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Mobile Commerce: Framework, Applications and Networking Support

UPKAR VARSHNEY
Department of Computer Information Systems, Georgia State University, Atlanta, USA

RON VETTER
Department of Computer Science, University of North Carolina, Wilmington, USA

Abstract. Advances in e-commerce have resulted in significant progress towards strategies, requirements, and development of e-commerce applications. However, nearly all e-commerce applications envisioned and developed so far assume fixed or stationary users with wired infrastructure. We envision many new e-commerce applications that will be possible and significantly benefit from emerging wireless and mobile networks. To allow designers, developers, and researchers to strategize and create mobile commerce applications, we propose a four-level integrated framework for mobile commerce. Since there are potentially an unlimited number of mobile commerce applications, we attempt to identify several important classes of applications such as mobile financial applications, mobile inventory management, proactive service management, product location and search, and wireless re-engineering. We discuss how to successfully define, architect, and implement the necessary hardware/software infrastructure in support of mobile commerce. Also, to make mobile commerce applications a reality, we address networking requirements, discuss support from wireless carriers, and present some open research problems.

Keywords: mobile commerce, layered framework, mobile applications, middleware, wireless networking

1. Background and motivation

Electronic commerce has attracted significant attention in the last few years. This high profile attention has resulted in significant progress towards strategies, requirements, and development of e-commerce applications [8]. The growth forecast for both business-to-consumer (B2C) and business-to-business (B2B) aspects of e-commerce over the next few years is phenomenal by any standard. One point that should be made here is that nearly all e-commerce applications envisioned and developed so far assume fixed or stationary users with wired infrastructure, such as a browser on a PC connected to the Internet using phone lines or a Local Area Network (LAN). We envision many new e-commerce applications will be possible and significantly benefit from emerging wireless and mobile networks. We term these applications "wireless e-commerce" or "mobile commerce".

Wireless and mobile networks have experienced exponential growth in terms of capabilities of mobile devices, middleware development, standards and network implementation, and user acceptance [18]. Currently, more than 800 million cell phones and other mobile devices are in use worldwide, and out of those, more than 140 million users are in US alone (`www.wow-com.com`). The worldwide numbers are projected to rise to 1 billion soon, thereby exceeding the combined total of all computing devices several fold. In addition, countries with a lack of regular telecom infrastructure are likely to adopt wireless and mobile communications to serve both urban and rural areas. *According to estimates by GartnerGroup, in 2004, at least 40% of business-to-consumer e-commerce will be initiated from smart phones supported by WAP (Wireless Application Protocol). A study from the Wireless Data and Computing Service, a division of Strategy Analytics, reports that the mobile commerce market may rise to $200 billion by 2004. The report predicts that transactions via wireless devices will generate about $14 billion a year.*

In this article, we examine how new m-commerce applications can be designed and supported by wireless and mobile networks and mobile middleware. How well these applications become adopted by a business will depend on how fast these applications can be deployed, the cost–value ratio, acceptance of new technologies by users and businesses based on easy to use and uniform interfaces, and the building of trust necessary to conduct m-commerce transactions while on the move. We strongly believe that with the widespread deployment of wireless technologies, the next phase of electronic business growth will be in the area of wireless and mobile e-commerce. We are aware that consensus within business and industry of such future applications is still in its infancy. However, we are interested in examining those future applications and technologies that will form the next frontier of electronic commerce.

To help future applications and technologies handle m-commerce, we propose the framework as shown in figure 1. This framework will allow developers and providers to strategize and effectively implement mobile commerce applications. The framework defines multiple functional layers, simplifying the design and development, so different parties (vendors, providers, and designers, etc.) can focus on individual layers. By following this framework, a single entity is not forced to do everything to build m-commerce systems, rather, they can build on the functionalities provided by others. This

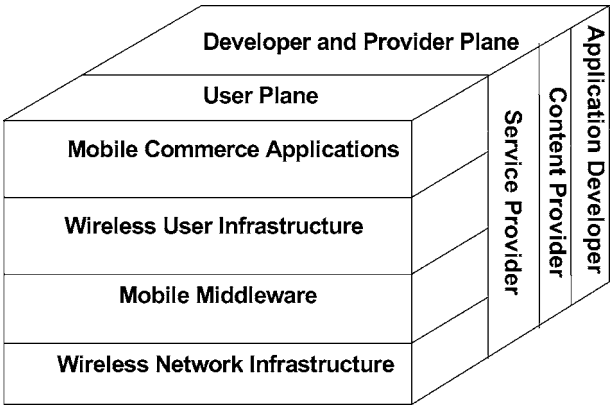

Figure 1. A framework for m-commerce.

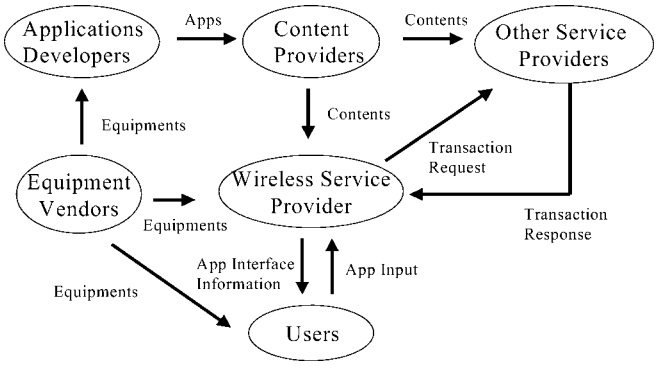

Figure 2. Mobile commerce life cycle.

will speed up the development of m-commerce applications as designers and developers can assume that certain functions will be provided by lower layers, and therefore, they need not focus on the capabilities and constraints of individual devices and networks.

This framework has four levels: m-commerce applications, user infrastructure, middleware, and network infrastructure. The framework shows that the design of new mobile commerce applications should take into consideration the general capabilities of user infrastructure (mobile devices), and not the individual devices. With its ability to hide details of underlying wireless and mobile networks from applications while at the same time providing a uniform and easy to use interface, mobile middleware clearly is an extremely important component in developing new mobile commerce applications. The network infrastructure also plays an important role in mobile commerce, as the user perceived service quality depends on available resources and capabilities of wireless and mobile networks.

An open framework will prevent the design and development of proprietary products and services that may be built in an ad hoc fashion. We believe that our framework will allow interoperability of m-commerce applications and products from different providers and vendors. This would help in the adoption of m-commerce on a global scale.

The framework also provides a developer and provider plane to address the different needs and roles of application developers, content providers, and service providers. Each one of these could build its products and services using the functionalities provided by others. A content provider can build its service using applications from multiple application developers. They can also aggregate content from other content providers and can supply the aggregated content to a network operator or service provider. Service providers can also act as content aggregators, but are unlikely to act as either an application or content provider due to their focus on the networking and service aspects of m-commerce. A service provider can also act as a clearing house for content and application providers in advertising and distributing their products to its customers. In any case, the developer and provider plane in our framework is likely to have multiple layers. Wireless carriers can play a very active and important role in the mobile commerce applications and services due to the fact that a mobile user is going through their networks to perform all mobile commerce transactions. Additionally, a mobile user is likely to prefer one common bill (bundled services) for voice, data, and mobile commerce services. However, there are many technical and non-technical hurdles (such as pricing for mobile commerce transactions) that need to be overcome before carriers can become major players in this emerging field. Many of these players and possible interactions are shown in figure 2.

We now turn to mobile commerce applications (section 2), followed by "what is needed to make it a reality" sections on user infrastructure and mobile middleware (section 3) and wireless network infrastructure (section 4). Then we discuss issues for wireless carriers and applications developers (section 5). We present several interesting research problems in mobile commerce (section 6). Finally, in section 7, we make some concluding remarks.

2. Emerging mobile commerce applications

Since there are potentially an unlimited number of mobile commerce applications, we attempt to identify several important classes of applications and provide examples within each class. Table 1 shows many such classes and example applications.

According to estimates from a report by Durlacher [9], more than half of the European mobile commerce market in the next few years may consist of financial, advertising and shopping services. In this paper, however, we attempt to cover a comprehensive range of mobile commerce applications under different classes with varying requirements in terms of devices, middleware, and networks.

In the following subsections, we discuss mobile financial applications, mobile advertising, mobile inventory management, proactive service management and other application classes in more detail. We provide some scenarios and include a discussion on the required infrastructure and related business issues.

2.1. Mobile financial applications (MFA)

Mobile financial applications are likely to be one of the most important components of m-commerce. These could involve

Table 1
Details and networking requirements of m-commerce applications.

Class of applications	Details	Examples
Mobile financial applications (B2C, B2B)	Applications where mobile device becomes a powerful financial medium.	Banking, brokerage, and payments for mobile users.
Mobile advertising (B2C)	Applications turning the wireless infrastructure and devices into a powerful marketing medium.	User specific and location sensitive advertisements.
Mobile inventory management (B2C, B2B)/ Product locating and shopping (B2C, B2B)	Applications attempting to reduce the amount of inventory needed by managing in-house and inventory-on-move. Applications helping to find the location of product and services that are needed.	Location tracking of goods, boxes, troops, and people. Finding the location of a new/used car of certain model, color and features.
Proactive service management (B2C, B2B)	Applications attempting to provide users information on services they will need in very-near-future.	Transmission of information related to aging (automobile) components to vendors.
Wireless re-engineering (B2C, B2B)	Applications that focus on improving the quality of business services using mobile devices and wireless infrastructure.	Instant claim-payments by insurance companies.
Mobile auction or reverse auction (B2C, B2B)	Applications allowing users to buy or sell certain items using multicast support of wireless infrastructure.	Airlines competing to buy a landing time slot during runway congestion (a proposed solution to air-traffic congestion problem).
Mobile entertainment services and games (B2C)	Applications providing the entertainment services to users on per event or subscription basis.	Video-on-demand, audio-on-demand, and interactive games.
Mobile office (B2C)	Applications providing the complete office environment to mobile users any where any time.	Working from traffic jams, airport, and conferences.
Mobile distance education (B2C)	Applications extending distance/virtual education support for mobile users everywhere.	Taking a class using streaming audio and video.
Wireless data center (B2C, B2B)	Applications supporting large amount of stored data to be made available to mobile users for making "intelligent" decisions.	Detailed information on one or more products can be downloaded by vendors.

Note: B2C: business-to-consumer, B2B: business-to-business.

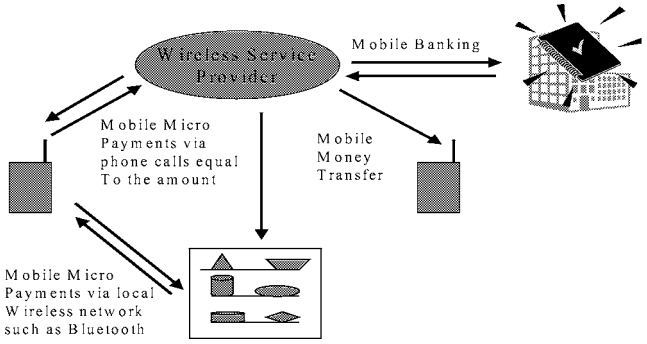

Figure 3. Several mobile financial services.

a variety of applications such as mobile banking and brokerage service, mobile money transfer, and mobile micro-payments as shown in figure 3. These services could turn a mobile device into a business tool, replacing bank, ATM, and credit cards by letting a user conduct financial transactions with mobile money. Certainly, more work is needed in providing transaction support in the applications and network infrastructure. Secure transactions are required before any of these applications are widely deployed.

One interesting mobile financial application is micro-payment involving small purchases such as vending and other items. A mobile device can communicate with a vending machine using a local wireless network to purchase desired items. Micro-payments can be implemented in a variety of ways. One way is that the user could make a call to a certain number where per-minute charges equal the cost of vending item. This approach has been used by SONERA, a Finish wireless provider, in their famous Coke (and now Pepsi) machine service [9]. In effect, it collects money from the users and credits it to the vending providers. Another way to perform micro-payments may be via using pre-paid numbers purchased from a service provider, bank, or credit-card company. To support financial transactions including micro-payments, a mobile service provider could act as a bank, acquire a bank, or compete with a bank. There are many questions that have to be addressed. One such question is the real cost of mobile micro-payments. Another question is how would a phone company or other payer make any profit on mobile micro-payments? There are several possible answers to this question. First, service providers could require pre-payments by users, thereby leading to some financial profits. Also, the cost of micro-payments may decrease with increased numbers of transactions or users. A provider can also charge a small amount for the payment service or can absorb the cost in order to provide this micro-payment as a competitive feature leading to increased number of customers and possibly higher revenues for wireless provider.

2.2. Mobile advertising

Mobile advertising is also a very important class of m-commerce applications. Using demographic information collected by wireless service providers and information on the current location of mobile users, very targeted advertising can be done. The advertising messages can be personalized based

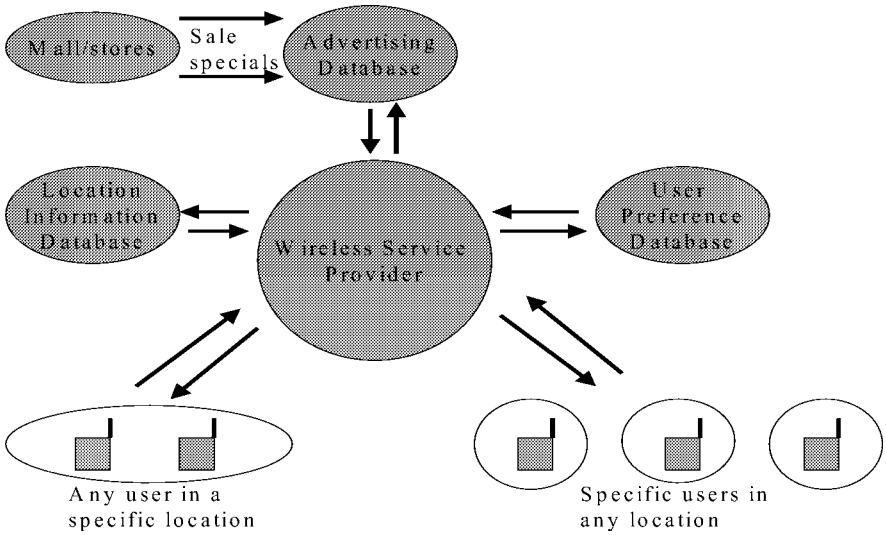

Figure 4. A possible scenario for mobile advertising and shopping.

on information provided by consulting the user at an earlier stage or by the history of users' purchasing habits. Advertisements sent to a user can also be location-sensitive and can inform a user about various on-going specials (shops, malls, and restaurants) in surrounding areas as shown in figure 4. This type of advertising can be performed using Short Messaging Service (SMS) or by using short paging messages to mobile users. The messages can be sent to all users located in a certain area (the geographic region can be identified by advertisers or even by users in advance), a user-specific message can be sent independent of the user's current location.

As more wireless bandwidth becomes available, content rich advertising involving audio, pictures and video clips can be produced for individual users with specific needs, interests, and inclinations. Also depending on interests and the personality type of individual mobile users, a network provider may consider using a "push" or "pull" method of mobile advertising based on a per-user basis or a class of users. Other interesting issues include the number of advertisements and the level and type of content that should be transmitted. These advertisements should be limited to avoid overwhelming the user with information and also to avoid the possibility of congestion of the wireless links. Wireless networks may consider such advertising lower priority traffic if network load crosses a certain threshold. Since these services need the current location information of a user, a third party may be needed to provide location services. However, this may require a sharing of revenues between the network service provider and location service provider. One very interesting question here is who owns the location information and in what ways such information can be shared between wireless service providers and others. Other issues include the amount of storage (user location and profiles) and real-time processing requirements to capture user information in a high variability environment. The dependability of infrastructure (database/networks) will also play an important role. The impact of a message transmission to an unintended receiver should also be considered. Many different ways to charge for advertising (size of message, number of customers, value of the items to be sold) can be used. It is also possible that direct advertising to users may be performed without much control from the wireless service providers.

2.3. Mobile inventory management (MIM)

This class of applications involves location tracking of goods, services, and possibly even people. The tracking of goods may help service providers in determining the time of delivery to customer, thus improving customer service and obtaining a competitive edge over other businesses. One very interesting application is "rolling inventory" – which may involve multiple trucks carrying a large amount of inventory while on the move. Whenever a store needs certain items/goods, it can locate a truck (preferably in nearby area) and just-in-time delivery of goods can be performed. The rolling inventory and delivery application can reduce the amount of inventory space and cost for both vendors and stores and may also reduce the time between when an order is placed and the goods are delivered (figure 5). Rolling inventory is a B2B m-commerce application while location tracking can be considered a B2C application. Using inexpensive embedded radio/microwave devices (chips), a wireless network can track goods and services. Since satellite signals may not work well inside a truck, a separate wireless LAN can be provided on-board for intra-truck communication and tracking. An interesting research problem is to determine an appropriate match for the amount of inventory carried by trucks in a geographical area with dynamically changing delivery demands. Also traffic in a city may affect the just-in-time delivery in nearby areas.

Another example of MIM is just-in-time delivery/movement of components in an assembly plant based on the rate of consumption of existing components (figure 6). A variety of new components can be moved a certain speed after receiving a wireless signal from the components reaching the assembly line or from a device on the assembly line itself. This will allow just-in-time delivery leading to a reduced inventory and

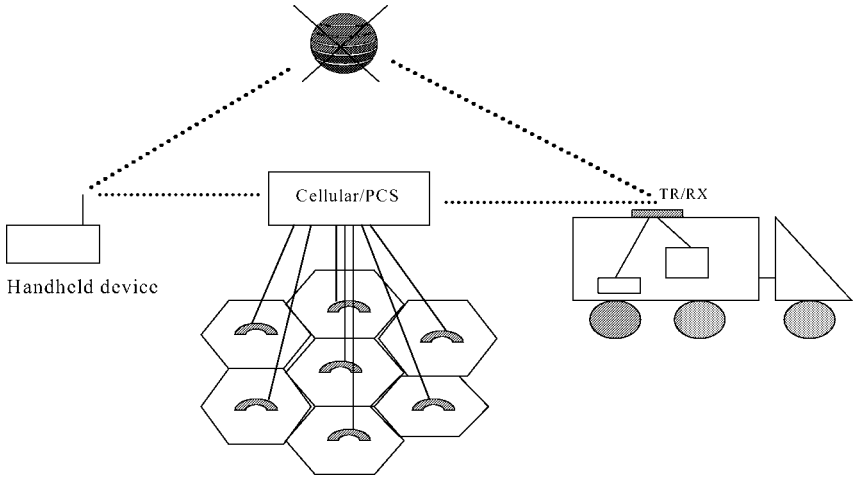

Figure 5. Location tracking of goods.

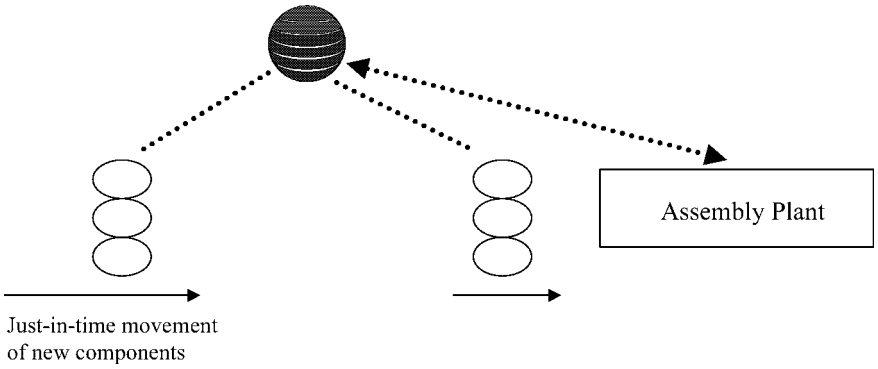

Figure 6. Location tracking and just-in-time movement of components.

assembling cost. If the new components are delayed for some reason, then signals can be sent to the assembly line for possible adjustment of the assembly speed to match the arrival time of new components. Such an application would reduce the inventory cost while increasing productivity by matching the speed of new component arrival to the rate of assembly.

For implementation purposes, location tracking of components can be broken into two components: indoor and outdoor. Indoor tracking can be performed by a chipset (Tx/Rx) and location information may be transmitted over a satellite or cellular/PCS system to the component supplier where such information is needed.

Implementation considerations in MIM include cost, reliability of wireless infrastructure, and the level of comfort with a new technology. Since these applications (especially the rolling inventory application) may present a paradigm shift in how inventories are managed today, an interesting research problem would be a study involving the cost and availability comparison of two inventory systems (regular and rolling) under dynamically changing demands. Potential MIM customers may include shipping companies, assembly plants (auto, manufacturing), airline/mass-transit industry, and supermarket chain stores. One positive factor is that many of these industries are already increasing their use of wireless technologies.

Possible wireless technologies that can be used with MIM include Global Positioning Satellite Systems (GPS) that are operated by the Department of Defense for location tracking (the accuracy level is based on the type of receiver and the type of user). Many luxury cars already have built-in GPS receivers that compute location information based on received signals from at least 4 (out of 24) GPS satellites. GPS may not work well for indoor environments, as they require line of sight transmission between devices and satellites. Another location tracking application is called E (enhanced) 911. E-911 allows operators to receive location information of cell phone users along with their emergency calls [5]. Since it is difficult for cellular/PCS systems to provide such location information, it is likely that a GPS chip will be installed on cell phones to help 911 operators to determine the location of mobile users. If such a chip is installed in cell/PCS phones, then location tracking of such users under normal circumstances will also be possible. Since, "people" can also be considered inventory resources, they could also be better managed.

2.4. Product location and search (PLS)

This class of applications includes locating an item in a particular area or location. This is somewhat different from the previous class of applications as here we are concerned with finding an item (or person) with certain specifications,

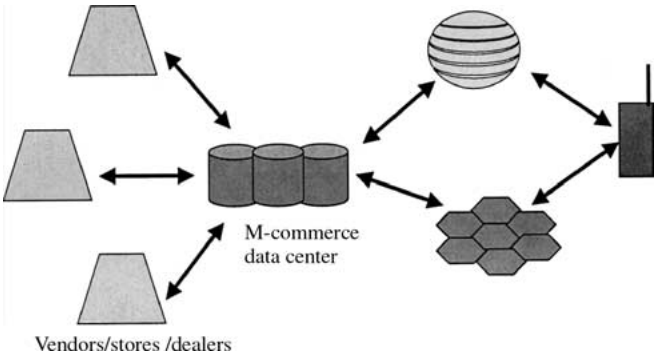

Figure 7. Product location and search.

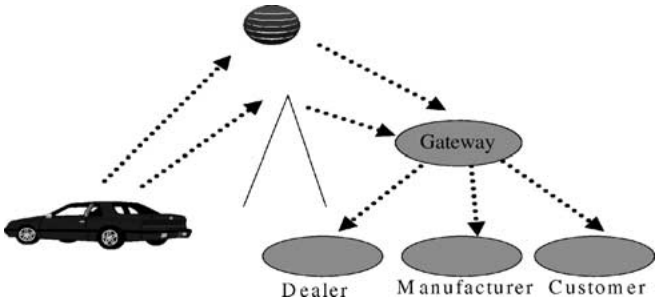

Figure 8. Information transmission on aging automobile components to dealers.

and whether it is available in a specified area or not. Potentially, there could be multiple places where such an item or an item of similar attributes (also specified by the user) are located. Currently, many people go to several stores to find an item (certain brand/size of TV, VCR or an automobile) and compare price and features. Using a mobile device (such as PalmPilot, Nokia Communicator or Net Phone) and a centralized/distributed database containing information on products, a user should be able to find the exact location of a store where a certain item is located. A list of locations and distance from a specified point can also be displayed. After that the user can buy on-line using a browser on his/her mobile device. In the case of multiple stores/vendors carrying an item desired by a user, they could compete to get the customer by real-time manipulation of prices or by offering instant discounts.

From a technological point of view, a mobile user can send a query message to a centralized location (shown in figure 7), which in turn can interface several different stores/dealers and decide if the item is available or not (and if yes, at what price). Alternatively, stores/vendors may connect their inventory record systems to this site. Since the inventory of different vendors may use different code names, a uniform product naming system (or existing code such as UPC) that allows for easy translation to standard web content will be required. If a database is not employed, the mobile user may need to query the stores directly. The amount of wireless traffic may become a problem if the total number of queries per item per user exceeds the capacity of the wireless infrastructure. To avoid high traffic levels, one may prefer to ship only product codes rather than entire data sets.

Two factors to consider are: (a) how the database will price its services to vendors/dealers and (b) the correctness of information (related to availability or price) from inventory to the database or website. We also believe that software agent technologies will prove to be invaluable as multiple agents can be deployed (cooperating & negotiating) to conduct various transactions at different places.

2.5. Proactive service management (PSM)

This class of applications is based on collecting pertinent information about current or near-future user needs and providing services to users proactively. One such application may involve collecting information about the aging components of an automobile (shown in figure 8). Many vendors including car dealers/repair shops can increase their business by acquiring information about aging components of an automobile. Information can be collected and used by car dealers for ordering components (thus reducing inventory costs). In a more elaborate scenario, several dealers/shops can compete for business by offering discounts or lower rates. Such information can also be collected and analyzed by manufactures to improve the design and manufacturing of future products. This service could even be offered as part of the warranty for new cars or could be purchased by current automobile owners. This would help reduce anxiety levels of owners and improve the general conditions of automobiles on the road leading to a reduced number of traffic jams, accidents, and even fatalities. From a technological point of view, automobiles can be equipped with smart sensors that keep track of how much wear and tear a car component has gone through. This information can then be transmitted using a radio/microwave/satellite system to a specified service center or other location. Some implications of such applications are privacy, security, reliability, and cost of deployment. However, we envision that car dealers, repair shops, automobile owners, and even law enforcement officers (from the public safety point of view) would be interested in such an application.

2.6. Wireless business re-engineering

Many insurance business situations involve going to customers premises, taking notes of a particular situation, going back to the office, and then taking suitable actions. This process takes a long time and is not very efficient. To improve this business practice, a wireless business re-engineering application can be used which allows on-the-spot claim adjustment. In such a scenario, a claim adjuster goes to the customer's place, takes pictures and stores them in his/her mobile device for uploading to the company's database. Next the adjuster downloads necessary information (customer's profile and coverage information) from insurance company's database. Using a small printer attached to the mobile device, he/she prints a claim check. This entire process is performed in minutes as opposed to days. The speed of this kind of service can significantly add to a company's bottom line and competitive advantage. Security and connectivity issues are

important as they may affect the perceived quality of service by a customer.

2.7. Mobile auction, entertainment and other services

With an increasingly mobile society, more and more people are on the move. While mobile, people may prefer to be involved in some business or entertainment activities. Many of these services can be offered to people through mobile devices and wireless networks. These include mobile auction/reverse auction, video-on-demand services, and other entertainment-oriented services. The technologies needed include mobile devices with capabilities to match desired applications, suitable mobile middleware, and wireless networks with high bandwidth (such as emerging LEO satellites or third generation wireless networks). Continued connectivity is a real important issue as it may affect the perceived quality of service for entertainment/information services. For auction/reverse auction, frequent disconnection may seriously affect the usefulness of this service unless it can be guaranteed that if users get disconnected, the state of auction will be maintained and disconnected users will not suffer any loss during periods of disconnection.

3. Wireless user infrastructure and middleware issues

To make the applications described previously a reality, several functional components are necessary as highlighted in figure 1. One important area includes mobile devices with sufficient power in terms of memory, display, and communications functionalities. The hand-held device is really the entry point for most mobile commerce systems. The capabilities or limitations of these devices will impact the type and frequency of which mobile commerce applications will be used.

The devices available today [10] can be characterized as either communication-centric or computing-centric, however, in near future such differences may cease to exist as these devices converge to a single intelligent mobile device. Many hand-held devices now support a variety of network interfaces and access ranges, from short-range Bluetooth, to wireless LAN, to wireless WAN access. Location support, video streaming, barcode readers and other features are also being implemented in many of the devices.

Although it is possible to do some simple mobile commerce transactions using a simple hand-held device, many sophisticated mobile commerce applications require other capabilities. For example,

- dynamic, adaptable and smart user interface that learns from and with user (adaptable to different applications, easy to use, more visual and natural with appropriate form factor, and multi-lingual support),
- ability to accept user input in many forms including voice,
- ability to display rich and usable contents,
- location awareness and ability to track users, products and devices,
- multi network interfaces for increased and reliable wireless access,
- basic security features to handle malicious code, support for authenticating user, servers, and applications,
- ability to work with and adapt to mobile commerce applications with diverse requirements (such as the types of transaction both push and pull, transaction rates, duration, and multicast),
- possible support for context awareness,
- ability to discover and download upgraded applications and software proactively,
- an operating system that can manage resources to support many of these functions.

Some of these features are already available in hand-held devices. For example, iMode devices using I-appli can use software applications downloaded from sites by employing an automatic transmission mode. These devices are also capable of receiving area specific (location-dependent) information and currently support a bi-lingual (Japanese and English) interface (`www.nttdocomo.com`).

Many of these capabilities will increase the size and weight significantly, and thus, potentially affect the usability and portability of these devices. Additional effort is required to better understand the engineering tradeoffs between device capability and device usability.

The above issues are likely to affect the widespread use of mobile commerce applications. If user interfaces are hard to deal with, a user may not see significant value in mobile commerce applications. If out of context information is pushed to users, many of them may not find the mobile commerce experience to be very pleasant. If location-based services are not usable in certain locations, it may affect whether users adopt such applications. Clearly, privacy and security issues are also very important, as most users do not want private information to be released to other parties. Finally, because of the financial value of many mobile commerce applications, security at a device level is also important. This issue becomes even more important when a user is moving between multiple heterogeneous wireless and mobile networks. It is possible that some of these capabilities may be realized with the help of servers and middleware, but it should be noted that the amount of traffic between servers and devices might be significant.

As the number of functions available on a mobile device increase along with improved storage and processing capabilities, an operating system that can manage the allocation of internal resources to multiple applications and processes is required. A general purpose OS is not suitable for such small hand-held devices due to real-time requirements, limited processing power, memory, and screen size, and due to the type of application that may be running. So an OS with a small footprint and reduced storage capacity is needed. Many emerging mobile OS are compared elsewhere [2]. These operating systems have attracted developers building applications, which can run on handheld and other smaller devices. For

example, Microsoft has released pocket versions of its popular software such as Outlook, Excel, and Word and 3Com is working with applications developers to create new and more sophisticated applications for its PalmPilot. Since UNIX has been used widely on the Internet and in other computing environments, the use of a "stripped down" version of UNIX with a smaller footprint may become important for mobile applications.

Hand-held devices are likely to affect the interoperability, implementability, and scalability of mobile commerce applications as well. Interoperability relates to the smooth interworking of m-commerce applications. A universal framework should be followed to allow for interoperability of products from different providers. Implementability relates to the difficulties in building m-commerce applications. As the resource requirements of some applications may exceed the resources provided in the devices and networks, resource constraints need to be carefully considered. Scalability is also an issue. As the number of users, transactions, and devices increase the system must be able to accommodate the corresponding increase in load and competition for computing and communication resources.

3.1. Wireless and mobile middleware for mobile commerce

Traditionally, middleware unites different applications, tools, networks and technologies; allowing user access via a common interface. Mobile middleware can be defined as an enabling layer of software that is used by applications developers to connect their m-commerce applications with different networks and operating systems without introducing mobility awareness in the applications (figure 9).

The use of middleware allows applications to run with better response times and much greater reliability. Typically, network-enabled middleware uses optimization techniques, such as header compression, delayed acknowledgements, and concatenation of several smaller packets into one, to reduce the amount of traffic on the wireless networks. Some middlewares also support intelligent restarts where after a lost connection, information transfer starts at the break point and not all over again. An example of mobile middleware is ExpressQ from Nettech (`www.nettechRF.com`). It stores messages when mobile user is out of the network range and forwards them when mobile user comes within range the next time.

In mobile commerce environment, middleware becomes very important due to the potential values of many m-commerce transactions, limited capabilities of devices, and diverse set of requirements presented by various m-commerce applications. The middleware may also affect the amount of processing required at a device, the amount of information that has to be transmitted over wireless networks and the level of security for mobile commerce transactions. Also the middleware should have transaction-orientedness as needed for many mobile commerce applications. Also, as many applications may require that certain information be sent to user periodically or when a certain event has occurred. For these applications, a middleware must also support "push" type of information transfer to devices. As middleware may be required to support wireless Internet or adapting standard web contents to wireless users. A possible alternative is the Wireless Application Protocol (`www.wapforum.com`). WAP is designed for interoperability of different wireless networks, devices, and applications using a common set of applications and protocols. Using the WAP architecture, wireless middleware can be deployed as a client on a mobile terminal and as a server on the gateway or intermediate server (figure 10). WAP uses a micro browser as the client software and supports text, graphics, and standard web content. It will support streaming media such as video in the near future. In WAP, a gateway acts as a proxy server to a mobile client and translates requests from WAP protocol stacks to protocol stacks employed by the information server on the other side. Encoders translate the content coming from the server into compact formats to reduce the amount of data that must be transmitted over the wireless network. This infrastructure ensures that a mobile user can access a wide variety of content and applications and also allows application developers to build m-commerce applications (using proven and existing technologies) that can run on a large base of mobile terminals.

WAP 2.0, released recently, adds the support for "push" operation, allowing information to be sent without an explicit request to users. It also supports a variety of user interfaces and standard Internet protocols such as TCP/IP and HTTP. It uses WML2 based on XHTML, and thus, it does not require proxy or gateway as shown in figure 10. However, to implement the push operation, and to get improved services and optimized communications, a WAP proxy is still neces-

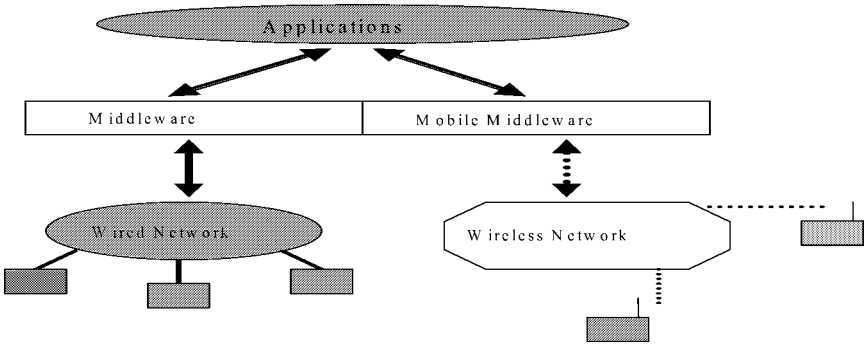

Figure 9. Mobile middleware for application and content adaptation.

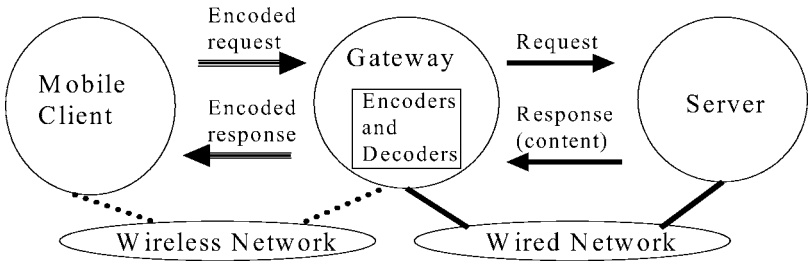

Figure 10. WAP architecture.

sary. So, the above architecture shown in figure 10 remains valid for mobile commerce transactions.

To allow for web content to be accessible from everywhere, from PCs to TVs to Palm devices to cellular phones, the World Wide Web Consortium (W3C) had developed several open recommendations. These recommendations include the Extensible Markup Language (XML) for richer semantic information, improved Cascading Style Sheets (CSS) and Extensible Style Sheet Language (XSL) to further separate content from presentation, and a Document Object Model (DOM) which defines a language-independent application programming interface that applications can use to access and modify the structure, content, and style of HTML and XML documents. Many of these specifications have been included in WAP 2.0 including the support for inline and external type style sheets, commonly supported by most Internet browsers. Additionally, it supports long-lived sessions that may be very useful of mobile commerce applications of longer duration. The suspend–resume function may also be used for applications that may not need to move continuous information throughout the session. WAP 2.0 is also likely to be used in iMode services which so far has been using a modified and compact HTML to provide content to its wireless users.

4. Wireless networking infrastructure

In addition to mobile devices and middleware, networking support from wireless networks is crucial in realizing mobile commerce applications. There have been significant advances in wireless and mobile networks in the last few years in terms of protocols, standards, technologies, Quality-of-Service, and user acceptance [13]. In this section, we present and discuss the wireless networking requirements for various mobile commerce applications.

Mobile financial applications require locating a device, user, or building in relation to the current location of a user for making financial transactions. Due to the potential value of such transactions, very high level of wireless infrastructure dependability may be required. To allow a user to make these transactions from anywhere anytime, the ability to roam across multiple wireless networks may be very useful. Similarly, many other m-commerce applications such as mobile advertising, mobile inventory management, product locating, and proactive service management may require location management support. Mobile advertising needs asymmetric multicast to send messages to certain users in certain locations, but such multicast does not have to be real-time. Also for mobile advertising, network dependability requirements may not be stringent as loss of some messages could be tolerated. For many m-commerce applications such as mobile entertainment and distance education services, the required Quality-of-Service in terms of bandwidth and delay may be significant. The specific requirements of each of the m-commerce applications are shown in table 2.

From the above discussion, it appears that mobile commerce applications would present five general networking requirements: location management, multicast support, network dependability, support for Quality-of-Service, and the ability to roam across multiple wireless networks. To help network designers and developers, we translate these five networking requirements into more specific attributes as shown in table 3.

Location management has attracted significant attention in wireless community. One such reason is an FCC ruling requiring cellular and PCS carriers to provide 911 centers with precise location information (say, within 100 meters) of callers (also termed E911) by 2001–2002 [5].

Possible solutions include the use of global positioning satellite systems, use of several base stations for triangulation for extracting the location information, and mixed handset-network protocols for location determination [4]. Such location support is crucial for many mobile commerce applications. Fortunately, location management has seen substantial work in the form of location-based services [6], specific location management issues [14,15], location-aware services [11], and location- and context-aware applications [1], location architectures for B2B mobile commerce environment [3]. Other networking requirements: support for multicast, wireless dependability, and roaming support across multiple wireless networks have not been addressed by researchers in sufficient detail. Some early work on these issues can be found in [12,16–18].

After identifying various networking requirements and specific attributes, we now present a global and comprehensive wireless infrastructure for mobile commerce applications as shown in figure 11. A mobile user can use mobile commerce applications in several different ways. It could be through infrastructure-based wireless networks such as cellular, PCS, and GSM networks, or could be through an ad hoc wireless network that can connect to the IP-based networks via satellites. A user could connect directly via satellite-based systems. In this scenario, a mobile user can roam across mul-

Table 2
Specific networking requirements of m-commerce applications.

Class of applications	Wireless networking requirements	Comments
Mobile financial applications (B2C, B2B)	Location management Network dependability Roaming across multiple networks	Secured unicast communications may be required.
Mobile advertising (B2C)	Location management Multicast Roaming across multiple networks	Asymmetric non-real time multicast may be required.
Mobile inventory management (B2C, B2B)/ Product locating and shopping (B2C, B2B)	Location management Network dependability Multicast Roaming across multiple networks	Multicast preferred but series of unicast communication may be tolerated.
Proactive service management (B2C, B2B)	Location management Network reliability Roaming across multiple networks	Unicast or asymmetric non-real time multicast.
Mobile office (B2C)/ Wireless re-engineering (B2C, B2B)	Roaming across multiple networks Network reliability Location management	Secured unicast communications may be required
Mobile auction or reverse auction (B2C, B2B)	Multicast Location management Network reliability Roaming across multiple networks	Real-time multicast with significant user input and coordination required.
Mobile entertainment services and games (B2C)/ Mobile distance education (B2C)	QoS Multicast Roaming across multiple networks Location management	Asymmetric real-time multicast required with some user input.
Wireless data center (B2C, B2B)	QoS Location management Roaming across multiple networks	Bandwidth requirements may be significant.

Note: B2C: business-to-consumer, B2B: business-to-business.

Table 3
Wireless infrastructure requirements for mobile commerce.

Networking requirements	Specific attributes
Location management	1. Location tracking for determining the location of an object 2. Location accuracy and response time 3. Frequency of location tracking 4. Horizontal and vertical location tracking
Multicast support	1. Support for multicast in infrastructure wireless networks 2. Support for multicast in ad hoc wireless networks (much more difficult due to dynamic topology and other factors) 3. Group connectivity under mobility/failure 4. Synchronization/atomicity of transactions from multiple users
Network dependability	1. Impact and frequency of component failure 2. Fault-tolerant design 3. User access to multiple networks 4. Levels of network availability
Quality-of-Service	1. Bandwidth requirements 2. Delay and delay variation 3. Tolerable loss characteristics
Roaming across multiple networks	1. Handoff among multiple wireless networks 2. Keeping track of users across networks

tiple different wireless networks and a dynamic QoS negotiation may be required due to vastly different resources and users of these networks. This infrastructure also supports efficient location management, multicast, and provides fault-tolerance to increase levels dependability. Since a user may access multiple networks that may provide different levels of horizontal and vertical location accuracy, response time and transaction rate, it may be possible to select one wireless network for mobile commerce transaction by translating location requirements of applications to specific attributes. Loss of access to one or more wireless networks due to various failures could be overcome by switching to the remaining wireless network and still support most of the requirements of m-commerce applications.

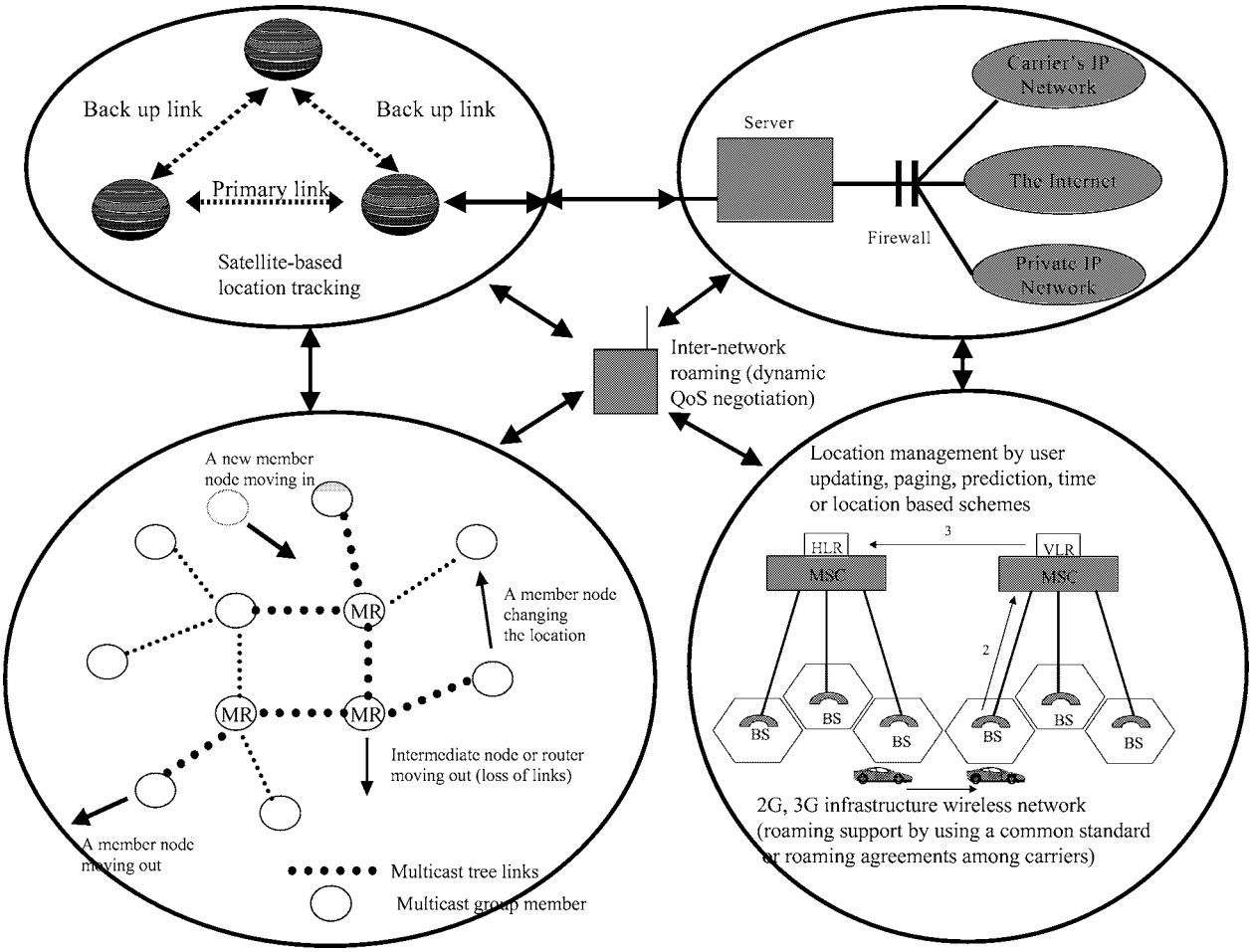

Figure 11. A global comprehensive wireless infrastructure for mobile commerce.

5. M-commerce issues for carriers and developers

Wireless carriers can play a very active and important role in the mobile commerce applications and services due to the fact that a mobile user is going through their networks to perform all mobile commerce transactions. Additionally, a mobile user is likely to prefer one common bill (bundled services) for voice, data, and mobile commerce services. Service providers can also act as content aggregators, but are unlikely to act as either an application or content provider due to their focus on the networking and service aspects of m-commerce. A service provider can also act as a clearing house for content and application providers in advertising and distributing their products to its customers. However, there are many technical and non-technical hurdles (such as pricing for mobile commerce transactions) that need to be overcome before carriers can become major players in this emerging field.

Currently there are many different standards for accessing wireless networks. The standards used in cellular and PCS systems in US and Europe differ considerably. This directly affects the interoperability and global roaming of mobile users. This could be a major hurdle for some mobile commerce transactions involving multiple wireless networks. Differences in standards along with other interests have also led to delays in the deployment of next (third) generation of wireless/mobile systems [7]. However, once 3G networks are deployed worldwide, global roaming should become a reality. For the time being, mobile users can use multi-function and multi-band phones to roam across several continents (however, roaming charges do apply!). We should note here that worldwide migration to 3G is still dependent on operators perception of market needs, possible incentives to carriers and operators, recovery on investment made in the existing first and second generation wireless systems, and perceived threats to monopoly wireless carriers in many countries.

Besides the above technological issues, wireless carriers are also likely to face challenges involving how to price mobile commerce services, and because several carriers are likely to be involved in completing a mobile commerce transaction, another issue is how to divide revenues among multiple carriers. There are many important issues that need to be addressed before mobile commerce applications can be widely deployed. These include the development of new business models for charging wireless customers and for revenue division among providers, maturity of application software, middleware support, vendor support, and user trust necessary

Table 4
Possible solutions to pricing of mobile commerce services and division of revenues.

Issue	Possible solutions	Comments
Pricing of mobile commerce services	Flat rate pricing	Simple to implement Unfair to some customers
	Based on the connection time or session duration	Simple to implement Unfair to some customers Delays in fixed networks and web servers will affect the user's cost
	Based on the number of transactions attempted	Difficult to implement Web servers and wireless links can have major affect
	Based on the number of transactions completed	Difficult to implement Desirable for most users
	Based on the number of users involved in a transaction (group multicast pricing)	Simple to implement
	Based on the number of networks/ISP/carriers involved in a transactions	Simple to implement A version is currently used for roaming charges
	Based on the number of packets transmitted/amount of traffic	Need to count packets (even when they multiply over certain links)
	Based on the QoS received	Difficult as link quality and other factors have to be measured and monitored throughout the session Very fair pricing
	Based on the combination of session duration, participants, number of transactions, QoS, and traffic	More accurate pricing More complex to implement
	Time sensitive pricing	Simple to implement
Division of revenues among multiple service providers	Ratio of distances traveled by packets in individual network	Difficult to implement
	Using number of packets and number of copies made in an individual network	Needs to count packets (even when they multiply over certain links)
	Using number of switches used (or processing power)	Requires counting the number of switches for every packet
	Using number of links involved in individual networks	Requires counting the number of links for every packet
	Using number of customers of a network involved in the session	Easy to implement
	Using a combination of above factors	More accurate but difficult to implement for revenue sharing

for conducting mobile transactions. Table 4 presents several solutions to pricing and revenue division in mobile commerce applications and services.

Now we look at issues important for developers of m-commerce applications. These issues are presented in table 5. One major issue is how to achieve application independence from the various device and wireless access technologies. However, designing for application independence is likely to increase the actual program code as these applications can no longer take advantage of certain inherent capabilities in specific devices or networks. While developing such programs, only certain basic functionalities about these technologies can be assumed. All of this increases the application usability across networks and devices, but the implementation is not likely to be the most efficient.

Also as users may go through phases of intermittent connectivity or frequent disconnectivity, any impact of these events on mobile commerce transactions should be carefully investigated. Due to the potential values of many mobile commerce applications, atomic transactions may be necessary. It is possible that mobile middleware may provide most of such functions and thus reducing the amount of work needed to support atomic transactions by applications.

Table 5
Some important issues for application developers.

Issues	Comments
Network processing and storage requirements	Bandwidth and delay requirements (real-time vs non-real time applications) Mobile device capabilities Disconnected operation Multicasting for group communications Symmetric vs asymmetric processing and storage
Application development	Use of any existing Software Development Kit (SDK) Simulation of environment where application will be used Maximum number of simultaneous users The size of application code Support for secure transactions Support for fixed users
Compatibility and interoperability	Independence from the underlying wireless access technologies Independence from the device functionalities Interoperability with IP Compatibility with Wireless Application Protocol (WAP)
Desirable features	Support for intermittent connectivity Adaptive to the user and network environment Support for "atomic" transactions Easy upgradability User specified features invocation

Table 6
Several interesting research problems.

	Research problem
1	What are some inherent differences in e-commerce and m-commerce? Do these differences require some minor modifications in the existing e-commerce approaches or do we need to start with completely new approaches? How mobility affects procurement, supply chain, B2C, B2B, web site effectiveness, and value added services?
2	What are some new applications that could become possible due to the use of mobile devices and wireless networks? How the support for these applications affects existing e-commerce implementation?
3	How the differences among wireless standards would affect the offering and acceptance of m-commerce applications? What are the roles of cultural and social factors in m-commerce adoption?
4	What is the current level of understanding of wireless networks, devices, middleware, and applications among IS managers, systems architects, developers, and academic researchers? What are some ways to enhance such understanding in a shortest possible time?
5	What are the major factors that can affect the adoption of mobile commerce research? Can we derive these from adoption factors of e-commerce or from wireless networks?
6	What is the current level of trust in mobile commerce transactions and how can it be increased?
7	What additional security problems are introduced by mobility of users and wireless links for mobile commerce applications? Are existing network security mechanisms sufficient for mobile commerce applications?
8	How pricing models for mobile commerce would be different from e-commerce? Can same models be used in Europe, America and other continents/countries?
9	What are the ways to design user interface for mobile commerce applications that could satisfy several conflicting requirements?
10	What strategies carriers, vendors, providers, and managers in the development of m-commerce applications and services should use?

6. Interesting research issues in mobile commerce

There are many interesting research problems in mobile commerce. Some of these are unique due to the limitations of mobile devices and wireless networks and some are similar to research problems that are currently being addressed by e-commerce researchers and developers. The problems that are unique to m-commerce are

- novel applications and services made possible due to the wireless networks and mobile devices,
- security and privacy problems that are unique to wireless networks and mobile devices,
- middleware issues that are unique due to device, network, and protocol limitations,
- role of different wireless networking standards,
- adoption factors of mobile devices that are significantly different in different parts of the world,
- context and location-awareness is unique to mobile commerce as many of the applications are sensitive to the context and the location of a user.

The research problems that can be addressed by the existing e-commerce research with some modifications and extensions are

- strategy of new service offering,
- role of m-commerce providers,
- trust building,
- adoption of new services,
- pricing models and sensitivity analysis.

These problems are presented in table 6. We are pursuing some of these research problems and work will be presented in future articles. It is our hope that current and new researchers would find these problems to be of considerable research interest and our work will fuel advances in mobile commerce applications, adoption, networking, pricing, and other emerging areas.

7. Conclusions and further research

Mobile commerce is an interesting and challenging area of research and development. It presents many issues that cover many disciplines and may best be addressed by an active participation of computer and telecommunications experts, social scientists, economists, and business strategists. In this paper, we have looked into several issues that we consider important for mobile commerce realization. We introduced several new classes of applications, reviewed networking requirements, and discussed application development support. Since the area of mobile commerce is very new and still emerging, we have added several interesting research problems that are either currently being addressed or should be addressed by the research and development community. We also believe that user trust will play a crucial role in acceptance and widespread deployment of mobile commerce applications.

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Upkar Varshney is an Assistant Professor in the Department of Computer Information Systems at Georgia State University, Atlanta. He received a Bachelor of Engineering in electrical engineering with Honors from University of Roorkee, MS in computer science and Ph.D. in telecommunications & networking, from the University of Missouri-Kansas City in 1988, 1992, and 1995, respectively. Before joining GSU, he worked as a Research Associate at the Center for Telecomputing Research (funded by Sprint, NorTel, BNR, MCI and State of Missouri) during 1992–1994 and taught at Washburn University, Kansas, during 1994–1998. Prof. Varshney has written over 50 papers in mobile commerce, mobile and wireless networking, wireless dependability, and high-speed networking. He has presented some very well received tutorials and workshops at major international conferences including ACM MobiCom, IEEE WCNC, IFIP HPN, and HICSS. He is also a respected speaker in wireless and mobile networking and applications. He has delivered over 50 invited speeches, including several keynotes at major conferences and workshops. He is actively involved with International Executive education programs at GSU. In October 2000, Prof. Varshney was awarded the prestigious Myron T. Greene Outstanding Teaching Award. He is on the editorial board of IEEE Computer. He has also served on the program committees of IEEE WCNC, IEEE LCN, ACM Workshop on Mobile Commerce, HICSS and several other international conferences. He is a member of ACM and IEEE and several SIGs and societies.
E-mail: uvarshney@gsu.edu

Ron Vetter is a Professor and Chair of the Department of Computer Science at the University of North Carolina at Wilmington. His research interests include wireless and mobile networks, multimedia systems, net-centric computing, and web-based instruction. His research activities have been supported by the USWEST Foundation, NSF, USDA, NASA, and others. He received the B.S. and M.S. degrees in computer science from North Dakota State University, Fargo, in 1984 and 1986, respectively, and the Ph.D. degree in computer science from the University of Minnesota, Minneapolis, in 1992. Dr. Vetter serves on the program committees for several computer science-related workshops and conferences each year and publishes scholarly work on a regular basis. Since 1992, he has published more than 70 journal, conference, and technical papers. In addition, he has received external grant funding in excess of two million dollars. Dr. Vetter serves on the editorial advisory board for Communications of the ACM and is an ACM Distinguished Lecturer. He also serves on the editorial board of IEEE Computer Magazine, is an associate technical editor for IEEE Communications Magazine, is a member of IEEE Computer Society's Conference and Tutorials Board, and serves as a chair of the Net-Centric Computing focus group for the Joint Task Force on "Year 2001 Model Curricula for Computing: CC-2001" organized by IEEE Computer Society and the ACM. Dr. Vetter is a frequent consultant to business and industry on computer communication and Internet related topics.
E-mail: vetterr@uncwil.edu