Support for Real-Time Decision-Making in Mobile Business Applications

Jocelyn San Pedro*, Frada Burstein* and Arkady Zaslavsky**
**School of Information Management & Systems*
***School of Computer Science & Software Engineering*
Monash University, Australia
{jocelyn.sanpedro, frada.burstein}@sims.monash.edu.au, a.zaslavsky@monash.edu.au

Abstract

Mobile users making real-time decisions based on current information need confidence about their context been taken into consideration in producing recommendations. We are researching the framework for assessing the impact of mobility in decision-making. This framework can be used for developing visual interactive displays for communicating to the user relevant changes in data quality when working in mobile environment. We describe a scenario where the user can benefit from decision support tools from her mobile device. We analyze this scenario from the perspectives of users, service providers and application developers and propose a framework for context-aware mobile decision support. Our framework uses dynamic context representation of data quality to represent uncertainties in the mobile computing environment. We aim to develop a mobile decision support tool that intelligently adapts to changes in environment, sends alerts and advice on quality of data during disconnection from the network.

1. INTRODUCTION

Users of mobile devices embrace today's world of widespread e-services. Users can make real-time decisions based on most up-to-date data from their wireless devices, such as portable computers, mobile phones and personal digital assistants (PDA). Business transactions, such as online shopping, banking, can be completed in a secure mobile computing environment. Travelers can enjoy short-time holidays if customized sightseeing and entertainment recommendations are available from their mobile device. A moviegoer can select from her PDA a movie that is currently showing in the nearest cinema at her preferred time (Jayaputera et al, 2003). A stock trader can monitor her stock investment from a PDA that provides alerts about interestingly behaving stocks (Kargupta et al, 2001).

Mobility presents various types of uncertainties in the decision environment. Firstly, information held in a mobile device is likely to be incomplete or outdated and may not reliably support user's needs in critical situations, such as weather forecasting, healthcare management or national defense. In another context, availability of e-services to support business transactions varies depending on the number of mobile users requesting services, changing locations of users, or type and size of mobile devices. Users will need support when they face critical situations and would welcome alerts about reliability of data in such situations, but may be dissatisfied with requests for attention when they are relaxing at home.

In this paper we explore factors that affect users' ability to make decisions in mobile environment. We proposed a framework for assessing the impact of mobility in decision-making (San Pedro et al, 2003). It can provide the basis for developing visual interactive displays for generating alerts about changes in quality of data (QoD).

In the following section, we consider a mobile decision making scenario with user using her mobile device for sending enquiry. While receiving response from the system, she gets disconnected. We analyze this scenario from the perspectives of the users, service providers (Providers) and application developers. We then come up with a framework for context-aware mobile decision support approach.

2. SAMPLE SCENARIO

Erika is within the vicinity of a large shopping centre and she likes to have a quick lunch. She subscribes to a location-based meal dealer service with a number of Providers that broadcast meal deals. She does not have time to check out all meal deals and so using her GPS-enabled mobile device, she sends a request for top three salad-chicken-drink meal deals that are cheap, fast and close to her current position. Erika receives data on top three with further information to support her choice. Provider A, ranks first and offers meal orders by phone and food available on arrival; Provider B ranks second and offers bottomless drink; Provider C ranks third and offers free ice cream. Because it is such a hot summer day and Erika will be happy with bottomless drink, she chooses B.

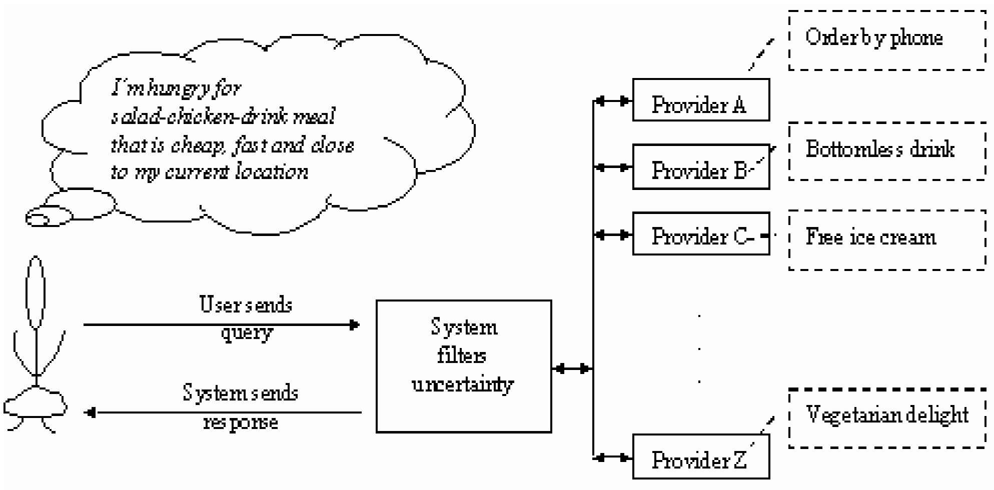

Figure 1. Sample scenario

As Erika approaches B's location, her mobile device alerts her that B no longer ranks 2nd but it is now 3rd on the list – the reason is that Provider B can no longer meet Erika's "fast" requirement for the next 15 minutes. Erika does not have 15 minutes to waste, so she checks her mobile device for any updates on the top three meal deal offers: Provider A still ranks first, Provider C now second and Provider B third. The data on Erika's mobile device is as shown in Table 1.

Table 1. Top three salad-chicken-drink meal deals

Provider	Rank	Cost	Time	Distance	Online special offer
A	*1*	*cheap*	*very fast*	*slightly close*	*order by phone; meal ready on arrival*
C	*2*	*fairly cheap*	*fast*	*very close*	*free ice cream*
B	*3*	*very cheap*	*not fast*	*slightly close*	*bottomless drink*

Erika is analyzing the tradeoffs when she gets disconnected from the network. Her mobile device alerts her that QoD from A's side is very low, but QoD remains the same for B and C. Because of low QoD in A, Erika chooses C as she feels confident that Provider C is very close, will continue to offer a fairly cheap salad- chicken-drink and free ice cream within the next 15 minutes.

2. 1 User's perspective

The user must be able to communicate her context when she sends a query, without having to select from a long list of menus. What does the user in the scenario mean by *cheap, fast,* and *close*? How would the user perceive the meaning of ranking? Why would *cheap, very fast, slightly close* meal offer by Provider A rank better than *fairly cheap, fast and very close* meal offer by Provider C? How would a Provider's special offer support the user's decision? What happens when the online special offer is no longer valid as the user gets disconnected from the network?

The above questions relate to some issues concerning the user. By having knowledge of contextual data about the user, the system as well as the Provider would be able to satisfy the user's request. For example, if the system knows the meal preferences of the user, e-service can be customised to her needs. The request can be sent immediately with just a click on favorite meal icon. Such data can be derived from the user's past preferences as well as personal profile (Grimm et al, 2002).

For example, in the sample scenario, *very cheap* could mean any meal costing from \$5 - \$10; *cheap* could mean \$7.50 - \$12.50; *slightly cheap* is in the range \$12.50 -\$15; and *not cheap* is any meal costing more that \$15. Fuzzy decision-making models provide an opportunity to handle this type of uncertain inputs and can be dynamically updated depending on the personal user profile data or the decision context (Shen et al, 2000). Other intelligent techniques such as possibility theory and rough sets-based prediction allows deriving of numerical data necessary for calculations of the decision model while operating with user's subjective qualitative categories (Krishnaswamy et al, 2002b).

Ranking has different meanings to different users. For example, one user may interpret the top alternative as the *cheapest, then fastest and finally closest* while another user may interpret the top one as being *equally cheap and fast but most importantly, closest* to her current location. Various multicriteria decision-making approaches (Pomerol and Romero, 2000) can be incorporated into the hand-held device to resolve conflict among many factors influencing the choice of the best alternative.

The user's perception of online offers can vary depending on time, location, subjective preferences, and many other factors. If user's context is taken into consideration, then the user may use this special offer as basis for selecting her preferred meal deal. For example, meal orders by phone can be very important to a user who is planning to have a quick luncheon meeting with three business clients. Free ice cream can be very appealing to a mother of two children, while bottomless drink can be attractive to a construction worker. Such services support more efficient communication of the marketing and advertising information by addressing current user's needs in a suitable way (Jin and Miyazawa, 2002; Chen and Kotz, 2000).

When a user gets disconnected from the network, she needs to know how well the available data on her mobile can support her choice of alternatives. In our sample scenario, we use the measure of QoD during disconnection mode to convey to the user the level of reliability of the available data. A measure of QoD should incorporate data attributes that are user-related and context related. For example, user's perception of relevance of data to current decision situation should be taken into consideration. In our sample scenario, the knowledge that Provider B cannot meet the user's "fast" requirement for the next 15 minutes is relevant to the user who does not have more than 15 minutes to wait for re-connection. After 15 minutes, Provider B can very well regain its position in the e-market and a user who has more than 15 minutes to choose a meal needs to know about this regardless of the network connectivity.

2.2 Service Provider's perspective

The Providers must be able to understand user's context as well as communicate its context to the user to gain competitive advantage over other Providers. For example, online special offers can adapt to user's location, time of day, or special circumstances that can make the service valuable to users. A Provider can incorporate a dynamic business model that can adapt to its capability to provide e-service, user's needs and system's capability to handle user's requests and response to these requests.

A range of online special offers would allow a Provider to communicate its context to the user and the system. While the Provider may be restricted to user's meaning of *cheap, fast, close,* it could gain competitive advantage by providing a special offer customized to the user's context. For example, a Provider will be able to offer meal orders through a mobile device to a businessman seeking a table for four; offer free ice cream to a mother of two children; or offer bottomless drink to a construction worker.

Delivering content to users based on their current needs and preferences is one of the biggest challenges for the ubiquitous computing (Davis, 2002). It requires context-aware applications development, which seeks user preferences to streamline transactions depending on current decision situation and available services (Chen and Kotz, 2000; Zaslavsky and Tari, 1998).

Offline special offers should also play an important factor in the sample scenario to deal with changes in network connectivity. By providing a measure of QoD during disconnection mode, the Providers can be confident that they are still capable of providing quality service despite disconnection from the network. Such measure should take into consideration Provider-related context, such as the currency, completeness, reliability and other data attributes based on the Provider's business model. A reliable, static business model can replace the dynamic model during disconnection and Providers can still ensure quality service to users. In our sample scenario, the cost of a meal can reliably remain fixed until the end of the month; the distance of a Provider from the location of user can be established by the user even when she gets disconnected if she is familiar with place; the capability of the Provider to offer fast service can be determined using a queuing model. Other models can be incorporated such as user mobility model (Shen et al, 2000; Sharaf and Chrysanthis 2002); dynamic cost calculation model based on various distance functions (Jin and Miyazawa, 2002), etc., so that the system can adapt intelligently during disconnection.

2.3 Application developer's perspective

In order to take into consideration contextual data on user, providers and system, the application developer needs to implement uncertainty models to allow the users, providers and system to communicate with each other through wireless communications network. There is a need for the user to convey her meaning of *cheap, fast, close* meal deals. The system must be able to interpret this in a way that Provider's perception of user's needs is consistent with the user's needs. There is also a need for the Provider to convey its capability to offer e-service. The system must be able to interpret this and communicate to the user so that user's perception of Provider's capabilities is consistent with Provider's capabilities. In general, a range uncertainty models should be provided in an application server to allow the system to adapt an appropriate model depending on context. Some of them, to deal with qualitative data, multiple potentially conflicting criteria were discussed in the context of user's perspective. The challenge of providing these models to support real-time decision-making is related to getting up-to-date and reliable data (Sharaf and Chrysanthis, 2002).

3. FRAMEWORK FOR MOBILE DECISION SUPPORT

In Figure 2, we present a framework for mobile decision support that (1) takes into account various contextual data; (2) incorporates models to represent uncertainties of mobile environment; and (3) provides a range of decision support tools to assist the user in making informed decisions based on available data. Contextual data about the user, available e-services and their Providers, and the system are contained in a database server. A collection of uncertainty models is available in the applications server and a range of decision support tools are accessed by user through a browser.

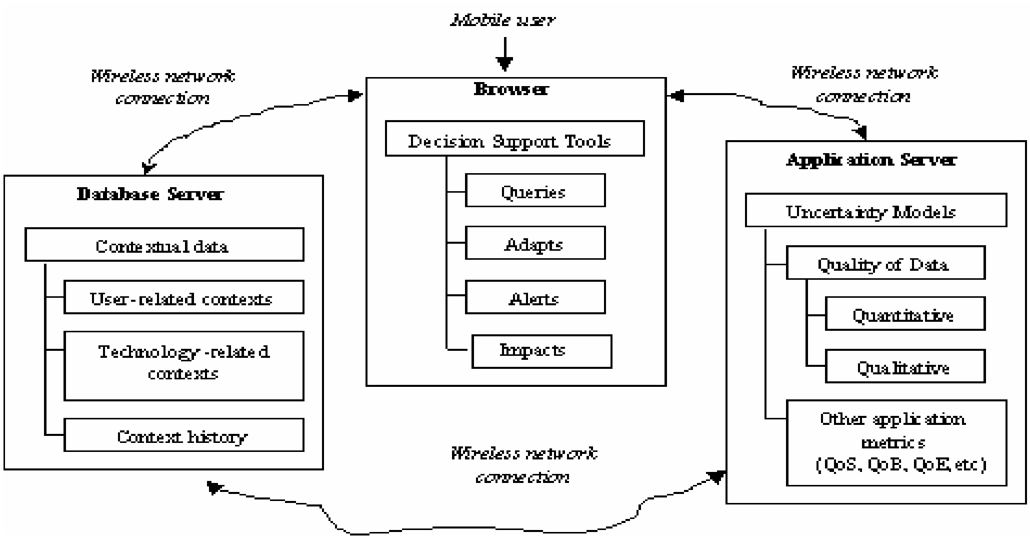

Figure 2. Framework for mobile decision support

The user, database server and application server are linked altogether by wireless network connection. When a user sends a query from her mobile device, the query is processed in the application server, filtered for any uncertainties using appropriate uncertainty models and presented to the user through browsers in forms that are easy to understand, easy to access and consistent to the user's perception. The query is also recorded for future use and matched against the contextual data contained in the database server for all retrieval purposes (learning from historical data, matching to find the Provider that best satisfies user's requirements, etc.). All data needed by the applications server to process the query are accessed from the database server. When the user gets disconnected from the network, or when there are changes in the environment, intelligent technologies are implemented to alert the user of these changes and their impact to the current decision situation.

3.1 Contextual data

There is a need to take into account various contextual data about the user, Providers, and the system if decision support is to be effective. In particular, to effectively support the user while working in a mobile environment, the system must be aware of the user's current circumstances – e.g. location, device, data requirements, preferences, decision situations, etc. We refer to these circumstances as *user-related contexts.* Knowledge of user-related contexts allows Providers to be flexible to user's preferences and to target user's needs. Such knowledge may be converted into competitive advantage if Providers can offer decision support to users anywhere, anytime and under any circumstances. However, there is still very little published research on the way users relate to mobile environment (Green et al, 2001) and it is still a question how intrusive mobile devices could be to provide the best value-added service without compromising privacy of the decision-maker. In the sample scenario, the user had to explicitly define her preferences within the first quivery. However, if she is a frequent visitor of the area she is currently in, or is always looking for a particular kind of service when in this area, the user-related context database should be able to retrieve some pre-coded preferences and incorporate them into decision support system alerts and advice facilities.

Technology-related contexts refer to technical aspects of mobile computing. These contexts include system software and hardware requirements, system input/output specifications and requirements, network connectivity, communication costs, communications bandwidth, quality metrics such as QoD, quality of service (QoS) and quality of business (QoB). Knowledge of these contexts lead to better quality products and services by making the mobile applications aware of the various technical aspects in which they are run. In our sample scenario, depending on where the user is making her enquiry from, more or less data can be displayed about the choices as well as there could be a choice of the amount of graphics to be sent with the options (Nzama et al, 2001).

Relevant contextual data should be accessible even during disconnection from the network, or when there are changes in the environment. One way to take into account the dynamics of the mobile environment is to provide a mechanism to learn from past events. In our proposed framework, we use *context history* to allow the system to learn from past circumstances. By using intelligent technologies, such as case-based reasoning or data mining the system can predict the future behavior of the user, performance of the equipment or outcome of applications.

3.2 Uncertainty models

There is a need to incorporate appropriate models to represent uncertainties of mobile environment if decision support is to be adaptive to changes in the environment. The use of appropriate uncertainty theory such as fuzzy sets theory, probability theory, rough sets theory, etc. will be useful in assisting the user to understand and perceive the current decision situation. For example, fuzzy sets may be used to represent user's subjective judgments of current decision situation (San Pedro and Burstein, 2003). Probability distributions can be useful in predicting decision scenarios (Kargupta et al, 2001). Rough sets theory can be used to estimate the computation and communication costs of e-service (Krishnaswamy et al, 2002b).

In this paper, as seen in Figure 1, we consider a particular uncertainty model for QoD. We view QoD as one metric representing the uncertainties in mobile environment, and thus should be described in terms of user-related and technology-related contexts. These contexts can be classified as either static or dynamic. The dynamic contexts are the ones that require appropriate uncertainty models.

Because these dynamic contexts can further be parameterised or classified into multiple attributes, we propose a dynamic multi-context representation of QoD. Such representation will be characterized by attribute/value pairs and/or criterion/value pairs. Depending on context of decision situation (e.g., restaurant search, taxi search, etc) relevant attributes and criteria for matching the user's preferences with Provider's capability, will be accessed from the database server and the best Providers will be retrieved and ranked using appropriate retrieval and ranking algorithms. Some qualitative attributes of QoD relate to accessibility, accuracy, completeness, currency, consistency with other sources, relevance, comprehensiveness, level of detail, easiness to read, easiness to interpret (Juran, 1998). Quantitative attributes of QoD relate to some metrics such as data fidelity, response time, reliability, processing capacity, bandwidth, waiting time, and other system metrics (Krishnaswamy et al, 2002a).

Web-based decision support systems like MARI (Tewari and Maes, 2001) and IARRA (San Pedro and Burstein, 2003) perform retrieval of alternatives that best match a given situation. There are still a few issues constraining the successful migration of decision support tools to mobile devices. These issues include limited source of energy to perform the search, limited bandwidth, small screen to display results of search, and other mobility-related constraints (Satyanarayanan, 1996).

In our sample scenario, we identified the changing capability of Provider B to meet the user's "fast" requirement, changing time and distance from the Provider as dynamic contexts influencing the QoD. There will be other dynamic contexts to consider, and so questions remain as to which and how these dynamic contexts can be readily accessed and handled by mobile applications.

3.3 Decision support tools

There is a need to provide a range of decision support tools to support real-time decision-making. Because of the complexities and uncertainties in mobile computing, most context-aware computing applications are limited to mobile information access. Real-time access to information, however, does not always support decision-making activities. A user needs to make informed decisions especially during critical situations. In this perspective, we exploit the possibility of extending context-aware computing to context-aware mobile decision support. In addition to taking into account various contexts and uncertainty models, we propose to provide a range of decision support tools such as query and alert services, intelligent adaptation to changes in environment, and impact assessment strategy.

Web-based interface between the database server and application server gives user ubiquitous access to the information she needs to make real-time decision based on the whole set of pre-defined as well as user-dependent data. The browser will be equipped with decision support tools that

- allow the user to send queries/ requests for e-data that will be useful in supporting her current decision–making activity;
- intelligently adapt to critical changes in the environment;
- alert the user about critical changes in the environment that are relevant to the current decision situation; and
- present information on impact of critical context changes to QoD in forms that will be easily understood and accessed by the user.

By providing a range of decision support tools, the user is able to communicate her contexts, and the system, in turn processes the query, filters the data for any uncertainty, adapts intelligently to changes in environment, and sends feedbacks and alerts to the user in forms that are easily accessible and understandable to the user.

A sensitivity-analysis-based alert facility that increases the quality of decision outcome and positively impacts the process. It assures least impact of uncertainty onto the final choice is derived from context changes. In our sample scenario, a message can be sent to the user to make her aware that data she is looking at is 15 minutes old. Such message will be useful when there is also some mechanism for checking historical data about the places she is about to visit. This is where her confidence in making the best choice can be re-enforced through the use of context-aware model.

Figure 2 suggests what factors to consider when modeling context in mobile decision situation. These factors define dynamic uncertain environment for making real-time decisions. Including these various factors as attributes into decision support model can help the user to get better quality decision support taking into consideration her current context, historical data, current and historical context of the Providers, as well as technical parameters of the transaction to be performed.

4. RESEARCH IN PROGRESS

By considering various contextual data, uncertainty models and a range of decision support tools, we get a holistic understanding of how mobile users may be supported in her decision-making activities. We list below the areas we are currently researching in relation to the proposed framework for mobile decision support.

4.1 Representation of contextual data

Representation of contextual data is still a challenging research domain in mobile computing. We are currently investigating existing models for representing contextual data to allow communication between user, Providers and the system. These include Composite Capability/ Preference Profiles (CC/PP) (Reynolds et al, 1999) and Comprehensive Structured Context Profiles (CSCP) (Held et al 2002). CC/PP and CSCP are profile representation models that are based on the Resource Description Framework (RDF) (Lassila and Swick, 1999). CC/PP is an XML-based metadata description framework for describing device capabilities and preferences. It is a strictly two-level profile structure. Each profile has a number of components and each component has a number of attributes. CC/PP is not suitable for our proposed framework for decision support because it lacks representation of user preferences and its two-level structure does not capture complex relationships among components and attributes (Indulska et al, 2003).

CSCP, also XML-based, allows representation of user context in addition to device and network contexts. CSCP avoids the two-level hierarchy and uses natural structures of profile information (Held et al, 2002). CSCP provides features to represent user preferences by assigning conditions and priorities to user preference attributes. CSCP has some features that may be suitable for our framework. However, no further work has been reported on CSCP at the time of writing of this paper.

We aim to come up with a model for context representation that would fit the proposed framework. In particular, it should allow high-level structured profile information about users, Providers, the system and their interrelationships, but is also decomposable, distributable and flexible to changes in the environment. Some features of a context representation model that we are interested in are those that

- allow profile information about the user, the providers and the system;
- allow incorporation of higher-level decision trees;
- allow identification of static and dynamic attributes;
- records context history in a form that can be merged or compressed, appended or extended when necessary, and adaptable to changes in environment;
- be accessible for alternative evaluation, comparison and filtering for selection of relevant alternatives; and
- easily converted to interactive visual display.

4.2 Fuzzy multicriteria decision-making models for QoD

We are currently investigating the use of fuzzy similarity functions to compare existing QoD in a mobile computing environment (which we refer to as mobile QoD) with an ideal QoD in a static environment (which we call static QoD). This will involve attribute-wise or context-wise fuzzy comparison between mobile QoD and static QoD using multicriteria decision-making approaches. QoD may be regarded as either locally *very low, low, medium, high and very high* in respect to one attribute, or globally *very low, low, medium, high and very high* after appropriate aggregation (such as aggregation by Integral Superiority Degree (San Pedro and Burstein, 2003), or some global utility functions (Tewari and Maes, 2001). When QoD becomes locally or globally *very low* (i.e., falls below threshold), a user using her PDA will be alerted indicating critical degradation in QoD, she becomes aware that any decisions based on current available data may have a very low level of confidence.

4.3 Sensitivity-analysis-based alert system

Our proposed approach to mobile decision support aims to assist the user by providing her assessment of impact of critical changes in the environment to her decision outcomes. Knowledge of such critical changes alone would alert the user but not necessarily support her decisions. By extending the functionality including GUI designs or visual interactive display for communicating the results of sensitivity analysis in accessible, understandable and adaptive form, these services can enhance the confidence in user’s decision-making ability. Such impact assessment will involve presentation of alternative scenarios that are best and worst cases and are least sensitive to changes in the environment.

5. CONCLUSIONS

This paper proposed a framework for mobile decision support that applies a multi-context representation of QoD. It aims to represent uncertainties in the mobile computing environment applying context-aware mobile service model. By considering various context values such as user-related contexts and technology-related contexts, the nature of mobile computing environment may be better understood and users may be better supported in their decision-making activities. We have described a sample decision situation and illustrated how it can be addressed when applying the proposed framework.

Technical implementation of this approach is under way. We plan to evaluate process and complexity of this type of services in relation to user satisfaction with the process and outcome of the decision, perceived quality of service, the number of transactions that will become possible to complete when taking uncertainty measure into consideration. This type of rigorous investigation of the real-time decision support systems does not appear to have been carried out previously.

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