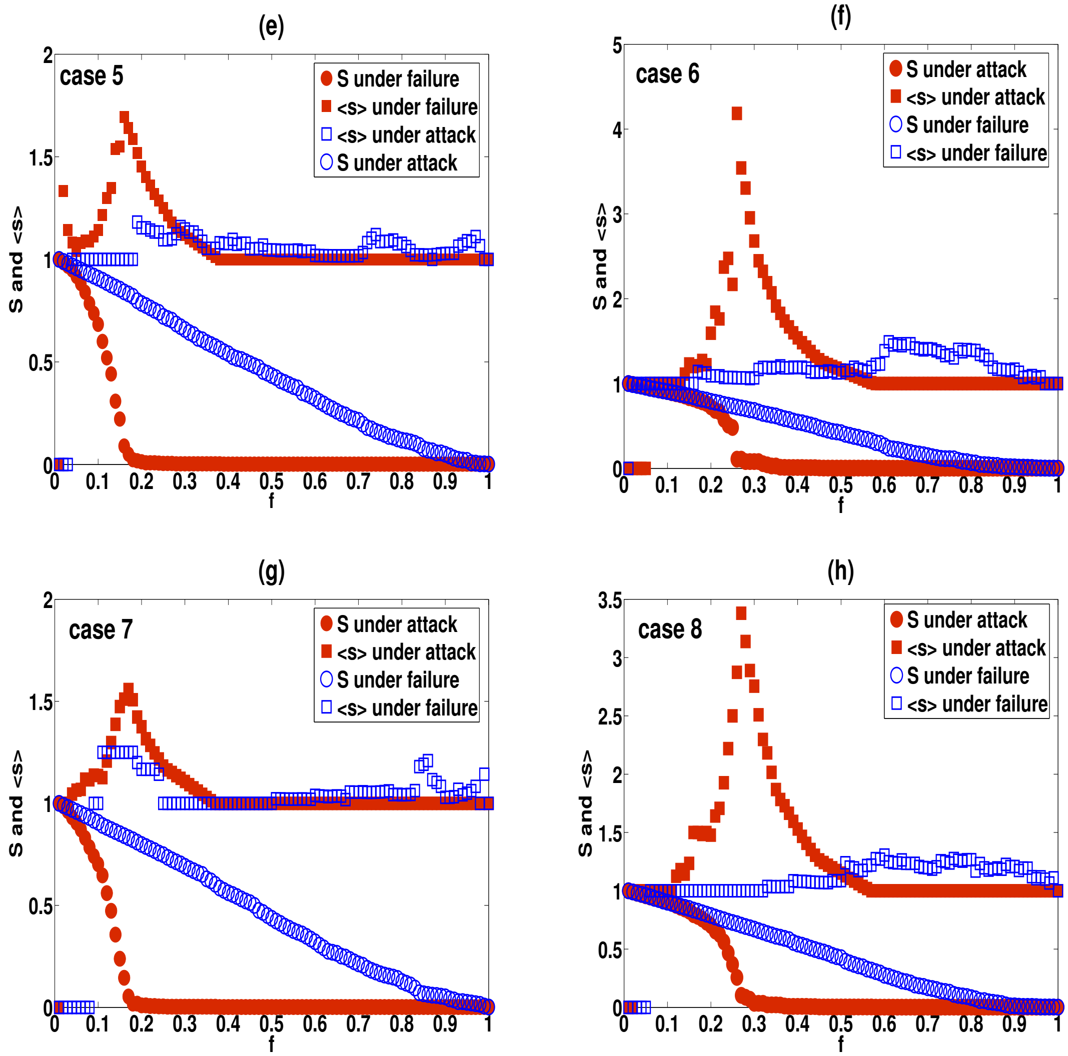


Figure 5.7: Network resilience of FADA network with network size of $N = 600$ under attacks and random failures, by ER random graph model setup. Referring to table 4.1, case 5: preferential registration and preferential new connections for new nodes; case 6: preferential registration and random new connections for new nodes; case 7: random registration and preferential new connections for new nodes; case 8: random registration and random new connections for new nodes.

by filled squares) that fall off from the main cluster, $\langle s \rangle$ reaches its peak value and if we continue to remove nodes, $\langle s \rangle$ starts to decrease, with the result that most of the nodes are from isolated clusters.

By observing the results shown in Fig. 5.6 and Fig .5.7, it is obvious that according to the critical values f_c, we can divide them into two groups as group A: (a), (c), (e) and

(g) and group B: (b), (d), (f) and (h). Referring to the table 4.1, we notice that group A is corresponding to cases that use preferential attachment to make connections for new joining nodes, while group B is corresponding to random attachment. In Fig. 5.6 and Fig .5.7, we can see that f_c of group A is smaller than in group B, where $f_c^A \simeq 0.21$ and $f_c^B \simeq 0.32$. Moreover, we find that $\langle s \rangle_{max}^A < 2$ is always smaller than $\langle s \rangle_{max}^B > 3$. Therefore, we can deduce that by using preferential attachment to generate new links degrades the robustness of the FADA P2P network against attacks because of its smaller threshold f_c of complete fragmentation.

Comparatively, the mechanisms of how to initially setup the FADA model (either by ER random graph model or scale-free model) and of how SMEs register their service proxies in FADA nodes play a less significant role in the resilience of the FADA system against attacks. Despite of this, we can still observe that $\langle s \rangle_{max}$ by using preferential registration is always larger than by using random registration, indicating that using preferential registration also degrades the robustness of the FADA system against attacks.

For the robustness of the system under failure, we find that the system does not display the threshold-like behavior as under attacks. S (presented by circles) decreases slowly and almost linearly with the increasing f, where the values of $\langle s \rangle$ (presented by squares) are between 1 and 1.5 for all the settings, indicating that despite of random failure, the network remains a large cluster with a few isolated clusters consisting of a single node or of two nodes, not a large cluster split into a few major clusters. Therefore, we may conclude that with all the different settings as in table 4.1, even for the ER random graph setup, random registration and random connections for new nodes, the FADA network is very robust to random failure. This observation is different from the [29] where the scale-free network is much more robust to random failure than exponential network. We conjecture that this improved robustness of the FAD network to random failure is because of the “fat tail” observed from results on the degree distribution, which is due to new connections generated during lookup procedures.

We conclude that due to the significant impacts of links generated during the lookup mechanism, the FADA network has a similar behavior as a scale-free network in the aspect of degree distribution and network resilience under all the settings. Through our simulation, we find that different settings can improve the network resilience to a certain level although they do not change the actual character of the FADA network.

5.5 Availability

As illustrated in Section 4, at each time step, 10 requests are sent to the system looking for proxies of specific services. The requests can reach nodes that are maximum 5 hops from the source node. The availability of the FADA network under different schemes to provide services proxies to specific requests is studied. We plot the request fail rate defined as the fraction of unanswered requests out of the total number of requests v.s time in Fig. 5.8. We have run the simulation until $t = 500$, when the size of the network is $N = 600$. However, because the request fail rate remains constant after $t = 200$, for visual purpose, we only present the result until $t = 200$. We find that the FADA network is unable to locate service proxies for requests when $t > 100$ approximately. The reason for this has been found to be the slow rate of registration and limited space of FADA nodes. At the initial stage of setup, the FADA network has plenty of registered services. However as time evolves, although we simulate continuous registration of services and renewal of services proxies, some of these registered services still may not be renewed so that they disappear from the network. Therefore, the amount of proxies in the network is small, to make the system work well. This implies the unwanted scenario that when not much SMEs registered their services proxies in the system or use it, the FADA network will experience bad performance. It also points out the problem of the tradeoff between the amount of registration of proxies in FADA nodes and the limited space of FADA nodes.

However, we can still observe the effects of different settings on the performance of the system when $t <= 100$. By comparing curves in Fig. 5.8 (a) and (b) when $t <= 100$, we can see that the request fail rate of case 8 is the highest among all, indicating that

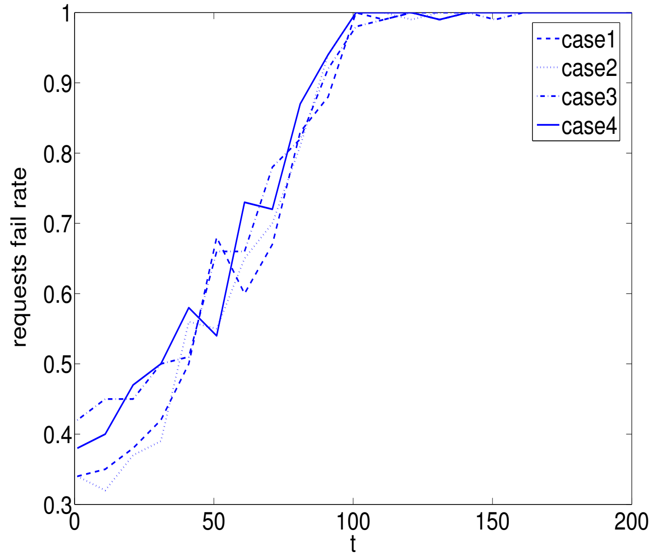
by using the ER random graph setup, random registration and random new connections, the network experiences the worst performance of finding required service proxies. Except for the case 8, the request fail rates of cases by using the ER random graph model setup presented in Fig. 5.8 (b) are smaller than for cases using scale-free model setup presented in Fig. 5.8 (a). Furthermore, by comparing curves in Fig. 5.8 (a), we find that the request fail rate under settings of case 1, 2 by using preferential registration is smaller than case 3, 4 by using random registration. Therefore, we deduce that if the network is initially constructed by using a random graph model and SMEs register the proxies of their services more in highly connected FADA nodes, the ability of the FADA system answering requests can be improved.

5.6 Efficiency

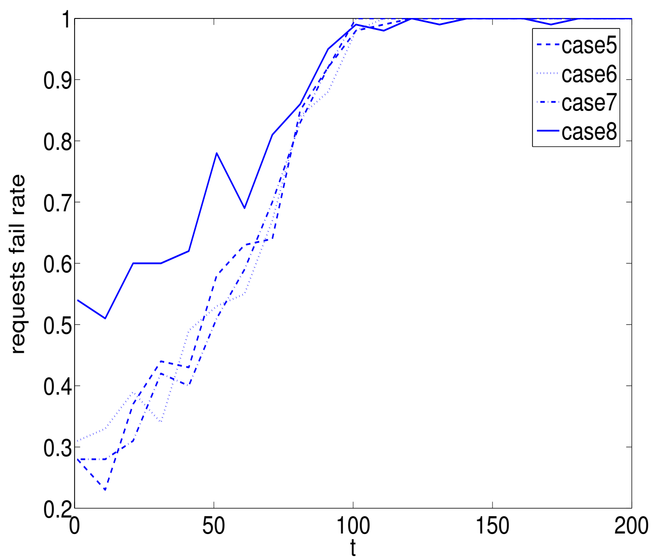
We investigate the efficiency of the FADA system by plotting the average minimum number of hops taken to answer requests as time evolves. Same as in the study of availability, we have also run the simulation until $t = 500$, when the size of the network is $N = 600$. However, because the value of the average number of hops to answer requests remains constant after $t = 200$, for visual purpose, we only present the result until $t = 200$. The minimum numbers of hops are averaged over the 10 requests at each time step. The minimum number of hops is specified as follows. When requests are broadcasted in the network, although limited by the maximum number of hops = 5, the proxies for a request can be found when the number of hops is 2, 3 or 4 and so on. Sometimes, within 5 hops, the FADA system can not find out the proxies of the services. When this happens, we set the minimum number of hops to 6.

In Fig. 5.9, we can see that, when $t > 100$, the values of the average minimum number of hops remains 6, meaning that the system can not work at all, and the explanation of this is the same as explained in section 5.8 on request fail rate. By comparing Fig. 5.9 (a) and (b), we find that the difference of effect by using SF setup as in (a) and RG setup as in (b) on the efficiency of the system is not very significant. But by using SF setup,

the fluctuation and randomness is less than using RG setup. Moreover, by comparing the curves in Fig. 5.9 (b), we can see that the average minimum number of hops under settings of case 1, 2 (preferential registration) is smaller than case 3, 4 (random registration), meaning that if SMEs register the proxies of their services more in highly connected FADA nodes, the FADA system can find out answers to requests within less hops which may improve the efficiency of the system.

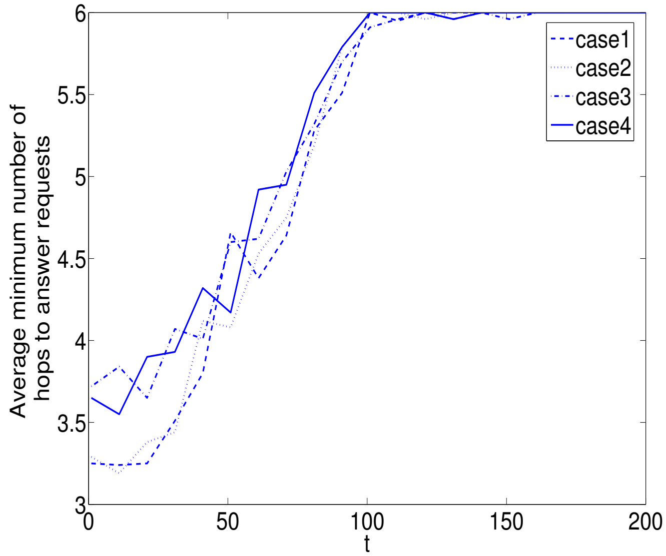


(a) By scale-free setup: case 1: preferential registration and preferential new connections for new nodes; case 2: preferential registration and random new connections for new nodes; case 3: random registration and preferential new connections for new nodes; case 4: random registration and random new connections for new nodes.

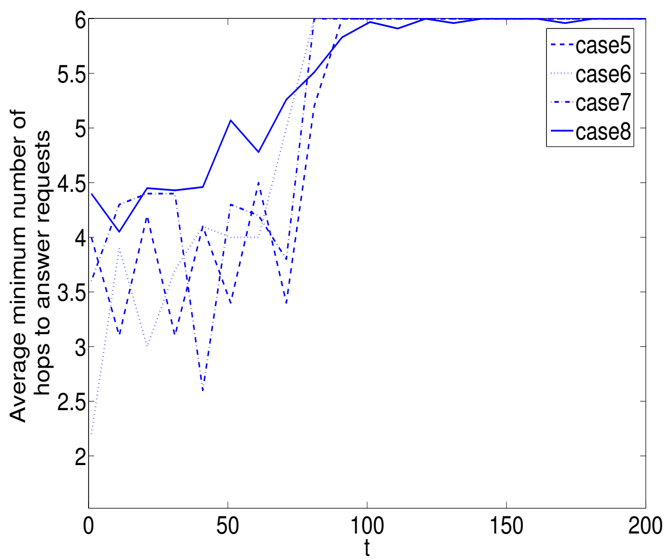


(b) By ER random graph setup: case 5: preferential registration and preferential new connections for new nodes; case 6: preferential registration and random new connections for new nodes; case 7: random registration and preferential new connections for new nodes; case 8: random registration and random new connections for new nodes.

Figure 5.8: Availability of the FADA network to locate service proxies to specific requests under different settings presented as case 1 to 8 in table 4.1, with network size of N=600.



(a) By scale-free setup: case 1: preferential registration and preferential new connections for new nodes; case 2: preferential registration and random new connections for new nodes; case 3: random registration and preferential new connections for new nodes; case 4: random registration and random new connections for new nodes.



(b) By ER random graph setup: case 5: preferential registration and preferential new connections for new nodes; case 6: preferential registration and random new connections for new nodes; case 7: random registration and preferential new connections for new nodes; case 8: random registration and random new connections for new nodes.

Figure 5.9: Efficiency of the FADA network to locate service proxies to specific requests under different settings presented as case 1 to 8 in table 4.1, with network size of N=600.

Chapter 6

Conclusion and Future work

6.1 Conclusion

Topology has been found to have significant impact on the performance of complex networks. In this paper, we introduced a Digital Business Ecosystem, which is aiming to provide an open-source distributed environment that can support the spontaneous evolution and composition of software services, components and applications for Small and Medium Enterprises (SMEs). Due to the characteristics of rapid change and heterogeneity of the system, it is important and challenging to design a topology that is resilient to failure of nodes and efficient for obtaining specific services.

We constructed and presented a novel "two coupled networks" model as a simplified version of the DBE system. Inspired by studies on different topologies in the territory of complex networks, we investigated the effects of different evolution principles of random graph and scale-free networks on the system through numerous simulations. The results showed that network properties such as degree distribution, resilience, availability and efficiency are strongly affected by different mechanisms used in the simulations, which can be summarized in the following points.

- *Degree distribution:* we can conclude that whatever the initial setup of the network, either by random graph model or scale-free model, there is little impact on degree

distribution. We observed the power-law distribution as in scale-free network in all the simulations, but with a “fat tail”.

- *Average number of links:* We find that the average number of links of nodes increases steeply as time elapses until at approximately $t = 100$, E starts to decrease exponentially.
- *Average path length:* We observe that the average path length ℓ decreases until the network evolves to $N = 200$ (corresponding to $t = 100$), ℓ start to increase monotonically. In addition, by using random new connections for new joining FADA nodes results in worst performance with largest average path length.
- *Network resilience:* we find our network is very robust against random failures of nodes. Moreover, the network resilience against attacks can be improved if we use preferential attachment for new connections from new joining nodes. We also observed that preferential registration may degrade the robustness against attacks.
- *Availability and efficiency:* the network can achieve better availability and efficiency by using preferential registration of proxies of services. This conclusion with the result on network resilience that preferential registration may degrade the robustness implies a trade-off between the network resilience and both the availability and the efficiency, when preferential registration is used. We also discovered that by using a random graph setup, random registration and random connections for new nodes, the network showed the worst performance among all setups.

6.2 Future work

One goal of our future work is to further investigate the interaction between business networks in business ecosystems, and the communication infrastructure such as the FADA P2P network. We will study how the evolutionary processes in the business network, such as the migration of different services between different SMEs will affect the performance of the communication network.

Bibliography

[1] Francesco Nachira and et.al. Towards a network of digital business ecosystems fostering the local development. *Discussion paper, Digital Busienss Ecosystem Project*, September 2002.

[2] Jonathan E. Rowe, Boris Mitavskiy, and Kennon Ballou. Deliverable 11.1: Report on the flow of software components in a static network. Technical report, University of Birmingham, http://www.digital-ecosystem.org, April 2005.

[3] Matei Ripeanu and Ian Foster. Mapping the gnutella network. *IEEE Internet Computing*, 50, January 2002.

[4] Eytan Adar and Bernardo A. Huberman. Free riding on gnutella. Technical report, September 2000.

[5] S. Ratnasamy, P. Francis, M. Handley, R. Karpand, and S. Shenker. A scalable content-addressable network. *In Proc. ACM SIGCOMM*, August 2001.

[6] S. Ratnasamy, P. Francis, M. Handley, R. Karp, and S.Shenker. Chord: A scalable peer-to-peer lookup service for internet applications. *In Proc. ACM SIGCOMM*, August 2001.

[7] A. Rowstron and P. Druschel. Pastry: Scalable, distributed object location and routing for large-scale peer-to-peer systems. *In Proc. Middleware 2001*, November 2001.

[8] B. Zhao, J. Kubiatowicz, and A. Joseph. Tapestry: An infrastructure for fault-tolerant wide-area location and routing. Technical Report UCB/CSD-01-1141, Computer science division, U. C. Berkeley, April 2001.

[9] Prasanna Ganesan, Qixiang Sun, and Hector Garcia-Molina. Yappers: A peer-to-peer lookup service over arbitrary topology. *IEEE INFOCOM 2003*, 2003.

[10] Kwangwook Shin, Seunghak Lee, Geuhwi Lim, H. Yoon, and Joong Soo Ma. Grapes: Topology-based hierarchical virtual network for peer-to-peer lookup services. *Proceedings of the International Conference on Parallel Processing Workshops (ICPPW'02)*, 2002.

[11] Marius Portmann and Aruna Seneviratne. Cost-effective broadcast for fully decentralized peer-to-peer networks. *Computer commuications*, 26:1159–1167, 2003.

[12] Albert-Làszlò Barabàsi and Reka Albert. Emergence of scaling in random networks. *Science*, 286:509, October 1999.

[13] B. M. Waxman. Routing of multipoint connections. *IEEE Journal on selected areas in communications*, 6:1617–1622, December 1988.

[14] Kenneth L. Calvert, Matthew B. Doar, and Ellen W. Zegura. Modeling internet topology. *IEEE Communications magazine*, pages 160–163, June 1997.

[15] Ellen W. Zegura, Kenneth L. Calvert, and Michael J. Donahoo. A quantitative comparison of graph-based models for internet topology. *IEEE/ACM transactions on networking*, 5(6):770–783, December 1997.

[16] Sally Floyd and Vern Paxson. Difficulteis in simulating the internet. *IEEE/ACM transactions on networking*, 9(4):392–403, August 2001.

[17] Zhiliang Ren, Zhidong Deng, Dianxun Shuai, and Zengqi Sun. Analysis of power spectrum and 1/f type power law in a complex computer network model. *Computer Physics Communications*, 136(3):225–235, May 2001.

[18] Paul Erdös and Alfrad Rènyi. On the evolution of random graphs. *Publ. Math. (Debrecen)*, 6:290, 1959.

[19] Duncan J. Watts and Steven H. Strogatz. Collective dynamics of 'small world' networks. *Nature (London)*, 393:440–442, 1998.

[20] S. Redner. How popular is your paper? an empirical study of the citation distribution. *Eur. Phys. J. B*, 4(2):131–134, 1998.

[21] R. Albert, H. Jeong, and A.-L. Barabàsi. Internet: Diameter of the world-wide web. *Nature (London)*, 401:130 – 131, September 1999.

[22] B. Huberman and L. Adamic. Internet: Growth dynamics of the world-wide web. *Nature*, 401:131, September 1999.

[23] M. Faloutsos, P. Faloutsos, and C. Faloutsos. On power-law relationships of the internet topology. *Comput. Commun. Rev.*, 29(4):251–262, Ocotober 1999.

[24] Sun Microsystems, http://fetish.singladura.com. *Core FADA*, April 2004.

[25] Jon M. Kleinberg. Navigation in a small world. *Nature*, 406:845, August 2000.

[26] Lada A. Adamic, Rajan M. Lukose, Amit R. Puniyani, and Bernardo A. Huberman. Search in power-law networks. *Physical Review E*, 64(046135), September 2001.

[27] Reka Albert and Albert-Làszlò Barabàsi. Topology of evolving networks: Local events and universality. *Phys. Rev. Lett.*, 85(24), 2000.

[28] Damien Magoni. Tearing down the internet. *IEEE Journal of selected areas in communications*, 21(6):949–960, August 2003.

[29] Reka Albert, Hawoong Jeong, and Albert-Làszlò Barabàsi. Error and attack tolerance of complex networks. *Nature*, (406):378–382, 2000.