HANDHELD DEVICES AND COMPUTING AND PAYMENT METHODS FOR MOBILE COMMERCE

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Abstract

The emergence of wireless and mobile networks has made possible the introduction of electronic commerce to a new application and research area: mobile commerce. Understanding or applying mobile commerce is an arduous task because it involves a wide variety of disciplines and technologies. To facilitate understanding and applying mobile commerce, this article gives careful study to four major subjects of mobile commerce: i) mobile commerce systems from a technical perspective, ii) mobile handheld devices including smart cellular phones and PDAs, iii) handheld computing including client- and server- side handheld programming, and iv) mobile commerce payment methods. Each subject will be described in detail and major technologies for the subject will be given too.

Introduction

With the introduction of the World Wide Web, electronic commerce has revolutionized traditional commerce and boosted sales and exchanges of merchandise and information. Mobile commerce is defined as the exchange or buying and selling of commodities, services, or information on the Internet through the use of mobile handheld devices. In just a few years, mobile commerce has emerged from nowhere to become the hottest new trend in business transactions. Despite a weak economy, the future of mobile commerce is bright according to the latest predictions (Juniper Research Ltd, 2004). However, it requires a tremendous effort to understand mobile commerce and construct a mobile commerce application because mobile commerce involves such a wide range of disciplines and technologies. To lessen the difficulty, this paper gives careful study to four major subjects of mobile commerce:

- `Mobile commerce systems`: Various system structures for mobile commerce have been proposed. A typical mobile commerce system generally consists of six components: i) mobile commerce applications, ii) mobile handheld devices, iii) mobile middleware, iv) wireless networks, v) wired networks, and vi) host computers.
- `Mobile handheld devices`: Handheld devices provide the equipment mobile users need to interact with mobile commerce applications. A mobile handheld device includes six major components: i) a mobile operating system, ii) a mobile central processor unit, iii) a microbrowser, iv) input/output devices, v) a memory, and vi) batteries.
- `Handheld computing`: Handheld computing is the future of computer science because 650 million smart cellular phones, not including PDAs (personal digital assistants), will be used by 2006 (InfoTech Trends, 2002). Handheld computing is the programming for handheld devices and it includes two kinds: client- and server-side handheld programming.
- `Mobile payment methods`: Mobile commerce security is defined as the technological and managerial procedures applied to mobile commerce to provide security properties. Among the many issues that arise with mobile commerce security, mobile payment methods, including macropayments and micropayments, are probably the most important.

Mobile Commerce Systems

A mobile commerce system is inherently interdisciplinary and could be implemented in various ways. Figure 1 shows a flowchart of how a user request is processed by a mobile commerce system.

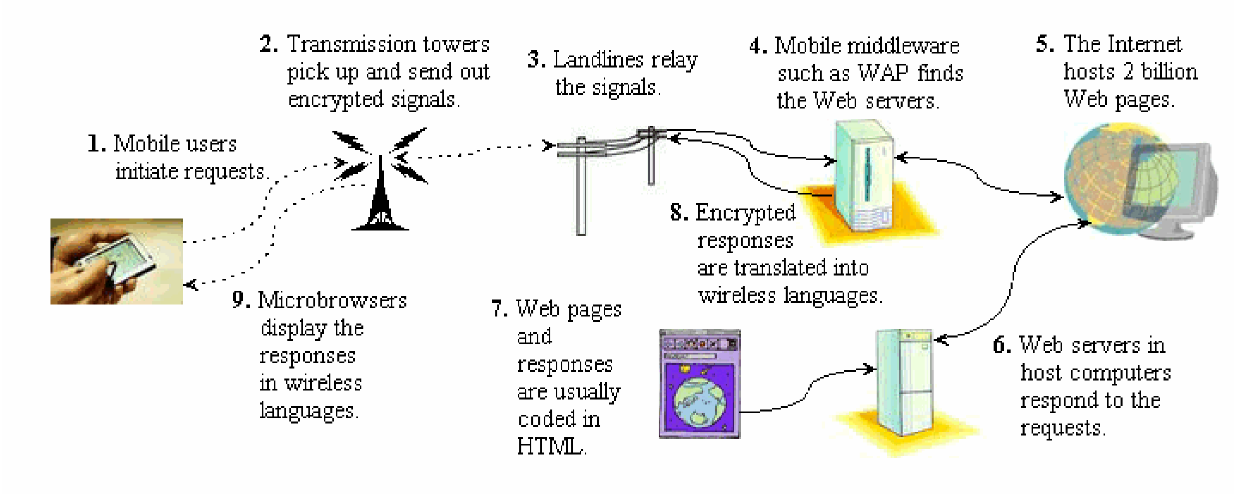

Figure 1: A flowchart of a user request processed in a mobile commerce system

Figure 2 shows the structure of a mobile commerce system and a typical example of such a system (Hu, Lee, & Yeh, 2004). The system structure includes six components: i) mobile applications, ii) mobile handheld devices, iii) mobile middleware, iv) wireless networks, v) wired networks, and vi) host computers. Related research on mobile commerce systems can be found in the article by Varshney, Vetter, & Kalakota (2000).

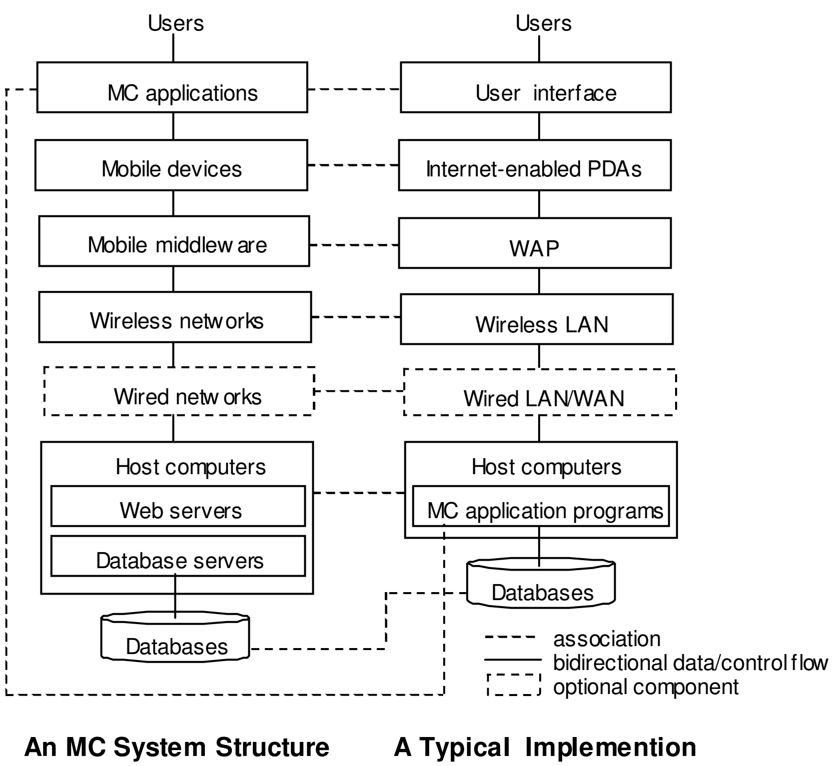

Figure 2: A mobile commerce system structure

Mobile Commerce Applications

The applications of electronic commerce are already widespread; mobile commerce applications not only cover these but also include new ones. For example, some tasks that are not feasible for electronic commerce, such as mobile inventory tracking and dispatching, are possible for mobile commerce. Table 1 lists some of the major mobile commerce applications (Sadeh, 2002).

Mobile Category	Major Applications	Clients
Commerce	Mobile transactions and payments	Businesses
Education	Mobile classrooms and labs	Schools and training centers
Enterprise resource planning	Resource management	All
Entertainment	Games/images/music/video downloads and on-line gaming	Entertainment industry
Health care	Accessing and updating patient records	Hospitals and nursing homes
Inventory tracking and dispatching	Product tracking and dispatching	Delivery services and transportation
Traffic	Global positioning, directions, and traffic advisories	Transportation and auto industries
Travel and ticketing	Travel management	Travel industry and ticket sales

Table 1: Major mobile commerce applications

Mobile Middleware

The term middleware refers to the software layer between the operating system and the distributed applications that interact via the networks. The primary mission of a middleware layer is to hide the underlying networked environment's complexity by insulating applications from explicit protocol handling disjoint memories, data replication, network faults, and parallelism (Geihs, 2001). Mobile middleware translates requests from mobile stations to a host computer and adapts content from the host to the mobile station (Saha, Jamtgaard, & Villasenor, 2001).

WAP and i-mode

According to an article in Eurotechnology.com (2000), 60 percent of the world's wireless Internet users use i-mode, 39 percent use WAP, and 1 percent use Palm middleware. Table 3 compares i-mode and WAP, along with details of each.

	WAP	i-mode
Developer	WAP Forum	NTT DoCoMo
Function	A protocol	A complete mobile Internet service
Host Language	WML (Wireless Markup Language)	CHTML (Compact HTML)
Major Technology	WAP Gateway	TCP/IP modifications
Key Features	Widely adopted and flexible	Highest number of users and easy to use

Table 2: Comparisons of two major kinds of mobile middleware

- `WAP (Wireless Application Protocol).` WAP (Open Mobile Alliance Ltd, n.d.) is an open, global specification that allows users with mobile stations to easily access and interact with information and services instantly. The most important technology applied by WAP is probably the WAP Gateway, which translates requests from the WAP protocol stack to the WWW stack, so they can be submitted to Web servers.
- `i-mode.` i-mode (NTT-DoCoMo, n.d.) is the full-color, always-on, and packet-switched Internet service for cellular phones offered by NTT DoCoMo. The i-mode network structure not only provides access to i-mode and i-mode-compatible contents through the Internet, but also provides access through a dedicated leased-line circuit for added security. Users are charged based on the volume of data transmitted, rather than the amount of time spent connected.

Wireless and Wired Networks

Network infrastructure provides essential voice and data communication capability for consumers and vendors in cyberspace. Wireless networking technologies are advancing at a tremendous pace and each represents a solution for a certain phase, such as 1G, 2G, and 3G, in a particular geographical area, such as the United States, Europe, or Japan. In this subsection, we will categorize them from the perspective of radio coverage into three networks:

- `Wireless Local Area Network:` Devices used in wireless local area network (WLAN) technologies are light-weight (easy to carry) and flexible in network configuration. In a one-hop WLAN environment, where an access point (AP) acting as a router or switch is a part of a wired network, mobile devices connect directly to the AP through radio channels. Data packets are relayed by the AP to the other end of a network connection. If no APs are available, mobile devices can form a wireless ad hoc network among themselves and exchange data packets or perform business transactions as necessary.

- `Wireless Metropolitan Area Network`: The most important technology in this category is the cellular wireless network. Cellular system users can conduct mobile commerce operations through their cellular phones. Under this scenario, a cellular phone connects directly to the closest base station, where communication is relayed to the service site through a radio access network (RAN) and other fixed networks.
- `Wireless Wide Area Network`: In large geographic areas lacking the infrastructure of wireless cellular networks, satellite systems can be utilized to provide wireless communication services. Communication through satellites is very similar to the scenario in cellular systems, apart from the differences in transmission distance and coverage range.

Wired networks is optional for a mobile commerce system. However, most computers (servers) usually reside on wired networks such as the Internet, so user requests are routed to these servers using transport and/or security mechanisms provided by wired networks.

Host Computers

A host computer processes, produces, and stores all the information for mobile commerce applications. This component is similar to that used in an electronic commerce system because the host computers are usually not aware of differences among the targets, browsers or microbrowsers they serve. It is the application programs that are responsible for apprehending their clients and responding to them accordingly. Most of the mobile commerce application programs reside in this component, except for some client-side programs such as cookies. This component contains three major components:

- `Web servers`: A Web server is a server-side application program that runs on a host computer and manages the Web pages stored on the Web site's database. There are many Web server software applications, including public domain software from NCSA and Apache, and commercial packages from Microsoft, Netscape, and others. Apache was developed in early 1995 based on code and ideas found in the most popular HTTP server of the time, NCSA httpd 1.3.
- `Database servers`: A database server manages database access functions, such as locating the actual record being requested or updating the data in databases. Some popular databases are Oracle10*g*, Microsoft Access, and IBM DB2. Other than the server-side database servers, a growing trend is to provide a mobile database or an embedded database to a handheld device with a wide range of data-processing functionality. Some leading embedded-databases are Progress Software databases, Sybase's Anywhere products, and Ardent Software's DataStage (Ortiz, 2000).
- `Application Programs and Support Software`: Web and database servers are mandatory for mobile commerce systems; application programs handle all server-side processing. However, to facilitate mobile commerce applications, some other support software is needed. For example, various programming languages, including Perl, Java, Visual Basic, C/C++, etc., and the CGI (Common

Gateway Interface) are necessary to transfer information between Web interfaces and CGI scripts are necessary.

Mobile Handheld Devices

Mobile users interact with mobile commerce applications by using small wireless Internet-enabled devices, which come with several aliases such as handhelds, palms, PDAs, pocket PCs, and smart phones. Mobile handheld devices are small general-purpose, programmable, battery-powered computers, but they are different from desktop PCs or notebooks due to the following special features:

- Limited network bandwidth,
- Small screen/body size, and
- Mobility.

Figure 3 shows a typical system structure for handheld devices, which includes the following six major components: i) a mobile operating system, ii) a mobile central processing unit, iii) a microbrowser, iv) input/output devices, v) a memory, and vi) batteries.

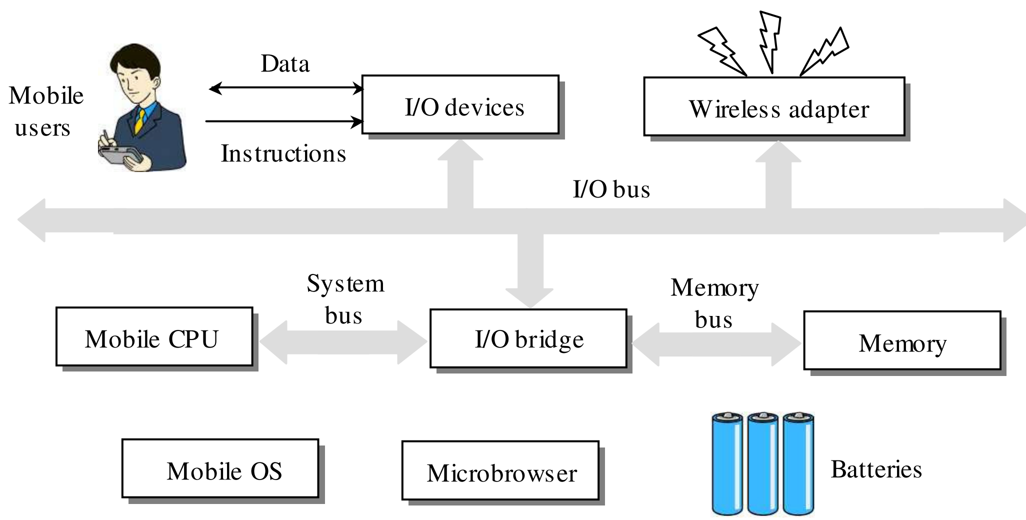

Figure 3: System structure of mobile handheld devices

A typical system structure for handheld devices includes the following six major components: i) a mobile operating system, ii) a mobile central processing unit, iii) a microbrowser, iv) input/output devices, v) a memory, and vi) batteries, which will be detailed in the following sub-sections.

Mobile Operating Systems

Simply adapting desktop operating systems for mobile handheld devices has proved to be a futile endeavor; an example of this effort is Microsoft Windows CE. A mobile operating system needs a new architecture and different features in order to provide adequate services for handheld devices. Several mobile operating systems are already available and each employs a different architecture and implementation. Figure 4 shows a generalized mobile operating system structure, which can be visualized as a six-layer stack.

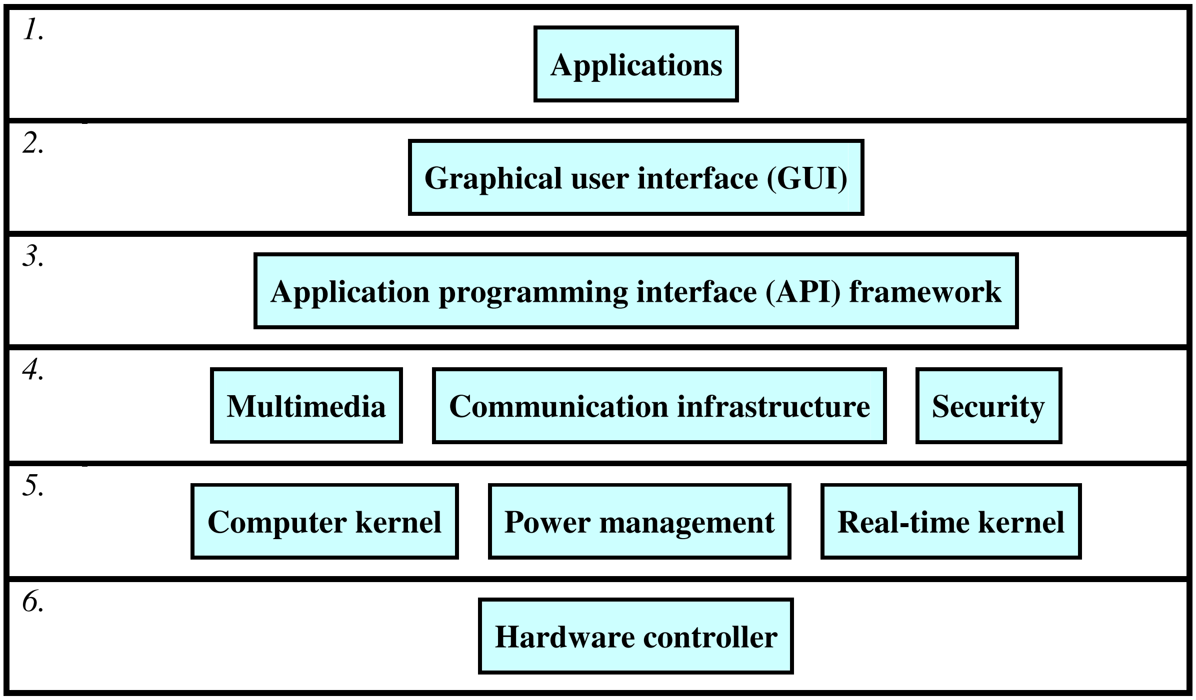

Figure 4: A generalized mobile operating system structure

Although a wide range of mobile handheld devices are available in the market, the operating systems, the hub of the devices, are dominated by just three major organizations. The following two lists show the operating systems used in the top three brands of smart cellular phones and PDAs in descending order of market share:

- Smart cellular phones: Microsoft Smartphone 2002, Palm OS 5, and Symbian OS 7. (Vaughan-Nichols, 2003)
- PDAs (Personal Digital Assistants): Palm OS 5, Microsoft Pocket PC 2002, and Symbian OS 7. (PCTechGuide, n.d.)

The market share is changing frequently and claims concerning the share vary enormously. It is almost impossible to predict which will be the ultimate winner in the battle of mobile operating systems.

Mobile Central Processing Units

The core hardware in mobile handheld devices is the mobile processors, and the performance and functionality of the devices are largely dependent on the capabilities of the processors. There used to be several brands available, but recently mobile processors designed by ARM Ltd. have begun to dominate the market. Handheld devices are becoming more sophisticated and efficient every day and mobile users are demanding more functionality from the devices. For example, In-Stat/MDR (2002) predicted that worldwide mobile Internet access device unit shipments would increase from approximately 430 million that year to approximately 760 million in 2006. To achieve this advanced functionality, in addition to the obvious feature, low cost, today's mobile processors must have the following features: i) high performance, ii) low power consumption, iii) multimedia capability, and iv) real-time capability.

Microbrowsers

Microbrowsers are a miniaturized version of desktop browsers such as Netscape Navigatorsand Microsoft Internet Explorers. They provide graphical user interfaces that enable mobile users to interact with mobile commerce applications. Due to the limited resources of handheld devices, microbrowsers differ from traditional desktop browsers in the following ways:

- smaller windows,
- smaller footprints, and
- fewer functions and multimedia features.

Figure 5 shows a typical microbrowser, a Mobile Browser version 7.0 from Openwave Systems, which includes the following features: compatibility with WAP or i-mode, multimedia support, color images and animation, and dual network stack, HTTP and WSP, support (Openwave Systems Inc., n.d.).

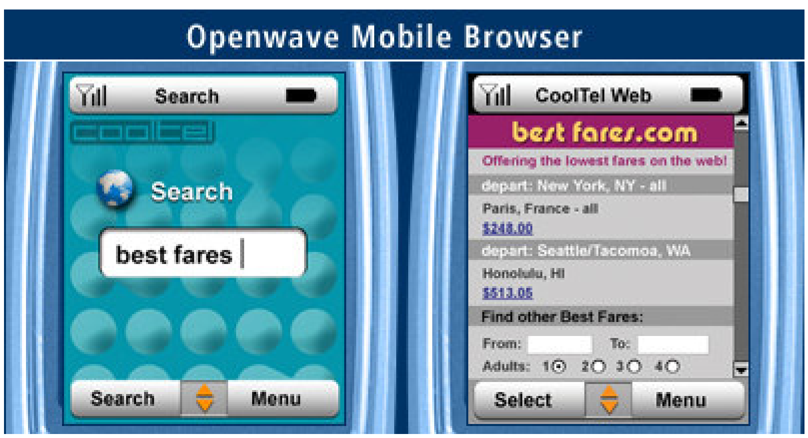

Figure 5: Openwave® Mobile Browser version 7

Input/Output Devices

Various I/O devices have been adopted by mobile handheld devices. The only major output device is the screen, whereas there are several popular input devices, including:

- `Keyboards`: There are two kinds of keyboards: built-in keyboards and external, plug-in keyboards. The problem with the former is that they are too small for touch-typing, whereas the latter suffers from inconvenience. Fabric keyboards that can be rolled up or folded around the handheld devices are being developed to relieve the problem of external keyboards.
- `Touch screens/writing areas with a stylus`: A touch screen is a display that is sensitive to human touch, allowing a user to interact with the applications by touching pictures or words on the screen, and a stylus is an input device used to write text or draw lines on a surface as input to a handheld device.

Memory

Desktop PCs or notebooks usually have between 64 to 256 Mbytes of memory available for users, whereas handheld devices typically have only 4 to 64 Mbytes. PDAs normally have more storage space than smart cellular phones. The former commonly have 16 Mbytes, and the latter may have a memory size as low as a few Kbytes. Three types of memory are usually employed by handheld devices: i) random access memory, ii) read-only memory, and iii) flash memory. It is expected that hard disks, which provide much more storage capacity, will be adopted by handheld devices in the near future. A comprehensive survey of storage options can be found in Scheible (2002).

Batteries

Rechargeable Lithium Ion batteries are the batteries most commonly used by handheld devices. The life of this kind of battery is short, generally only a few hours of operating time. Battery technology will not significantly improve unless and until manufacturers begin to switch to fuel cells, which is unlikely in the near future. A fuel cell operates like a battery, but unlike a battery, a fuel cell does not run down or require recharging and will continue to produce energy in the form of electricity and heat as long as fuel is supplied. Since the fuel cell relies on chemical energy rather than combustion, emissions would be much lower than emissions from the cleanest existing fuel combustion processes.

Handheld Computing

Handheld computing is the future of computer science because 650 million smart cellular phones, not including PDAs, will be used by 2006. Handheld computing is the programming for handheld devices and it includes two kinds: client- and server- side handheld programming.

Client-Side Handheld Programming

Client-side handheld programming is to develop embedded applications such as an address book on handheld devices. Some of the popular mobile environments/languages for this kind of programming are listed below:

- `BREW (Binary Runtime Environment for Wireless)`: It is an open-source on-line application development platform for wireless CDMA (Code Division Multiple Access) devices from Qualcomm Inc. (n.d.). Because BREW runs in between the application and the chip operating system software, the application can use the device's functionality without the developer needing to code to the system interface or even having to understand wireless applications.
- `J2ME (Java 2 Platform, Micro Edition)`: It is a technology developed by Sun Microsystem that allows programmers to use the Java programming language and related tools to develop programs for mobile wireless information devices such as cellular phones and personal digital assistants (Sun Microsystem, Inc., n.d.). J2ME consists of programming specifications and a special virtual machine, the K Virtual Machine, that allows a J2ME-encoded program to run in the mobile device. J2ME consists of two elements—configurations and profiles
- `PalmOS`: Palm OS (Palm Source, Inc., n.d.) runs on almost two out of every three mobile stations. Its popularity can be attributed to its many advantages, such as its long battery life, support for a wide variety of wireless standards, and the abundant software available. The plain design of the Palm OS has resulted in a long battery life, approximately twice that of its rivals. It supports many important wireless standards, including Bluetooth and 802.11b local wireless and GSM, Mobitex, and CDMA wide-area wireless networks.
- `Windows mobile`: Microsoft Windows CE, introduced in 1996, was not well received primarily because of battery-hungry hardware and limited functionality, possibly due to the way that Windows CE was adapted for mobile stations from other Microsoft 32-bit desktop operating systems. Microsoft later introduced Pocket PC (n.d.) and Smartphone (n.d.), which were designed with better service for mobile users in mind and offers far more computing power than Windows CE.
- `Symbian`: EPOC16 from Psion Software is a 16-bit version of an operating system that has been available for several years and is embedded in many mobile stations; EPOC32 is a 32-bit open operating system that supports preemptive multitasking. In mid-1998, Psion joined forces with Ericsson, Nokia, and Motorola to form a new joint venture called Symbian OS (2004), with the aim of establishing EPOC as the de facto operating system for mobile stations.

Server-Side Handheld Programming

Server-side handheld programming is to develop handheld applications such as mobile Web contents for mobile handheld devices. Many mobile applications such as instant messaging and emails require the supports of server-side programs. Mobile Web contents is the most common one of these applications. They are usually implemented by using a three-tier architecture: i) user interface, ii) functional module, and iii) database management system. Figure 6 shows a generalized system structure of database-driven mobile Web sites.

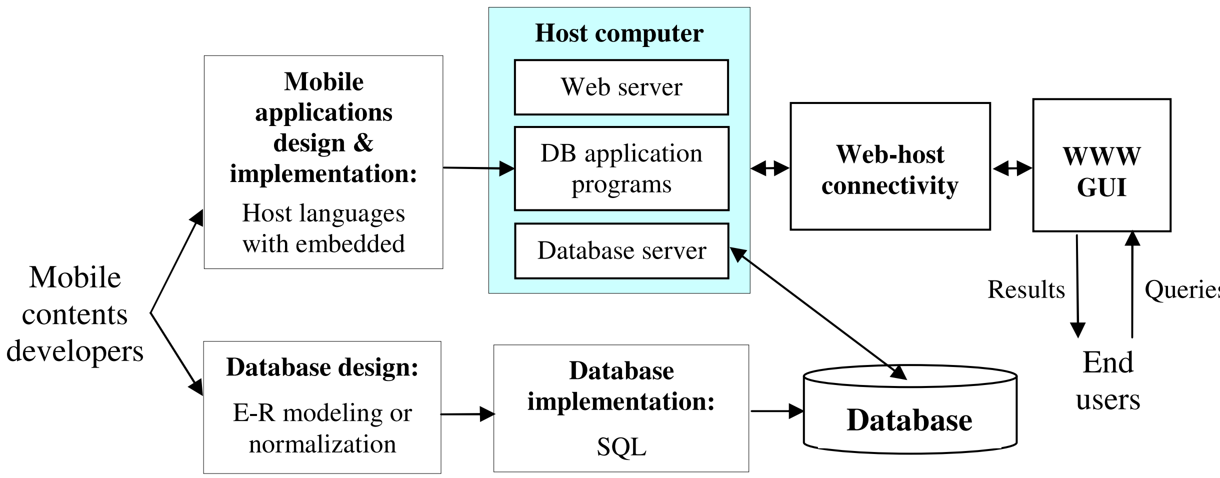

Figure 6: A generalized system structure of database-driven mobile Web sites

Mobile Commerce Payment Methods

Mobile commerce security is defined as the technological and managerial procedures applied to mobile commerce to provide security properties. Among the many issues that arise with mobile commerce security, mobile payment methods are the most important. They are the methods used to pay for goods or services with a mobile handheld device.

Requirements and Properties

The requirements and properties of secure mobile commerce information and systems are as follows (Lee, Kou, & Hu, 2004):

- `Confidentiality`: The information and systems must not be disclosed to unauthorized persons, processes, or devices.
- `Authentication`: Ensures parties that a transaction is not an impostor and is trusted.
- `Integrity`: The information and systems have not been altered or corrupted by outside parties.
- `Authorization`: Procedures must be provided to verify that a user can make the requested purchases.
- `Availability`: An authorized user must have timely, reliable access to information in order to perform mobile commerce transactions.
- `Non-repudiation`: Ensures a user that the transaction performed by him/her can not be denied.

The requirements for mobile commerce security are:

1. Confidentiality, authentication, integrity, authorization, availability, and non-repudiation must be rigorously enforced.

2. They should be interoperable for most systems.
3. They should be acceptable by the current or future systems with reduced cost.
4. No mobile commerce transactions are deferred/deterred because of the deployment.

The requirements for mobile payment methods are the same as the ones of mobile commerce security with an additional item:

5. They should allow content providers to provide affordable, easy-to-use, efficient and interoperable payment methods to users.

Macropayment and Micropayment Methods

They are usually two kinds of mobile commerce payment methods:

- `Macropayments`: This kind of payments is used by traditional electronic commerce and they usually involve amounts more than US $10.00. Payments by credit cards are the most common method for macropayments.
- `Micropayments`: These usually involve amounts less than US $10.00, which are too small to be economically processed by credit cards. The amounts are usually charged to users' phone bills.

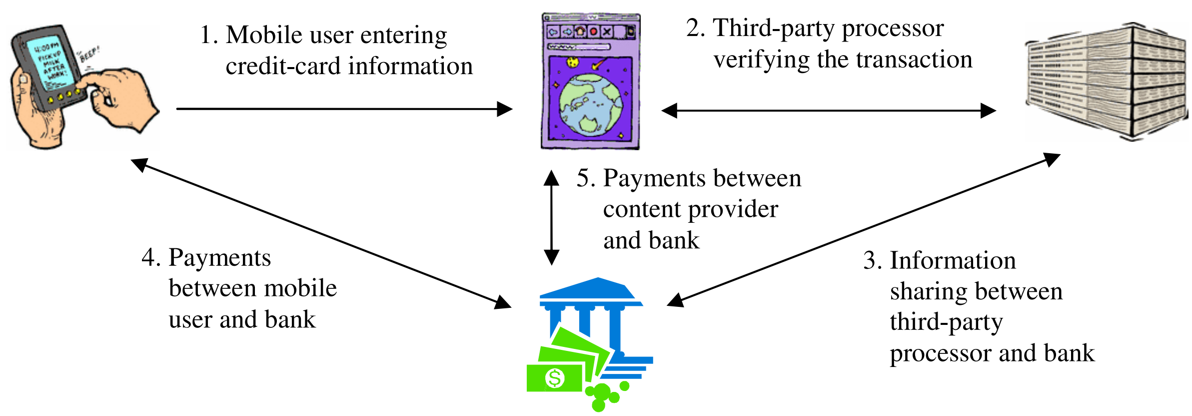

Figure 7: A typical macropayment scenario

A typical macropayment/micropayment scenario is as follows and they are illustrated in Figures 7 and 8, respectively:

1. A mobile user submits his/her credit-card or personal information to the mobile content via a handheld device.
2. A third-party processor verifies and authorizes the transaction.
3. The third-party processor routes verification and authorization requests to the card issuing bank or mobile carrier.
4. The user pays his/her monthly credit-card or phone bill.
5. The bank pays the mobile content provider or the mobile carrier pays the mobile content provider directly or through a bank after deducting transaction fees.

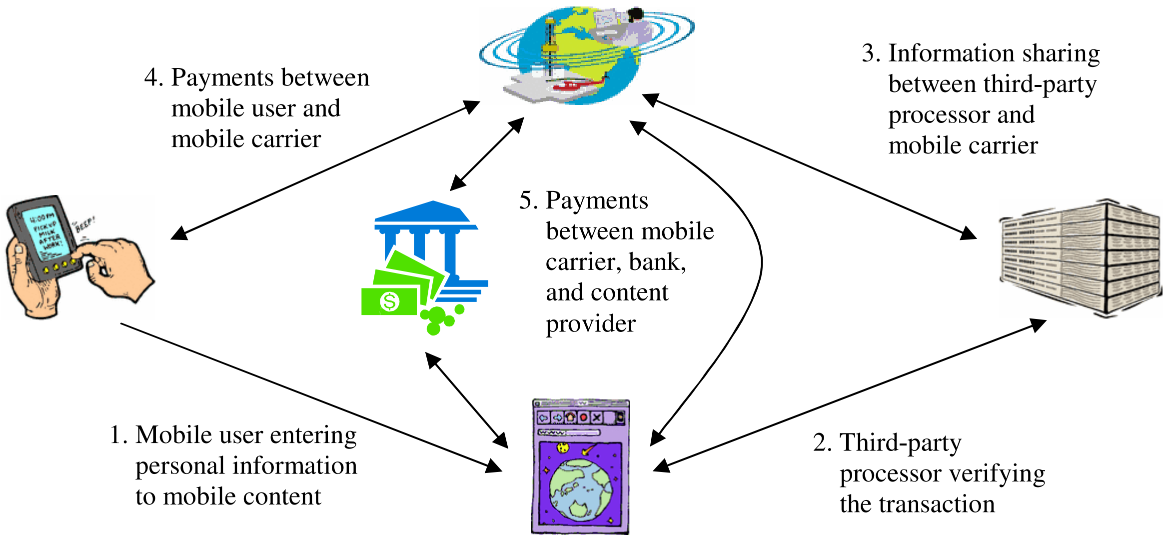

Figure 8: A typical micropayment scenario

Conclusions

This section gives conclusions of the four mobile commerce themes discussed in this article:

1. `Mobile commerce systems`: A mobile commerce system involves a range of disciplines and technologies. This level of complexity makes understanding and constructing a mobile commerce system an arduous task. To facilitate this process, this chapter divided a mobile commerce system into six components: i) mobile commerce applications, ii) mobile handheld devices, iii) mobile middleware, iv) wireless networks, v) wired networks, and vi) host computers.
2. `Mobile handheld devices`: Mobile handheld devices are one of the core components of mobile commerce systems, as they are needed for mobile users to directly interact with mobile commerce applications. Understanding the devices and knowing their functions and capabilities is vital for the success of mobile commerce applications. A handheld device relies on a wide range of disciplines and technologies for its success. To facilitate the understanding, this chapter broke down the functions of a handheld device into six major components: i) mobile operating systems, ii) mobile central processing units, iii) microbrowsers, iv) input/output devices, v) memory, and vi) batteries.
3. `Handheld computing`: Handheld computing is the programming for handheld devices and it includes two kinds:
    - `Client-side handheld programming`: It is to develop embedded applications such as an address book on handheld devices.
    - `Server-side handheld programming`: It is to develop handheld applications such as mobile Web contents for mobile handheld devices.
4. `Mobile payment methods`: Another important issue for mobile commerce is mobile security and payment. Mobile commerce systems can prosper only if

information can be securely exchanged among end systems (consumers and vendors). Security issues (including payment) include data reliability, integrity, confidentiality, and authentication and are usually an important part of implementation in wireless protocols/systems. Solutions are updated frequently, due to the lack of a comprehensive wireless security infrastructure and standard. A unified approach has not yet emerged. Among the many themes of mobile commerce security, mobile payment methods are probably the most important. These consist of the methods used to pay for goods or services with a mobile handheld device, such as a smart cellular phone or an Internet-enabled PDA. A typical mobile payment process includes: i) registration, ii) payment submission, iii) authentication and authorization by a content provider, and iv) confirmation.

REFERENCES

Eurotechnology. (2000). *Frequently Asked Questions about NTT-DoCoMo's i-mode.* Retrieved December 16, 2004 from http://www.eurotechnology.com/imode/faq.html

Geihs, K. (2001). Middleware challenges ahead. *IEEE Computer*, 34(6), 24-31.

Hu, W., Lee, C., & Yeh, J. (2003). Mobile commerce systems. In Shi, N. (Ed.), *Mobile Commerce Applications* (pp. 1-23). Idea Group, Inc.

InfoTech Trends. (2002). *Smarthphones Forecast to Reach 650 (mil) by 2006*. Retrieved December 12, 2004 from http://www.infotechtrends.com/smartphones_analysis.htm

In-Stat/MDR. (2002). *Demand Increasing for Mobile Internet Access Devices—Handsets Represent Primary Growth Driver*. Retrieved July 08, 2004 from http://www.instat.com/press.asp?ID=250&sku=IN020280MD

Juniper Research Ltd. (2004). *Mobile Commerce & Micropayment Strategies*. Retrieved September 03, 2004 from http://www.juniperresearch.com/reports/17_MCommerce/main.htm

Lee, C., Kou, W., & Hu, W. (2004). Mobile commerce security and payment methods. Hu, W., Lee, C., & Kou, W., editors, *Advances in Security and Payment Methods for Mobile Commerce* (pp. 1-18). Idea Group, Inc., 2004.

Microsoft Corp. (n.d.). *Pocket PC*. Retrieved June 25, 2004 from http://www.microsoft.com/windowsmobile/products/pocketpc/default.mspx

Microsoft Corp. (n.d.). *Smartphone*. Retrieved June 23, 2004 from http://www.microsoft.com/windowsmobile/products/smartphone/default.mspx

NTT-DoCoMo. (n.d.). *i-mode*. Retrieved November 28, 2004 from http://www.nttdocomo.com/

Open Mobile Alliance Ltd. (n.d.). *WAP (Wireless Application Protocol)*. Retrieved November 21, 2004 from http://www.wapforum.org/

Openwave Systems Inc. (n.d.). *Mobile Browser V7*. Retrieved July 15, 2004 from http://www.openwave.com/products/device_products/phone_tools/mobile_browser_7.html

Ortiz, S. Jr. (2000). Embedded databases come out of hiding. *IEEE Computer*, 33(3), 16-19.

Palm Source, Inc. (n.d.). *Palm OS*. Retrieved December 22, 2004 from http://www.palmsource.com/palmos/

PCTechGuide. (n.d.). *Mobile Computing*. Retrieved July 2, 2004 from http://www.pctechguide.com/25mobile.htm

Qualcomm, Inc. (n.d.). *BREW.* Retrieved February 02, 2005 from http://brew.qualcomm.com/brew/en/

Sadeh, N. (2002). *M-commerce: Technologies, Services, and Business Models* (pp. 177-179). New York: John Wiley & Sons.

Saha, S., Jamtgaard, M., & Villasenor, J. (2001). Bringing the wireless Internet to mobile devices. *IEEE Computer*, 34(6), 54-58.

Scheible, J. P. (2002). A survey of storage options. *IEEE Computer*, 35(12), 42-46.

Sun Microsystem, Inc. (n.d.). *Java 2 Platform, Micro Edition (J2ME).* Retrieved January 12, 2005 from http://java.sun.com/j2me/

Symbian Ltd. (n.d.). *Symbian*. Retrieved December 10, 2004 from http://www.symbian.com/

Varshney, U., Vetter, R. J., & Kalakota, R. (2000). Mobile commerce: A new frontier. *IEEE Computer*, 33(10), 32-38.

Vaughan-Nichols, S. J. (2003). OSs battle in the smart-phone market. *IEEE Computer*, 36(6), 10-12.