Effect of the Degree of Neighborhood on Resource Discovery in Ad Hoc Grids

Tariq Abdullah[1], Koen Bertels[1], Luc Onana Alima[2], Zubair Nawaz[1]

[1]Computer Engineering Laboratory, EEMCS, Delft University of Technology, Mekelweg 4, 2624 CD, Delft, The Netherlands
{m.t.abdullah, k.l.m.bertels, z.nawaz}@tudelft.nl
[2]LOA DEPENDABLE IT SYSTEMS S.A., 4, Rue d'Arlon, Luxemburg
luc.onana.alima@loa-dits.com

Abstract. Resource management is one of the important issues in the efficient use of grid computing, in general, and poses specific challenges in the context of ad hoc grids due to the heterogeneity, dynamism, and intermittent participation of participating nodes in the ad hoc grid. In this paper, we consider three different kinds of organizations in an ad hoc grid ranging from completely centralized to completely decentralized (P2P). On the basis of self organization mechanisms, we study the effect of the neighborhood degree of a node for finding resources on the efficiency of resource allocation. We investigate the message complexity of each organization and its corresponding efficiency in terms of task/resource matching and the response time. We show that the intermediate state of the ad hoc grid with multiple adaptive matchmakers outperforms both a completely centralized and a completely decentralized (P2P) infrastructure.

1 Introduction

Recent advances in personal computer processing power and Internet bandwidth has enabled achieving tremendous computing power via opportunistic resource sharing [1,2,3]. Opportunistic resource sharing is done in very dynamic environments where the addition of new nodes, system/network failures or variation in resource availability is expected. Therefore, in this context, resource management becomes one of the most important and complex part of grid middleware.

Resource discovery approaches for grids in general, and especially for ad hoc grids, can be categorized as completely centralized [1,3,4,5] and completely/ partially decentralized [6,7,8,9,10]. Generally, completely centralized resource discovery systems and peer-to-peer (P2P) systems are often considered to be mutually exclusive and residing on the two extremes of the infrastructural spectrum. In the GRAPPA project [11], we consider them to be a part of a continuum and study the effect of either of the extremes or any intermediate state between the two extremes using a micro-economic based resource discovery mechanism. This paper is based on our earlier work [12,13], where we presented the mechanisms and algorithms that enable the ad hoc grid to self-organize according to the workload of the ad hoc grid. In this paper, we look at the impact of adoption of a particular infrastructure, taken from the infrastructural continuum.

The contributions of this paper are as follow: First, we define the degree of neighborhood of a node for resource discovery in completely centralized, multiple adaptive matchmakers and in completely decentralized (P2P) environment in an ad hoc grid. Secondly, we analyze the effect of varying the degree of neighborhood in completely decentralized (P2P) ad hoc grid. Thirdly, we compare the results of varying the degree of neighborhood in completely decentralized approach with completely centralized approach and with multiple adaptive matchmakers approach. Fourthly, we perform the message complexity analysis of the above mentioned resource discovery approaches in order to understand the communication cost of a particular resource discovery approach. Finally, we give recommendations for trade offs in resource discovery on an infrastructural spectrum ranging from completely centralized to completely decentralized approaches in the ad hoc grids.

The rest of the paper is organized as follows. Section 2 provides an overview of related work. Section 3 describes the required background knowledge to understand the proposed model. Section 4 explains the proposed model. Section 5 provides message complexity analysis. The experimental setup and results discussion are presented in Section 6, While section 7 concludes the paper and briefs about the future work.

2 Related Work

Different approaches are used for resource discovery in the ad hoc grids. These approaches vary from completely centralized to completely decentralized ones. The completely centralized approaches [1,2,3,5] for the ad hoc grids employ a client-server architecture. A trusted server distributes the jobs to clients. The clients request jobs, the centralized server allocates the jobs to the clients, the clients run the jobs, and the server collects the results. The completely centralized approaches provide high throughput. However, robustness and reliability is maintained by the server. Furthermore, the above mentioned approaches have a single point of failure and the complete system becomes unavailable in case of network or server failure.

In completely/semi decentralized approaches, each node or group of nodes negotiates for its required resources with other nodes. Iamnitchi et al. [8] proposed a resource discovery approach in completely decentralized grid environments and evaluated different request forwarding algorithms. Their approach employs time to live (TTL) for resource discovery. TTL represents the maximum hop count for forwarding a request to the neighboring nodes. The TTL approach is simple but may fail to find a resource, even though that resource exists somewhere in the grid. Attribute encoding [6,7] is used for resource discovery in structured overlay network. The available resources are mapped to the nodes of a P2P structured overlay network in the attribute encoding approach. There can be a load imbalance due to attribute encoding, when the majority of encoded attributes are mapped to a small set of nodes in the overlay network.

A zone based hybrid resource/service discovery approach using Zone Routing Protocol is presented in [9]. This work is closely related to our work. The main differences from our work are the use of micro-economic approach for resource discovery and the extension of a structured overlay network [12] for ad hoc segmentation/desegmentation. The reasons for using a micro-economic approach for resource discovery in ad hoc grid are described in Section 3.1. Zhou et al. [10] exploited blocks of idle processing cycles and grouped them into geographic and night time aware overlay networks. Unfinished tasks are migrated to another night time zone when the current night time zone ends. The main drawback of this work is that the host availability model is not based on the resource requirements of a job.

This paper defines and implements a micro-economic based resource discovery approach with varying the degree of neighborhood of nodes in an ad hoc grid. Secondly, the paper analyzes the effect of the degree of neighborhood on resource discovery. Thirdly, the results are compared with the completely centralized approach and with multiple adaptive matchmakers approaches for resource discovery. Finally, the paper provides recommendations to define trade-offs for a micro-economic based resource discovery mechanism on an infrastructural spectrum ranging from the completely centralized to the completely decentralized environments.

3 Background Knowledge

Before presenting the proposed model, first we explain the necessary concepts needed to understand the proposed model and the experimental results.

3.1 Micro-Economic Based Resource Discovery

An overview of Continuous Double Auction (CDA) based resource discovery mechanism is provided in this section. CDA is one of the many-to-many auctions in micro-economic theory. CDA supports simultaneous participation of producer/consumer, observes resource offer/request deadlines and can accommodate variations in resource availability.

Our ad hoc grid consists of autonomous nodes. Each node has *resource consumer*, *resource producer* and *matchmaker* agents. A node can be a consumer/producer of resources (such as CPU, memory, disk space or bandwidth) and/or a matchmaker at the same time. A *producer node* offers its available resources (such as CPU, memory, disk space or bandwidth). A *consumer node* requests the desired resources in order to execute its jobs. The node playing the role of a mediator between the consumer and the producer nodes is named the resource allocator or a *matchmaker* in this work. These three kinds of agents are also three main participants in CDA based resource discovery mechanism. The resource provider agent submits resource offer (called *ask*) and the resource consumer submits resource request (called *bid*) to the matchmaker agent. A resource request (bid) is specified by number of constraints such as requested resource quantity, job execution duration, job validity period (denoted by Time to Live (TTL) and represents the time duration during which a request can be processed), and bid price. Similarly, a resource offer (ask) is also specified by a number of parameters such as offered resource quantity, offer validity period (TTL, represents the time duration during which the offer can be availed), and ask price.

The matchmaker stores all received bids/asks in its request/offer repositories. The matchmaker is responsible for finding the *matched bid/ask pairs* from received bids and asks of the consumer and producer agents respectively. A matched bid/ask pair represents a pair where the resource request constraints are satisfied by the matching resource offer. The matchmaker finds the matches between the consumers and producers by matching asks (starting with lowest price and moving up) with bids (starting with highest price and moving down). The matchmaker searches all available asks (resource offers), for finding a matched bid/ask pair, on receiving a bid (resource request). A bid/ask is stored in the matchmaker repository until a match is found or its TTL is expired. The details of CDA based matchmaking mechanism and ask/bid price calculation formula can be found in [14].

3.2 Resource Discovery with Multiple Adaptive Matchmakers

In multiple adaptive matchmakers resource discovery approach in an ad hoc grid, a new matchmaker(s) is introduced or removed according to the workload of the matchmaker [12]. There can be n nodes in our experiments. There can be a maximum of m $(m < n)$, out of n nodes, matchmakers in the multiple adaptive matchmakers approach.

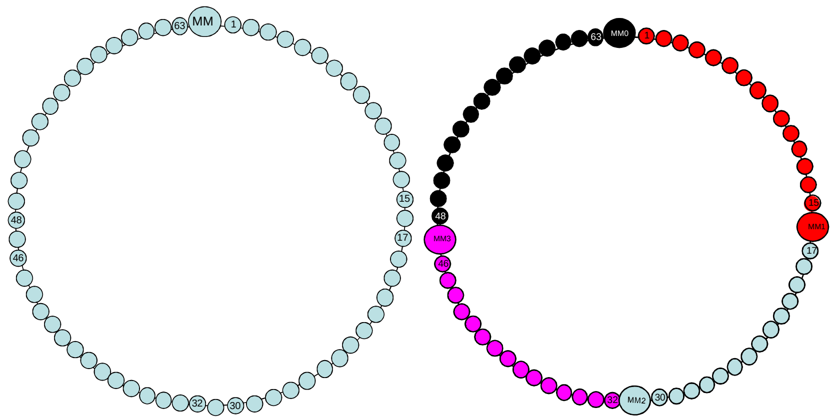
Each joining consumer/producer/matchmaker node is provided a zone number to which the node belongs. The whole identifier space is divided into zones. Each zone has a responsible matchmaker. It is ensured that each consumer/ producer node is under the responsibility of a matchmaker. When a matchmaker becomes overloaded then it promotes its predecessor matchmaker node to perform matchmaking. The consumer/producer nodes under the responsibility of an overloaded matchmaker are now under the responsibility of the predecessor matchmaker. In the case that the predecessor matchmaker is already performing matchmaking (i.e. active) then the excess workload is forwarded to the successor matchmaker of the overloaded matchmaker.

Conversely, when a matchmaker is underloaded then it demotes itself and informs its predecessor and successor matchmakers about the change in its matchmaking status. The successor matchmaker of the demoted matchmaker becomes the responsible matchmaker for consumer/producer nodes that were previously under the responsibility of the demoted matchmaker. After demoting itself, the demoted matchmaker will forward the request/offer messages to its successor matchmaker. The demoted matchmaker also informs the consumer/producer node under its responsibility, about its matchmaking status change and about the new matchmaker.

A consumer/producer node finds its responsible matchmaker node with the provided information after joining the ad hoc grid. In case there is only one matchmaker in the ad hoc grid then it becomes the responsible matchmaker for all the consumer/producer nodes. The consumer/producer node can submit request/offer to the matchmaker node after finding the responsible matchmaker node. Each matchmaker node maintains matchmaking status information (active/inactive) about its predecessor and successor matchmaker nodes, after joining. The matchmaker does so by exchanging matchmaking status information with its successor and predecessor nodes.

4 The Neighborhood on the Infrastructural Continuum

In this section, we explain the degree of neighborhood of a node on the following points of an infrastructural spectrum that ranges from completely centralized to completely decentralized extremes.

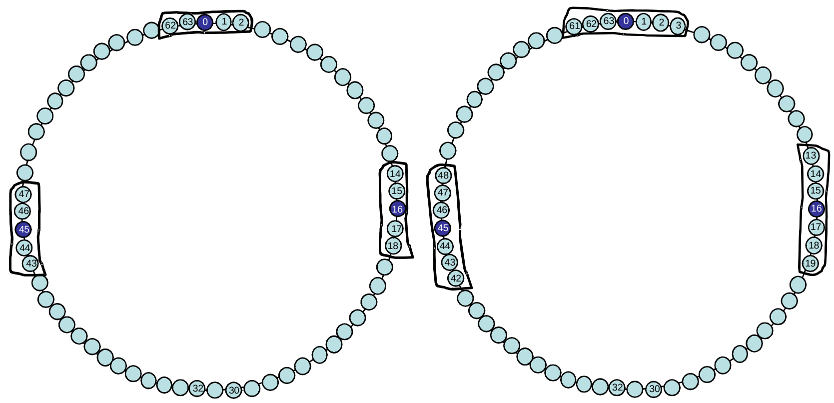


(a) (b)

Fig. 1: Neighborhood on the infrastructural spectrum. **(a)** Completely centralized**. (b)** Multiple adaptive matchmakers.

In order to explore the difference in resource allocation efficiency between the completely centralized and the completely decentralized (P2P) approaches, we introduce the notion of neighborhood. The degree of neighborhood of a node defines the visibility region of a node by defining the number of nodes accessible from that node. We explain the degree of neighborhood of node on the following points on an infrastructural spectrum:

– Completely Centralized Approach



(a) (b)

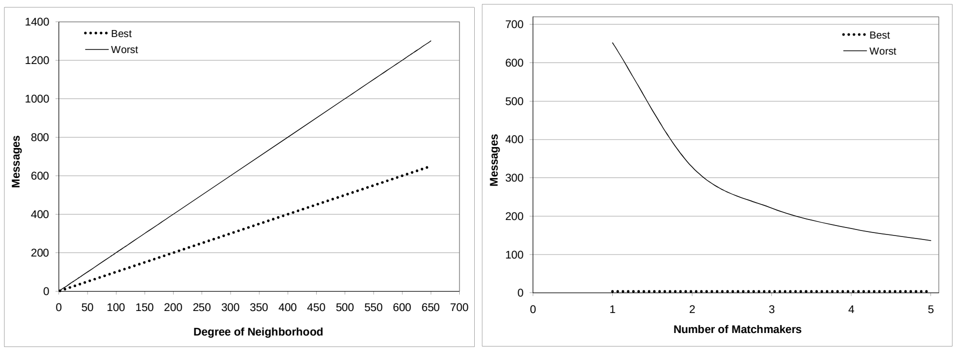
Fig. 2: Neighborhood on the infrastructural spectrum. **(a)** Completely decentralized degree=4. **(b)** Completely decentralized degree=6.

- Multiple Adaptive Matchmakers Approach
- Completely Decentralized (P2P) Approach

In the **completely centralized approach,** with a single matchmaker, all consumer/producer nodes (see Section-3.1) send their resource requests or resource offers to the matchmaker. The matchmaker finds matches for resource requests from received resource offers and informs the matched consumer/producer nodes. As all participating consumer/producer nodes can send their request/offer message to the matchmaker only, therefore the neighborhood of a consumer/producer node is n (n being the total number of the nodes in the ad hoc grid). This is represented in Figure-1a, where there is only one matchmaker.

In the **multiple adaptive matchmakers approach**, an intermediate centralized approach using multiple adaptive matchmakers, each consumer/producer node is under the responsibility of one matchmaker at any given point in time. The matchmaker is demoted or promoted according to the workload of the matchmaker(s) in the ad hoc grid. Then number of matchmaker(s) and the responsible matchmaker of a consumer/producer node may also change by the promotion/demotion of the matchmaker(s) [12]. As each consumer/producer node is under the responsibility of only one matchmaker at any given point in time, therefore the neighborhood of a consumer/producer nodes is $^n/_m$ (n being the total number of the participating nodes and m being the number of matchmakers). This is represented in Figure 1b, where multiple matchmakers are represented with different colors and the consumer/producer nodes in each zone are represented by the color of their responsible matchmaker.

In the **completely decentralized (P2P) approach**, where every node is its own matchmaker, each node looks for the appropriate resources from all the nodes in its degree of neighborhood. The ad hoc grid is implemented on top of



(a) (b)

Fig. 3: **(a)** Number of messages exchanged when varying the degree of neighborhood in completely decentralized (P2P) approach. **(b)** Number of messages exchanged in centralized and in multiple adaptive matchmakers approach.

Pastry [15], a structured P2P overlay network. The degree of neighborhood of a node is implemented and varied with the help of Pastry node's leaf set [15] in our ad hoc grid, which is explained below.

We consider a Pastry node with nodeID x for explaining the degree of neighborhood in the ad hoc grid. Each node in Pastry is assigned a 128 bits unique node identifier (referred to as *nodeID* hereafter). A Pastry node's leaf set contains L closest nodeIDs to the nodeID x. The leaf set, L, comprises of $|L|/2$ numerically closest larger nodeIDs and $|L|/2$ numerically closest smaller nodeIDs, relative to any node's nodeID in a Pastry overlay network. Here $|L|$ represents the cardinality of the leaf set L. The visibility of a node in the ad hoc grid increases with an increase in its degree of neighborhood. The neighborhood degree 4 and 6 of different arbitrary nodes (with nodeIDs 0, 16 and 45) in a completely decentralized ad hoc grid are represented in Figures 2a and in 2b respectively.

Typically, a Pastry node can route a message to another Pastry node in less than $\log_{2^b} N$ steps [15]. A Pastry node directly sends a message to its leaf set members. As the neighborhood is implemented as the leaf set, therefore, all the message exchange between our ad hoc grid nodes take only *one* hop instead of $\log_{2^b} N$ hops.

5 Message Complexity Analysis for Finding a Match

It is important to understand the cost implications of a particular organization of the ad hoc grid. To this purpose, we analyze the number of messages exchanged for finding a matched pair in the completely centralized, multiple adaptive matchmakers and in completely decentralized (P2P) resource discovery approaches.

First, we analyze the **completely centralized approach**. Let n be the total number of participating nodes. These nodes can play the role of a consumer or

	Best Case	Worst Case
Total Centralized (One Matchmaker)	4	$n+2$
Multiple Matchmakers	4	$m+n_i+1$
Varying the degree of Neighborhood	$d+1$	$2d+1$

Table 1: Messages exchanged to find a match.

a producer at any given time. There is only one matchmaker in the centralized resource discovery approach. In the best case, a consumer node sends a request to the matchmaker and a producer node sends a resource offer to the matchmaker. The matchmaker finds a match and a reply message is sent to the consumer and producer nodes. In the worst case, $n-1$ nodes will send their offers to the matchmaker. Only then the matchmaker can find a suitable offer for the received request and a matched message is sent to both matching consumer and producer nodes. Hence, only 4 messages are required in the best case and $n+2$ messages are required in the worst case to find a matched request/offer pair in the centralized resource discovery approach.

In case of the **multiple adaptive matchmakers approach**, each matchmaker is responsible for certain number of nodes out of all the participating nodes. An overloaded matchmaker forwards its excess workload to its neighboring matchmaker. The details of matchmaker(s) promotion/demotion and excess workload forwarding are discussed in [12]. Let n be the total number of participating nodes, m be the number of matchmakers, where $m < n$, and n_i be the number of nodes under the responsibility of matchmaker m_i, where $i = 1, 2, 3, ..., m$, in the ad hoc grid, such that: $n = \sum_{i=1}^{m} n_i$

The best case for a matchmaker in the multiple adaptive matchmaker approach is the same as that of the centralized approach. However, in the worst case, a request/offer message may be forwarded to at most $m-1$ matchmakers [12]. Therefore, the maximum number of messages to find a match will be $(m-1) + n_i + 2$, where n_i is the number of nodes under the responsibility of $(m-1)^{th}$ matchmaker and 2 represents the matched message sent to both matched consumer and producer.

For the **completely decentralized (P2P) approach** with varying the degree of neighborhood, let n be the total number of nodes and d be the degree of neighborhood, such that $d = 2, 4, 6, 8, ..., n$ in the ad hoc grid. In the best case, all the neighboring nodes will send offers to the current node, for its resource request, and one matched message will be sent to the matching producer node. Hence, the number of messages will be $d+1$. The worst case scenario of this protocol, varying the degree of neighborhood, was explained in the start of this section. A node will send its resource request/offer to all neighboring nodes, and all neighboring nodes will send a resource offer/request to the sender node. The sender node will send a confirmation message to the selected producer/consumer node. Total number of exchanged messages to find a matched pair will be $2d+1$.

It is important to point out that the differentiating point in the analyzed resource discovery approaches, is the matchmaker's ability to search for a required resource from the nodes under its responsibility or in its degree of neighborhood. The matchmaker agent can look at the submitted offers of the nodes under its responsibility in the completely centralized and in multiple adaptive matchmakers approach. The matchmaker agent is limited by the degree of neighborhood (except when $d = n$) and cannot search the resources of all participating nodes. Figure 3a and 3b compare the number of messages required to find a match in the varying the degree of neighborhood approach with centralized and multiple adaptive matchmakers approach, respectively, in the ad hoc grid.

Although the distribution of ad hoc grid nodes among two or more matchmakers vary according to the workload of the matchmakers [12], we assume $n_i = {}^{n}/_{m}$ for the case of multiple adaptive matchmakers, while comparing the message complexity for varying the degree of neighborhood in completely decentralized approach with other two approaches in Figure 3a and 3b. $1MM$ represents one matchmaker of the centralized approach, whereas $2MM, ..., 5MM$ represent two or multiple matchmakers of the multiple adaptive matchmakers approach in Figure 3b. The number of messages exchanged in different resource discovery approaches are summarized in Table 1.

6 Experimental Setup and Results

We developed our ad hoc grid experimental platform on top of Pastry [15]. Although we used Pastry, in principle any other structured overlay network can be used. Pastry is a self-organizing and adaptive overlay network. Pastry is used for node arrival/departure, node failure handling, and for message routing in this work. Node join/leave and Pastry message routing is explained in [15].

The experiments are executed on PlanetLab [16]. PlanetLab is a global, community-based effort and is used mostly for network related experiments. The PlanetLab nodes are connected through the Internet. Research institutions/ organizations contribute a minimum of 2 computing machines. The researchers of the corresponding institute/organization are granted access to a pool of more than 1000 PlanetLab nodes.

The experiments are executed to answer the questions discussed in Section 1. The first set of experiments are executed to analyze the effect of varying the degree of neighborhood. In the second set of experiments, the experimental results with varying the degree of neighborhood are compared with total centralized approach and with multiple adaptive matchmakers approach for resource discovery in an ad hoc grid.

The number of participating nodes varies from 15 to 650. The number of matchmakers varies from 1 to 5 in the experiments with multiple adaptive matchmakers. TTL of the request/offer messages is set to 10000 milliseconds in order to cater the delays observed in PlanetLab. In this work, we have only considered computational power (CPU cycle) as a resource. However, other resources like memory, bandwidth and disk storage can also be incorporated in this model. The job execution time, job deadline, budget, and request/offer computational resource amount are randomly generated from a predefined range. The request/offer resource quantity varies for each request/offer message. Data presented is obtained after the system reaches a steady state, when $1/4th$ of the experiment time is elapsed.

Matchmaking efficiency, response time and the message complexity are analyzed in these experiments. Message complexity analysis is explained in Section 5. The matchmaking efficiency in time interval $T = [T_{start}, T_{end}]$ is defined as:

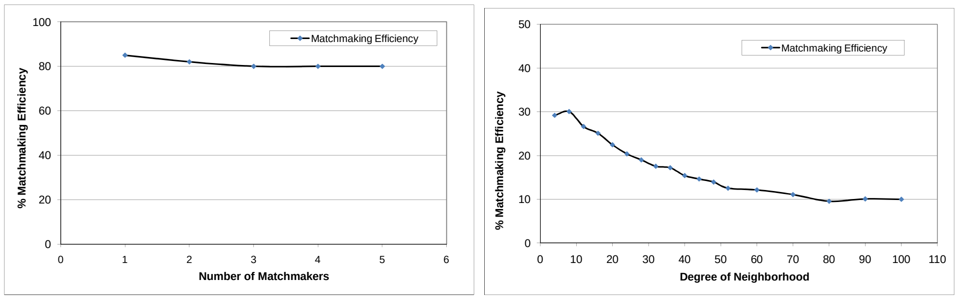
$$(\sum_{T_{start}}^{T_{end}} Matched\ Message / \sum_{T_{start}}^{T_{end}} Total\ Message) * 100$$

Where T_{start} and T_{end} represent the start and end time of the time interval $T = [T_{start}, T_{end}]$. The response time denotes the time interval, starting from the time a message is received, and ends at the moment when a match is found for the received message. The response time is calculated as: $RT = T_{match} - T_{receive}$, where RT represents the response time, T_{match} is the time when the matchmaker agent found a matching offer/request for the received request/offer message and $T_{receive}$ is the receiving time of the received request/offer message.

All the experiments are executed in different network conditions, including task intensive ($tasks >> resources$), balanced ($tasks \approx resources$) and resource intensive ($tasks << resources$) network conditions. The task intensive network condition in our experiments is the case when approximately 80% of the participating nodes act as resource consumers and 20% as resource producers. The consumer-to-producer ratio is $50\% - 50\%$ in the balanced network condition and the consumer-to-producer ratio is $20\% - 80\%$ in resource intensive network condition. The experimental results of balanced network condition are presented and explained in the next section.

6.1 Experimental Results

First, we look at the matchmaking efficiency in the completely centralized resource discovery approach (number of matchmaker as 1 in Figure 4a) and with multiple adaptive matchmakers resource discovery approach (number of matchmakers > 1 in Figure 4a). The **completely centralized approach** shows higher matchmaking efficiency for small workloads. However, one matchmaker cannot maintain its matchmaking efficiency with the increasing work load. The matchmaking efficiency keeps on decreasing with increasing work load of the matchmaker. This phenomenon can be understood with the following explanation. With the increasing workload, the matchmaker has to process more messages, so it takes more time to find matched pairs. This results in an increased response time of the matchmaker. Since each request/offer message has a validity period (TTL), therefore the TTL of the request/offer messages start expiring with increased processing time of the matchmaker and consequently the matchmaking efficiency of the matchmaker decreases with increasing workload of the matchmaker. The work load threshold for one matchmaker system, decreasing matchmaking efficiency with increasing workload of a matchmaker are explained in our earlier work [13].

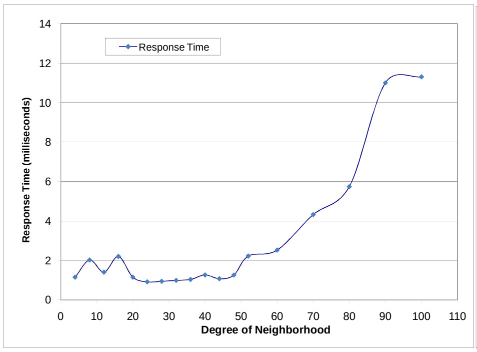


(a) (b)

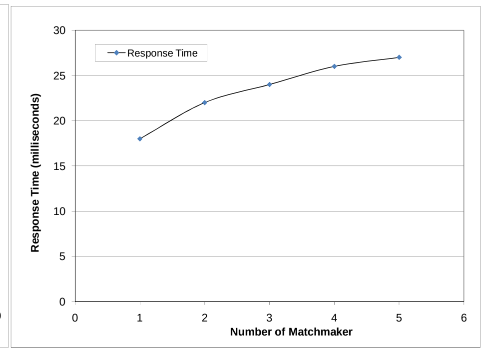
Fig. 4: **(a)** Matchmaking efficiency of centralized and multiple adaptive matchmakers approach. **(b)** Matchmaking efficiency with varying the degree of neighborhood in completely decentralized (P2P).

The matchmaking efficiency of **multiple adaptive matchmakers approach** is not affected by the increasing workload. The adaptive mechanism introduces more matchmaker(s) when needed by an overloaded matchmaker(s). Hence, the matchmaking efficiency remains the same with the increased number of matchmakers. The matchmaking efficiency of completely centralized resource discovery approach is slightly higher than that of multiple adaptive matchmakers approach (Figure 4a). The matchmakers in multiple adaptive matchmakers approach communicate with other matchmakers in order to promote/demote matchmakers and for sharing their access workload with the other matchmakers [12]. Some of the request/offer messages expire during this process. Since, there is no communication or work load sharing with other matchmakers in the completely centralized approach, the maximum matchmaking efficiency of the completely centralized system is slightly higher than that of the multiple adaptive matchmakers system. However, the completely centralized approach is not scalable and can have a single point of failure [12,13].

Figure 4b shows the matchmaking efficiency of the resource discovery approach with varying the degree of neighborhood in a **completely decentralized (P2P) ad hoc grid**. The matchmaking efficiency initially increases with an increased degree of neighborhood. This seems logical as with an increased degree of neighborhood, the chances for finding a required resource/offer also increase. However, this trend starts decreasing with further increase in the degree of neighborhood due to the increased number of request/offer messages (refer to Figure 3a). The matchmaker agent of each node has to process more messages. The increased processing time results in TTL expiry of request/offer messages and consequently a drop in the matchmaking efficiency. The experiments were repeated for $n = 100$, 250 and d was varied from $d = 2, 4, 6, 8, ..., n$. The same matchmaking pattern as in Figure 4b was observed.



(a)



(b)

Fig. 5: **(a)** Response time with varying the degree of neighborhood in the completely decentralized (P2P) approach. **(b)** Response time of centralized and multiple adaptive matchmakers approach.

An alternative view of the above discussed phenomenon is to consider the average response time. Figure 5a shows the average response time to find a match with varying the degree of neighborhood in a **completely decentralized (P2P) ad hoc grid**. In our experiments, the response time stays stable up to 50 hops in the P2P case. The response time increases more than proportional once the number of hops goes beyond 60 (Figure 5a). The over proportional increase in response time is due to the communication overhead incurred with the increased degree of neighborhood in the completely decentralized (P2P) ad hoc gird.

We observe an increase in the response time of **multiple adaptive matchmakers approach** with increased number of matchmakers (Figure 5b). This increase is due to the segmentation of the ad hoc grid and due to increased communication as explained in Section 5. The experiments were also executed under resource intensive and task intensive network conditions. We observed the same trend of the matchmaking efficiency and response time as discussed above.

It can be concluded from the above discussion that neither a completely centralized nor a completely decentralized (P2P) is generally a suitable infrastructures for resource discovery in an ad hoc grid. A completely centralized infrastructure is not scalable and can have a single point of failure. On the other hand, a completely decentralized (P2P) infrastructure incurs excessive communication overhead that results in an increased response time and decreased matchmaking efficiency. An intermediate infrastructure having multiple adaptive matchmakers seems most efficient in terms of response time and in finding matches. The intermediate infrastructure with multiple adaptive matchmakers should be preferred whenever possible in the ad hoc grid.

7 Conclusions

In this paper, we analyzed the effect of varying the degree of neighborhood on resource discovery in a local ad hoc grid. For this purpose we defined and implemented the degree of neighborhood for participating nodes. Results were obtained for completely centralized, multiple adaptive matchmakers and for completely decentralized resource discovery approaches in an ad hoc grid. Results show that the ad hoc grid becomes less efficient with increased degree of neighborhood in completely decentralized approach, due to the excessive messages being exchanged. The results also confirmed that an intermediate ad hoc grid infrastructure with multiple adaptive matchmakers is preferable in a local ad hoc grid. In future, we will investigate the resource discovery approaches in hybrid environments for multiple adaptive matchmakers approach, where both the centralized matchmaking and P2P matchmaking will occur.

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