AN INTER-ORGANIZATIONAL PEER-TO-PEER WORKFLOW MANAGEMENT SYSTEM
P2P based Virtual Organization Concept

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Abstract: Current inter-organizational cooperation technologies and approaches do not adequately support cross-organizational workflow. These approaches concentrate on automating the public workflow in isolation from the internal workflow management systems inside the cooperating organization. Integrating Peer-to-peer (P2P) and workflow technology enables virtual enterprises to dynamically form and dismantle partnerships between organizations workflow management systems. In addition, P2P workflow based systems support various forms of workflow interoperability e. g capacity sharing, chained execution, subcontracting, case transfer, loosely coupled and public to private approach. This paper describes a novel peer-to-peer inter-organizational workflow management framework (P2P inter-org WFMS), which includes workflow advertisement, workflow interconnection, and workflow cooperation. Each organization acts as a workflow peer (WFP) in a virtual enterprise. Sun Microsystems's JXTA P2P networking environment is used for prototype implementation. XPDL (XML Process Definition Languages) is used for process definition as it offers portability between different Process Design tools. The internal WFMS in each organization is being implemented using TIBCO Business Studio ™.

1 INTRODUCTION

Workflow is the automation of business processes, in which tasks, documents and information are passed from one participant to another for action, according to a set of procedural rules. A workflow management system (WFMS) is the software tool for defining, executing and monitoring the workflow. Current workflow management systems focus on the automation of business processes within the boundaries of a single organization (Liu, et al, 2005). However, as a result of the current increase in cooperation across organizational boundaries, there is an increased need for inter-organizational workflow management systems (inter-org WFMS).

Traditional WFMS are based on the following requirements (Riempp and Nastansky, 1997): (1) all actors, routing paths and storage locations in the workflow are known. (2) Legal, organizational and security aspects are under control of a single management. (3) Hardware, operating systems and workflow management applications are mostly homogeneous. In contrast, for inter-org WFMS, the actors, routing, and storage locations are not established in advance. In addition, the organizations involved have different legal and organizational systems, different security aspects, and heterogeneous hardware, operating systems and workflow applications.

The cooperation between organizations to execute a shared process can take the form of a "virtual organization". Riempp (1998) defines the virtual organization (VO) as a temporary coalition of several, legally independent organizations, with the purpose of offering a jointly manufactured product or jointly provided service to customer who perceive the VO as a singular entity. Virtual organizations require flexible, on-the-fly alignment of business partners; in other words, adaptive workflow capabilities (Buhler and Vidal, 2005).

Recently, researchers have shown an increased interest in the integration of P2P and workflow technology to improve efficiency (Berry and Muhlberger, 2002; Coon, 2002; Yan, 2006; Fakas

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and Karakostas, 2005; Aldeeb et al, 2007). P2P is an innovative technology that is both flexible and scalable and provides communication autonomy. Furthermore, P2P WFMSs are proposed to avoid the bottleneck and the central point of faults caused by client/server workflow systems and to improve scalability, system openness and support incompletely specified processes. The aim of the research presented in this paper is to extend the current P2P WFMSs to an inter-org WFMSs. A novel peer-to-peer inter-org WFMS framework which overcomes the limitation of the current inter-org WFMSs is proposed. This paper is organized as follows, in section 2, some existing inter-organizational cooperation technologies and workflow approaches are presented along with a discussion of intra-organizational P2P WFMSs. The proposed inter-organizational P2P WFMS with its architecture is introduced in section 3. Prototype implementation is described in section 4, and section 5 concludes the paper with discussion of future work.

2 RELATED WORK

2.1 Inter-organizational Cooperation Technologies

Electronic Data Interchange (EDI) is traditionally used in e-commerce to exchange standardised structured data between cooperating organizations (Aalst, 2000a). A Value Added Network (VAN) is used for EDI transmission for security and additional features. Despite the benefits of using VAN, it is complex, has multiple interpretations, and requires significant technical expertise to deploy. For these reasons, e-commerce is moving to Web-Based EDI, which allows organizations to interact with their partners using the Web. However, EDI solutions are concentrating on the data transaction and there is no explicit inter-organizational workflow features (e.g. allocating and re-allocating task to the participants, coordination and routing and monitoring). Integrating EDI technology with workflow is required for efficient e-commerce.

Web services are now the standard for e-business and requires several XML-based technologies to transport and to transform data between programs and databases (Newcomer, 2002), including WSDL, SOAP and UDDI. Web services represent loosely coupled interactions, which are well suited to integrating disparate software domains and bridging incompatible technologies. Web services are simpler than EDI and it is easier to exchange electronic documents via the internet. Perrin et al. (2003) implement the middleware between partners in a VO as web services to provide dynamic and flexible integration between them. The electronic business XML (ebXML) is another technology to enable business-to-business (B2B) transactions by exchanging a standard XML-based business messages (Newcomer, 2002). The ebXML messaging specification is based on SOAP, with attachments. It does not use WSDL and UDDI but does add several qualities of service, such as security, guaranteed messaging mechanism. ebXML architecture extends basic Web services concepts and they overlap in many areas. In general, ebXML specifications can be seen as enhancements to Web services. These cooperation technologies are tools for inter-organizational cooperation without explicit inter-organizational workflow mechanism. Extra effort is needed to add important workflow aspects, such as autonomous actions, deliberatively cooperative behaviour, messages routing to participants, and querying other participants for status information of a workflow instance.

2.2 Inter-organizational Workflow Approaches

Aalst and Weske (2001) proposed a Public-To-Private approach to inter-organizational workflows based on a notion of inheritance. This approach consists of three steps: (1) create a common understanding of the inter-organizational workflow by specifying a shared public workflow, (2) partition the public workflow over the organizations involved, and (3) for each organization, create a private workflow which is a subclass of the respective part of the public workflow.

CrossFlow (Grefen et al, 2001) is an approach aimed at providing high-level support for workflows in dynamically formed virtual organizations. In CrossFlow, partially defined contracts are used by service providers to advertise their services, and by service consumers to search for services. As such, the contract is the basis for dynamic partnerships. A contract specification language is needed to form the matchmaking process and to generate the contract enactment infrastructure dynamically.

The Workflow-based Internet Service (WISE) (Lazcano, G. et al., 2000) is aimed at designing, and implementing software tools for business to business e-commerce over the Internet. The designed software platform includes four modules: process definition module, process enactment module, monitoring and analysis module, and coordination and communication module.

Chebbi et al. (2006) propose a view-based approach to dynamic inter-organizational workflow cooperation. This approach allows for partial visibility of workflows and their resource in the cooperating organizations. Varying degrees of visibility of workflows enable organizations to retain required levels of privacy and security of internal workflows.

2.3 Intra-organizational P2P Workflow Management Systems

In P2P WFMS (Fakas and Karakostas, 2005; Yan, 2006; Aldeeb et al, 2007), peers join "virtual communities" according to their capabilities and discover each other using the services provided by an open P2P network. The coordination is performed by notification messages exchanged between peers. Two functions are conducted by P2P WFMS: A Build-time function, which includes workflow process modelling, storing process definitions and distributing the process to workflow peers, and a Run-time function, which includes workflow instantiation and task coordination. P2P network provides services that include advertisement services, group services, peer services, pipe services, and discovery services. In P2P WFMS, a workflow peer (WFP) is a software component that can reside on any machine on the P2P network enabling direct communication with other workflow peers to enact the workflow process. The internal structure of the WFP consists of user, task, and flow components. It also maintains four data repositories – a peer repository, a resource and tools repository, a task repository and a process repository. Each WFP is associated with a workflow participant and each performs a part of the workflow. Once the task is completed, the WFP informs its successor and the next task of the process is executed. Process co-ordination is achieved by the exchange of both information and control messages between peers.

The few proposed P2P WFMS in the literature are designed for intra-organisational workflow scenarios (Yan, 2006; Fakas and Karakostas, 2005; Aldeeb et al, 2007). Despite the advantages of applying P2P for intra-organisational WFMS, it is unlikely that all business circumstances in one organization would require enforcement of a peer to peer workflow where no one has the overall control. In other words, P2P intra-organisational workflow is not a general solution and will be based on the requirements and the internal structure of the organization. However, given the discussion of Inter-organisational WFMS in section 2.2, P2P WFMS would seem a good general solution for inter-org WFMS where no central control exist and the partners are autonomous workflow actors, who can join and leave VO at any time. In addition, the participating organizations can implement internal centralized client/server or decentralized P2P WFMS based on their requirements.

A novel inter-org WFMS is introduced in the next section. This system will play the role of business process integration and management (BPIM) which involves linking both intra-organizational and inter-inter-organizational workflow together to achieve the desired business process. The inter-organizational system is based on a P2P platform while the internal WFMSs for the organizations involved can be decentralized P2P WFMS or classical centralized client/server WFMS.

3 INTER-ORG P2P WFMS

For inter-organizational business processes, the execution of workflow may generate a very high load. This load can affect workflow servers and the underlying communication network (Bauer et al., 2003). To improve scalability and efficiency, integrating P2P technology with inter-organizational workflow is proposed. In inter-org WFMS, there is cooperation between information systems that belong to autonomous organizations; they can at any time join or leave the shared process. This can be achieved by applying P2P workflow for inter-organizational WFMSs where P2P WFMS can be a promising solution. Each organization involved in the inter-org workflow will be represented by a workflow peer (WFP) and these peers will form a P2P virtual organization. The P2P open network will be the gateway between the various WFMS of the cooperating organizations. The goal is to utilize P2P technology to support organizations involved in a shared cooperative workflow across organizational boundaries. A public workflow model is agreed between different organizations which collaborate as peers, while keeping their internal private workflow within their boundaries.

Figure 1 shows an overview of the proposed P2P inter-organizational workflow management system using a simple case study. In the case study, three organizations customer, supplier and manufacturer are involved in managing a workflow process. This includes; workflow advertisement, workflow interconnection, and workflow cooperation. Each organization acts as a workflow peer (WFP) in this process. The three workflow peers discover each other by the advertisement service provided by the P2P network infrastructure. Communication between peers is achieved using structured messages. The detailed mechanism and the functionalities of the peer-to-peer workflow system can be found in (Yan, 2006; Fakas and Karakostas, 2005; Aldeeb et al, 2007). As shown in Figure 1, the customer organization is implementing an intra-org P2P WFMS. When the customer participates in forming the VO, its inter-org WFP will be part of two P2P groups. The first group is an internal group within the boundary of the organization while the second group is the external VO group. However, the other two partners in the VO implement a client-server internal WFMS. Existing workflow management systems can plug into the P2P VO if they can fulfil the following two conditions: First, the WFMS can call an external application (which is the virtual organization WFP in this case). Second, the WFMS allows external applications to invoke any step within its workflow.

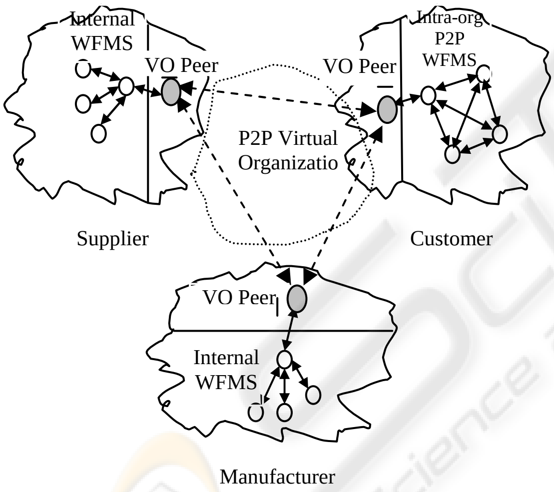

Figure 1: Inter-org P2P WFMS overview.

Figure 2 shows the sequence diagram for the inter-org workflow. This includes three phases of interactions. The first phase is WFP identification where associated WFPs for customer, supplier, and manufacturer publish their services and join different groups of a specific product or service e.g. (customers will form a group of customer of specific product). Each WFP find a desired partner. Second phase is the WFP interconnection; starting with electronic negotiation and connection then a virtual P2P organization is formed. The third phase is WFP

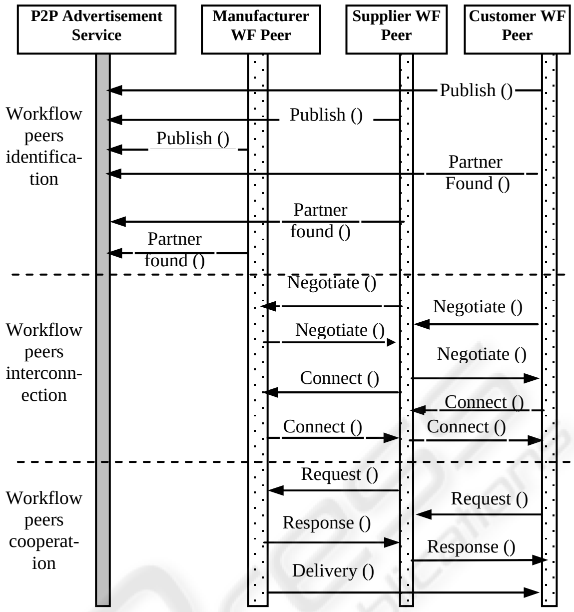

Figure 2: Inter-organizational P2P WFMS interaction sequence diagram.

cooperation, instantiating a workflow instance and coordination of tasks by message exchange between peers. In addition, one of the cooperating workflow peers in the virtual organization will play the role of 'Exception Handling Peer (EHP)'. The function of the EHP is handling the workflow exceptions and applying an appropriate recovery policy. The exception handling mechanism is described in section 3.3.

3.1 Inter-org WFP Internal Structure

Figure 3 shows the high level internal structure of the WFP. This peer consists of the following parts: a user interface to create, deploy and monitor the workflow, an enactment component which serves as a workflow engine to enact the tasks associated to this peer, a process repository to store the workflow, and an exception handling unit. There are two network interfaces: the first one is to send and receive messages to and from other peers in the virtual organization. The second interface to invoke and exchange information with the internal WFMS.

3.2 Build-time and Run-time Function of the System

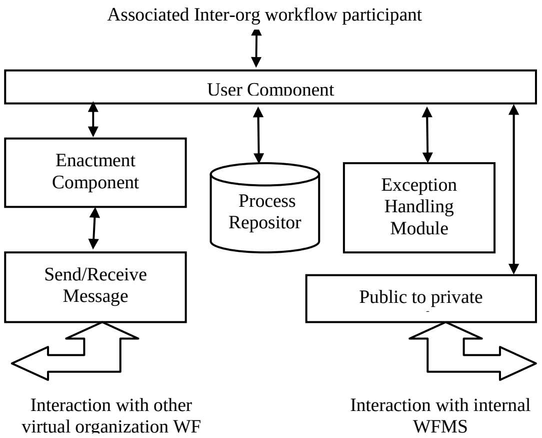

Figure 3: Inter-org WFP Internal Structure.

Loosely coupled is a mechanism to model and analyse inter-organizational workflow where each partner takes care of a specified part of the process (Aalst, 2000b). In this mechanism, the partners are working independently but synchronization at certain points is necessary to ensure the correct execution of the whole process. The proposed system can be considered as loosely coupled P2P system. During build-time, the workflow peers in the virtual organization model and define their parts in the public workflow and the message structure is agreed between them. At run-time the workflow initiator peer is responsible for initiating a workflow instance. The coordination of this workflow instance will be achieved by notification messages exchange between peers.

3.3 Adaptability and Exception Handling

Workflow adaptability is the ability of the workflow processes to react to exceptional circumstances (Sadiq et al., 2005). So far, a little progress has been reported in addressing exception handling in inter-organizational business processes (Luo et al., 2003; Reichert et al., 2003). Workflow exceptions in the P2P WFMS can be classified to two types of workflow exceptions: local workflow exception and global workflow exception. Local workflow exception affects the task of one workflow peer. The workflow peer can handle this exception by applying one of two possible self-recovery policies; forward recovery or backward recovery. Forward recovery policy is based on correcting and isolating the effect of the exception and returning the workflow task to a normal state so the normal operation can be continued. In contrast, backward recovery policy is based on restoring the workflow task to a consistent state that occurred before the appearance of the exception. If the local workflow exception can not be handled within the affected workflow peer, it can propagate to the other workflow peers leading to a global workflow exception. This type of exceptions will, of course, affect more than one workflow peer and a coordinating node is required to deal with this exception. In this research, the coordinating node is the exception handling peer (EHP). The EHP can be a dedicated peer in the VO or any other workflow peer with an exception handling capabilities can play this role in addition to its basic role. The EHP captures exceptions from the workflow peers, characterizes the exceptions and applies a recovery policy. This mechanism is based on separating the business logic and exception handling logic to make it easy to keep track of both (Hagen and Alonso, 2000). Furthermore, this will facilitate the process of verification and later modification of business and exception handling logic. In addition, the EHP can select an appropriate exception handler based on the situation and according to prior knowledge.

In P2P WFMS as a distributed system, backward recovery of one workflow peer of communicating peers will often require other peers in the group to be rolled back because of the interdependencies caused by message communication. The result is a cascade of rollbacks called the ‘domino effect’ (Miller and Tripathi, 2004). To avoid the domino effect in the proposed P2P WFMS a conversation scheme (Miller and Tripathi, 2004) is used. A P2P conversation is formed by a group of workflow peers affected by an exception, and a workflow peer in the P2P conversation can only communicate with workflow peers that are in the same conversation. This can prevent the error propagation and limits the domino effect. In exception handling mode, the EHP coordinates the exception handling process in the P2P conversation. The P2P conversation represents an atomic action consisting of interactions in a group of peers. After the effect of the exception is contained and resolved, the P2P conversation will be dissolved and the workflow peers will return to the normal mode of the P2P WFMS.

The EHP is provided with a Case Based Reasoning (CBR) unit to handle exceptions which need to be managed in similar way, but may occur in different instances. CBR (Watson, 1997) is an artificial intelligent technique which can be defined as the process of solving problems by using or adapting solutions to old similar problems. CBR can be described by the CBR-cycle which comprises four activities (Watson, 1999):

1- Retrieve similar cases to the problem description
2- Reuse a solution suggested by a similar case
3- Revise or adapt that solution to better fit the new problem if required
4- Retain the new solution once it has been confirmed or validated

CBR can add great value to the exception handling in workflows as the CBR system collects and stores cases; the WFMS becomes more resistant because it has a large set of knowledge to handle future exceptions (Cardoso et al., 2001). The nearest neighbour technique is a widely used in CBR (Hwang and Tang, 2004). The similarity between the new exception (target) and previously stored exceptions (source) is determined using the following equation:

$$Similarity(T,S) = \sum_{i=1}^{n} f(T_i, S_i) \times w_i \qquad (1)$$

Where T is the target exception case; S is the source exception case; *i* an individual exception attribute from *1* to *n*; *f* a similarity function for exception attribute *i* in exception cases T and S; and w the importance weighting of exception attribute i.

In the VO, exception attributes, which are stored as a case include: workflow instance number, status of workflow instance, exception type, exception description, time of creation, use counts, associated workflow peer number, exception solution. The nearest neighbour approach is applied by first retrieving similar exceptions and then selecting the nearest similar exception. The associated exception handler is then applied. If the distance between cases is greater than a set similarity threshold then a new temporary case is established and a new exception handler is created. Frequent appearance of certain exceptions and the usage of their associated stored cases may lead to creation of a new version of the workflow schema and business process evolution.

4 PROTOTYPE IMPLEMENTATION

Currently, the feasibility of the ideas presented in this paper are being implemented, validated, and tested using a proof-of-concept prototype. Current progress on the prototype and a case study are described in this section.

4.1 Workflow Specification Language and Implementation Tools

Sun MicroSystem's JXTA is the networking environment for P2P while XPDL (XML Process Definition Languages) is used for process definition as it offers portability between different Process Design tools. The internal WFMS in each organization is being implemented using TIBCO Business Studio™. TIBCO Business Studio™ is selected because it supports several industry standards, namely Business Process Modeling Notation (BPMN) and XPDL. In addition, TIBCO Business Studio™ provides two types of tasks; send task and receive task. Send Tasks are used to send messages to a system or person outside of the Process (in this prototype send task is used to call and instantiate the JXTA platform for the VO workflow peer). Receive Tasks are used to wait for a message from a system or person outside of the Process (in this prototype receive task is used by the VO workflow peer to invoke the internal WFMS).

4.2 Case Study

Figure 4 shows the case study used for the prototype implementation in Petri-net representation. Three organizations, namely a customer, a supplier and a manufacturer, are involved in managing a workflow process. A workflow instance starts at the customer internal WFMS when a specific product is required. The internal WFMS will send an external request for this product to the workflow peer which represents the customer in the VO. This request is an XML message contains the order details (Order No, product Name, Description and Quantity etc). The customer workflow peer will initiate a public workflow instance by sending the order to a selected supplier workflow peer which in turn will select a manufacturer workflow peer. A P2P VO is formed to manage a public workflow instance (product order). The status of this public workflow instance at any time is available for all the VO peers because every VO workflow peer is capable to query other workflow peers for status information of workflow instance. The sequence of these tasks and interaction is shown in figure 4. Another scenario for the prototype implementation will consider that the customer has an internal P2P WFMS. In this case,

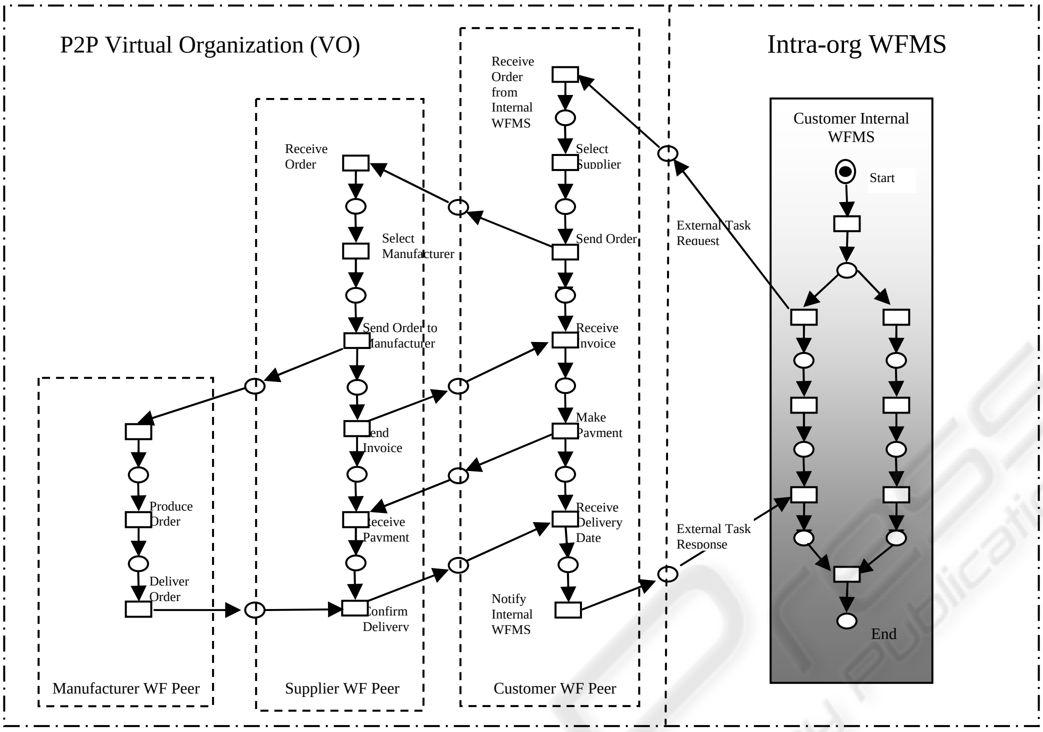

Figure 4: The prototype implementation and public-to-private workflow interaction.

JXTA P2P network is the infrastructure for both customer internal P2P WFMS and The P2P VO. A workflow peer in the internal customer WFMS will be part of the VO peers as well. This workflow peer will initiate a workflow instance for a specific product and the order will be sent to the supplier peer and manufacturer peer. The rest of the workflow process is similar to the first scenario. In this case study, the customer workflow peer in the VO is provided with an exception handling capabilities and will play the role of the EHP in addition to its basic role. Ad-hoc changes will be made in the running workflow instance to examine the exception handling procedures mentioned in section 3.3.

5 CONCLUSIONS AND FUTURE WORK

Applying P2P technology for inter-organizational workflow is the novelty of the ideas presented in this paper. Inter-organizational P2P WFMS can be considered as a business process integration and management (BPIM) tool which facilitates linking both intra-organizational and inter-inter-organizational workflow together to conduct the desired business process. In addition, P2P workflow management systems can be a promising solution for inter-organizational workflow because of the autonomy that facilitates the partners which act as a workflow peers in inter-organizational business process. A P2P inter-organizational workflow approach provides the mechanism for workflow peers to do the following: discover other peers and their services, publish their available services, exchange data and control messages with other peers, route messages to other peers , query peers for status information related to a workflow instance, and dynamically form and dismantle groups. The P2P WFMS previously designed for intra-organizational WFMS is being upgraded for inter-organizational scenario using a prototype implementation for a case study. The adaptability and exception handling can be achieved by applying workflow peer self-recovery policies, P2P conversation, and the EHP concepts. The EHP within the virtual organization will be responsible for handling the exceptions in the P2P conversation. This peer will acquire knowledge from previous exceptions using case based reasoning. Evaluation of the proposed system will be carried out and comparison with other inter-org workflow approaches.

Future work will include exception classification in P2P inter-organizational workflow and calculation of exception's re-occurrence rate in the VO. This will help to confirm the value of using CBR as a methodology for exception handling in the system.

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