

two factors: consumer needs and services to meet such needs. A potential application domain where context aware model plays an important role is the smart network-centric context aware services. Such systems can promote and mediate user's interactions with mobile devices, various servers and communities of common interests.

In a traditional E-commerce environment, users need to use a personal computer to conduct a business transaction and mostly adopt client/server model in which a commercial transaction generally requires a stable communication connection being established between the client and the server. Obviously, the client/server approach poses a barrier to the development of M-commerce applications. First, it will become expensive and unreliable when a lot of data has to be transferred between the client and the server. Second, it will be impossible to retain a long-time connectivity between the client with a mobile device and the remote server. Third, it typically requires clients to check trading opportunities frequently and make most decisions manually. In addition, compared with the desktop oriented client/server or browser/web-server model, mobile hand-operated devices have some physical constraints, such as small screen size, poor network connectivity, low transmission bandwidth, and limited battery capacity. Therefore, in order to ease the access and participation of mobile users, the mobile agent paradigm has been increasingly recognized as a promising framework for developing M-commerce applications [8]. Typical research includes general agent-based M-commerce systems [9][10], as well as specific M-commerce applications such as context aware negotiation [11], stock trading [12], and E-Marketplaces [13], etc.

Although mobile agent paradigm has been recognized as a more suitable candidate in automating or assisting customers to conduct business transactions in a mobile environment, the research in this area is still in very early stages. Due to various mobile devices, evolving wireless and telecommunication technologies, heterogeneous platforms and existing and emerging business models, there is still a long way to go in terms of developing the right user friendly devices and interfaces, describing and specifying M-commerce models and services, and assessing products against socio-economic factors that may affect their adoption or diffusion.

In this paper, we will discuss some important issues in the design of a mobile agent environment to support context aware M-commerce applications. Section II will present some basic concepts and a brief overview of an existing mobile agent platform. In Section III, we discuss design considerations of some key system components, such as mobile portal, business model, Web services, etc. Finally, we give concluding remarks as well as future works.

II. MOBILE AGENTS AND CONTEXT AWARENESS

Mobile agent systems are seen by many researchers as being the appropriate technology to develop large scale distributed applications. The agent model has been recognized as a highly effective implementation technique in E-commerce or M-commerce. Especially the mobile agent paradigm has been deployed as a good candidate to

overcome the limitations of connectivity, latency and bandwidth of wireless and telecom networks. For example, a nomadic user can dispatch mobile agents from a handheld device to perform an M-commerce application. Once the application has been launched, the user may disconnect from the network. The execution results can either be sent back by mobile agents through SMS/email, or be collected when the user receives a notice and reconnects to the network.

In addition, modern E-commerce and M-commerce applications have a great demand for context awareness, that is, a need to gather and exploit user/environment information in order to adapt application behaviors. Most M-commerce applications focus on location awareness, while ignore the aspects of user preference. Generally speaking, context could be any information that is helpful to characterize the situation of an entity, where the entity can be a person, a place, a physical resource or a computational object. Furthermore, context could be either explicitly indicated by the user or implicitly extracted from other information sources. Certainly, mobile customers want to find the best deal in an M-commerce environment. The best deal can only be obtained by appropriately combining information gathered from various shopping services in the physical vicinity. To facilitate the development of extensible and interoperable context aware applications and make contextual data usable and sharable by M-commerce applications, it is essential to have a set of principles for specifying any given context from any domain. To achieve this, a set of well-defined, uniform context models and protocols is required. As a formal representation of entities, ideas, and events, along with their properties and relations within a system of categories, ontology allows sharing a common understanding of information and deriving additional information from what is already known.

Undoubtedly, in the design of a mobile agent based M-commerce system, significant effort is required from the designers and programmers to develop programming languages, tools and user-friendly interfaces. In our previous research, we have implemented an experimental infrastructure for developing mobile agent based applications [14]. It provides an algorithmically complete programming and execution environment which includes implementations for agent servers, a logic programming language extended with a rich application programming interface, and a Java-GUI based IDE from which users can do editing, compiling, and invoking agent applications. In this research, we propose to extend the existing prototype of the mobile agent system to be a unified mobile agent platform for supporting M-commerce applications. To achieve this, the agent execution platform must be constructed with respect to the special requirements of mobile commercial users and constraints of mobile devices as well as different wireless and telecommunication networks. The key aspects that are being explored are market structure and dynamics, evolving technologies of mobile devices, wireless and telecommunication networks, Web services and business models. In other words, the proposed system should be able to help mobile users to discover, locate, negotiate, monitor

and notify, on behalf of users to carry out goal-driven commerce tasks on an anywhere and anytime basis.

III. IMPORTANT DESIGN ISSUES

The proposed infrastructure to support M-commerce applications will incorporate several research areas, especially the concepts of mobile agent, context aware computing, Web services, workflow management, as well as their related models and methodologies. Besides, there are many possible business scenarios, namely, B2C, B2B, C2C and C2B, for developing M-commerce applications. At this stage, our research project focuses on C2B, i.e., a business activity is initiated by a mobile consumer. To simplify discussion, we present a brief overview of system architecture in Fig. 1 and discuss the design and the relevance of these system components.

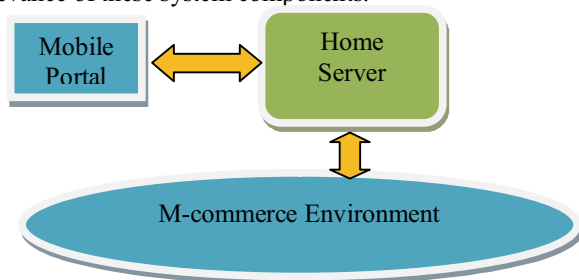


Figure 1. A Brief Overview of System Architecture

A. Device Agent – the Mobile Portal

The most obvious issue related to developing an agent based M-commerce platform is how to manage the limited computational resources on mobile devices. Generally speaking, there are two types of mobile platforms: embedded agent and mobile portal [15]. With embedded agent scheme, a mobile device hosts thin (mobile) agents which serve as the stubs of specific M-commerce applications. With mobile portal, a mobile device acts as a user interface which controls agents resided in a remote host server. A portal is considered a single user access point for presentation level integration of M-commerce information. However, in the modern design of a portal, collaborations among other components, such as Web services, Web content management, searching mechanism, workflow business process and context aware intelligence, shall also be considered. In our system, we adopt a hybrid scheme, that is, the user may dispatch a lightweight agent through an interface on the mobile portal to initiate M-commerce applications. The mobile portal will be implemented in Java ME/SDK which is a state-of-the-art toolbox for developing mobile applications.

The mobile portal is in fact a compact agent execution engine. It will assist user to customize an M-commerce application by setting parameters, preferences, permissions and some special personal information. Based upon user's input, an abstract workflow message in XML will be generated and delivered by a thin agent to its home server for further processing.

B. Context Aware Workflow Composition

In M-commerce applications, it is desirable that business activities to be completed quickly with high quality and low cost. A well-designed workflow management system can provide potential competitive advantage to manipulate a series of tasks within a business transaction to produce a final result. In recent years, Web services are growing and evolving rapidly in M-commerce applications. The development of new service composition by integrating existing services is generating considerable interests in business communities. In order to explore the flexibility and availability of mobile agent and Web services, we define two types of concrete services in our system, namely, E-service and A-service. An E-service represents a common Web service which includes the service provider, the purpose of the service and the method of invocation. On the other hand, an A-service indicates an agent-based service which includes the remote agent host, name of the vendor agent, and the method of agent communication. To invoke an A-service, a mobile agent must migrate to the remote agent server and communicate with the named vendor agent. A vendor agent is a persistent agent acting as the representative of the vendor. It provides services interactively with the mobile agent to implement authentication, query, negotiation, etc. To get the benefits of the Web service standardization and to avoid the redesign of another service discovery mechanism, we adopt UDDI registry [16] with some extension. Concretely speaking, a new tag <AgentService> is added to a UDDI service registry if the service is an A-Service, that is, the service is implemented by agent-agent interaction.

The major portion of our context aware workflow management system resides on the home server. Having received the abstract workflow from the Portal, a workflow manager will be invoked to extract atomic activities from the XML message and use system defined selection rules and contextual information to search available services from an UDDI server. Based upon the search results, the workflow management system will hook up a concrete implementation to each atomic activity, that is, to invoke a web service if the result returned by discovery module is of type E-service, or to create a mobile agent if the result is of type A-service. An E-service will be invoked by the standard SOAP protocol, while an A-service is carried out by a mobile agent who migrates to one or more remote hosts and communicates with various vendor agents to obtain required services.

C. Context-aware Programming

To design an agent-based context-aware M-commerce environment, it is important to have a mechanism that enables (mobile) agents to adapt their behavior dynamically to the current environmental context. In our system, the context model is constructed with respect to three important aspects. First, a common ontology must be specified to enable computational entities such as agents and services in open and dynamic distributed systems to have a common set of concepts about context while interacting with one another. Secondly, a well defined declarative semantic model shall be provided as a means for intelligent agents to exploit various existing logic reasoning mechanisms to reason about

contextual information. Third, a context processing mechanism must be embedded in agent coding languages to support context oriented programming. Clearly, embedding context awareness into programming is a relative new research topic [17]. We will investigate further for this matter, especially the way of handling dynamic context of the execution environment.

In designing an agent platform for various M-commerce applications, inter-portability and compatibility between different programming languages should be supported. One possible solution is to introduce a new language construct as language extensions [18]. However, in order to simplify the task of implementing a multi-language mobile agent platform, we intend to configure the system into an open architecture. Based upon the type and the coding language of an agent, the kernel engine of an agent server will automatically hook up a proper interpreter/emulator to the running agent. A new programming language can be added to the system by registering an add-on module. This module contains function entries that are used by the engine to access specific features of the language. Different languages may have different policies and strategies to handle security as well as different protocols for agent communication and migration. We also consider those functions as add-on features for flexibility. For example, when a Java agent initiates a move method call, its corresponding migration module may capture the agent execution state through the Java's serializing feature which provides a means for translating a graph of objects into a byte-stream and thus achieves migration at a coarse granularity. Certainly, mixing mobile agents coded in different languages within a single program offers a great opportunity to create multi-domain applications. For example, an M-commerce application may dispatch a mobile agent written in a logic programming language to carry out a goal-driven task, and at the same time to deploy an agent in Java to present results in a user friendly graphic interface. No doubt, designing a generic language add-on facility is a complex task and may involve unforeseen difficulties. To exercise this, we have chosen Java as the candidate to be added into our existing infrastructure.

OMG Mobile Agent System Interoperability Facility (MASIF) Specification and IEEE FIPA Mobile Agent Specification can be regarded as frameworks towards a unified distributed mobile object middleware, which enable technology and location transparent interactions between static and mobile agents, and enable agents to exchange messages in an Agent Communication Language (ACL). We will try to make our system design in compliance with these standards and at the same time try to find solutions for some open problems, such as location transparent communication, agent location tracking, infrastructure for agent server discovery, support for transactional behavior, fault tolerant execution of mobile agents, and so on.

D. Security

Security is the main concern of any new technology. In mobile agent research, a variety of security mechanisms and protocols have been proposed or developed by some companies and research groups [19][20][21]. No doubt, the

security challenge in M-commerce is much more severe than the one in traditional distributed computing. As the number of E-markets and online commercial transactions grow at phenomenal rates, one of the main challenges in our project is the design and implementation of mobile agent based infrastructure that is able to carry out various M-commerce transaction steps, such as searching, negotiation, authentication, payment, *etc.*, in a secure manner. However, the potential benefits of mobile agents cannot be fully explored without proper measures against the real security threats. In general, security threads can be classified into four categories:

- comprised hosts and mobile agents attempt representing different parties that may exhibit malicious behavior toward one another,
- mobile agents are exposed to third party intruders through the network,
- agents interfere with each other or gain unauthorized access to internal state, and
- agents carrying malicious mobile code try to corrupt remote hosts or invoke unauthorized access to resources.

Clearly, an agent based M-commerce system must cope with exposed data services and insecure communication channels in wireless and telecommunication networks to protect the privacy, integrity and availability of agents and commercial data sources. The objective of our research is to provide basic mechanisms that are generally incorporated in mobile agent systems to support security and to equip mobile agents with system tools such that those agents can search for online commerce sites, move from hosts to hosts, gather information and access products, carry out intelligent commerce transaction, and make the final purchasing decision through the aggregation of the local results.

In the current design of our system, the integrated security mechanism consists of three kernel components: secure migration protocol, agent verifier and security monitor. New topics in this research include improvement of host protection techniques and investigations of how to protect agents against malicious servers [22].

IV. CONCLUSIONS

In this paper, we presented the design and architecture which integrates mobile agent technology and context aware workflow to accommodate M-commerce applications. The novelty of our proposal is that it uses an ontological context model to provide personal and environmental contextual information and supports the composition of context-aware services. As a consequence, it not only utilizes existing web service and service discovery protocol, but also employs mobile agents to achieve flexible network roaming for interactive services.

The research reported in this paper is an on-going project and still in its very early stage. Our next steps are to complete the workflow management system and to integrate the system with a mobile agent infrastructure. In addition, there are some aspects that should be further investigated. First, we shall study how to model user behavior though data

mining and reasoning, and how to predict the user's actions based on various profiles and history. Secondly, we will investigate a proper design of the mobile portal in order to manage the limited computational resources of handheld devices and provide a user friendly interface. We also plan to investigate and simulate prototypes of mobile portal under different mobile operating systems, such as Embedded Linux, Window Mobile, and iPhone OS. Thirdly, we will investigate the development of M-commerce agents with more intelligent decision-making and learning capabilities in the context of automated business transaction. Finally, we will develop a communication mechanism called Mobile Socket, and incorporate with ebXML to provide an open, XML-based infrastructure that enables the global use of electronic business information in an interoperable, secure, and consistent manner by vendors and mobile users.

ACKNOWLEDGMENT

The authors would like to give thanks to the Natural Science and Engineering Council of Canada and the Natural Science Foundation of P. R. of China (90912003, 60773108 and 90812001) for supporting this research.

REFERENCES

- [1] Bhasin, M.L., "E-Commerce and M-Commerce Revolution: Perspectives, Problems and Prospects", *The Chartered Accountant*, December, (2005), pp.824-840
- [2] Wu, J.H. and Hisa, T.L., "Developing E-Business Dynamic Capabilities: An Analysis of E-Commerce Innovation from I-, M-, to U-commerce", *J. of Organizational Computing and Electronic Commerce*, 18, (2008), pp. 95-111
- [3] Dekleva, S., Shim, J.P., Varshney, U. and Knoerzer, G., "Evolution and Emerging Issues in Mobile Wireless Networks", *Communication of the ACM*, Vol. 50, No. 6, (2007), pp. 38-43
- [4] Bai, L., Chou, D.C., Yen, D.C. and Lin B., "Mobile Commerce: Its Market Analyses", *Int. J. of Mobile Communication*, Vol. 3, No. 1, (2005), pp. 66-81
- [5] Ngai, E.W.T. and Gunasekaran, A., "A Review for Mobile Commerce Research and Applications", *Decision Support Systems*, 43, (2007), pp. 3-15
- [6] Junglas, I.A. and Watson, R.T., "Location-Based Services", *Communication of the ACM*, Vol. 51, No. 3, (2008), pp. 65-69
- [7] Sadeh, N.M., Chan, T.C., Van, L., Kwon, O. and Takizawa, K. "Creating an Open Agent Environment for Context-aware M-Commerce", *Agentcities: Challenges in Open Agent Environments*, LNAI, (2003), pp.152-158
- [8] Kowalczyk, R., Uliuru, M. and Unland, R., "Integrating Mobile and Intelligent Agents in Advanced E-Commerce: A Survey", *Agent Technologies, Infrastructures, Tools and Application*, LNCS 2592, (2009), pp. 295-313
- [9] Bădică, C., Ganzha, M. and Paprzycki, M., "Mobile Agents in a Multi-Agent E-Commerce System", *Proc. of the Seventh International Symposium on Symbolic and Numeric Algorithms for Scientific Computing*, IEEE, (2005), pp. 207-214
- [10] Mihailescu, P., Binder, W. and Kendall, E.A., "MAE: A Mobile Agent Platform for Building Wireless M-commerce Applications", *The 8th ECOOP Workshop on Mobile Object systems: Agent Applications and New Frontiers*, Málaga, Spain, (2002)
- [11] Matos, F.M. and Madeira, E.R.M., "A Context-Aware Negotiation Model for M-commerce", *The 2nd International Workshop on Mobility Aware Technologies and Applications (MATA 2005)*, LNCS 3744, (2005), pp.230-239
- [12] Boman, M. and Sandin, A., "Implementing an Agent Trade Server", *Decision Support Systems*, 42, Elsevier Science Publishers, (2006), pp. 318-327
- [13] Kowalczyk, R., Braun, P., Mueller, I., Rossak, W., Frankczyk, B. and Speck, A., "Deploying Mobile and Intelligent Agents in Interconnected E-marketplaces", *Journal of Integrated Design and Process Science*, Vol. 7, No. 3, (2003), pp. 109-123
- [14] Li, X., "On the Implementation of IMAGO System", *International Journal of Computer Science and Network Security*, Vol. 6, No. 2a, (2006), pp. 107-118
- [15] O'Hare, G.M.P., Grady, M.J.O., Muldoon, C. and Bradley, J.F., "Embedded Agents: A Paradigm for Mobile Services", *Int. J. of Web and Grid Services*, Vol. 2, No. 4, (2006), pp. 379-405
- [16] Acharya, D., Prabhu, N. and Kumar, V., "Discovering and Using Web Services in M-Commerce", *Technologies for E-Services*, LNCS 3324, (2005), pp. 136-151
- [17] Hirschfeld, R., Costanza, P., and Nierstrasz, O., "Context-oriented Programming", *Journal of Object Technology*, Vol. 3, No. 3, (2008), pp. 125-151
- [18] Tarau, P. and Majumdar, A., "Interoperating Logic Engines", *Eleventh International Symposium on Practical Aspects of Declarative Languages (PADL 09)*, LNCS 5418, (2009), pp. 137-151
- [19] Borselius, N., *Mobile Agent Security*, *Electronic & Communication Engineering Journal*, Vol. 10, (2002), pp. 211-218
- [20] Karnik, N., Tripathi, A., *Security in the Ajanta mobile agent system*, *Software Practice and Experience*, Vol. 31, No. 4, (2001), pp. 301-329
- [21] Gray, R., Kotz, D., Cybenko, G., Rus, D., *D'Agents: Security in a Multiple Language Mobile-agent System*, *Mobile Agents and Security*, *Lecture Notes in Computer Science*, Springer-Verlag, No. 1419, (1998), pp. 154-187
- [22] Rhazi, A.E., Pierre, S. and Boucheneb, H., "A Secure Protocol Based on a Sedentary Agent for Mobile Agent Environments", *J. of Computer Science*, 3 (1), (2007), pp. 35-42