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Adaptive Content Delivery Over the Mobile Web

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Abstract

Delivering Web content to wireless handheld devices presents many challenges. Inherent limitations of wireless handheld devices, relatively low wireless network bandwidth and user mobility make it necessary to deliver data as succinct as possible to reduce transmission delay and fit into the small screen display. To achieve this goal, Web content has to be tailored to adapt to the mobile Web. Other than filtering out formats and contents not supported by wireless browsers, a rang of adaptation approaches exist. This paper presents a classification scheme for evaluating current content adaptation approaches in terms of version adaptation, template adaptation, personalization adaptation, and usability adaptation. A three-dimensional model of content adaptation is proposed to guide the development and assessment of adaptive content delivery over the mobile Web. This model introduces the concept of dimensionality of adaptation and incorporates platform and user requirements for content adaptation.

Keywords: Mobile Web, wireless handheld device, content transformation, transcoding, mobile computing, mobile services, usability, personalization

Introduction

With a growing number of mobile users and advances in wireless communication technologies, content delivery to wireless handheld devices is gaining increasing attention. The mobile Web, by embedding lightweight Web browsers into wireless handheld devices, enables users to perform many interesting and time-critical tasks such as checking stock quotes and booking an airplane flight anytime and anywhere. The mobile Web, therefore, has become the central data exchange channel for extending current Internet business model to mobile services model (Shim et al. 2002).

Inherent constraints of wireless handheld devices and the current state of wireless network necessitate Web content be adapted to the wireless platforms and mobile users. Various adaptation approaches exist. A basic approach is to remove unsupported data formats and scripting components to reduce the data transmission over the wireless network. The use of XML language suite could enable more flexible content delivery (e.g., Han et al. 2000). Furthermore, Web personalization techniques may be applied to meet the need of mobile users (Anderson et al. 2001c; Lankhorst et al. 2002). Usability guidelines may also be incorporated in content adaptation to enhance the ease of use of mobile services (e.g., Chan et al, 2002).

This paper presents a classification scheme for analyzing content adaptation approaches in four groups: version adaptation, template adaptation, usability adaptation, and personalization adaptation. Building on review of research in these four areas of adaptation, we propose a three-dimensional adaptation model for guiding the assessment and future research of adaptive content delivery. We also introduce a concept of dimensionality of adaptation that incorporates the considerations of platform requirements for content conversion, as well as user requirements in terms of usability and personalization. The proposed classification scheme and the model together form a unique and integrated perspective on adaptive content delivery. The paper is organized into four sections: (1) background research on mobile services and content adaptation issues; (2) current adaptation approaches under the proposed classification scheme; (3) a model for guiding and assessing content adaptation approaches; and (4) conclusions and further research questions.

Defining Mobile Services

Several frameworks have emerged to define the wide range of mobile computing applications and services. One such framework presents ten classes of mobile applications, ranging from retail, auction, financial services, advertising, inventory management, to mobile office, distance education, and data center (Varshney and Vetter 2002). Another framework groups mobile services into goods, services, content for consumer e-commerce, and activities among trading partners (Kannan et al., 2001). Anckar and D'Incau (2002) present a framework that differentiates mobile services by wireless values or mobile values. Wireless values refer to the use of wireless technology, such as PDAs or cell phones. Mobile values arise from the mobile use of the technology in meeting users' time-critical needs and arrangement; spontaneous needs and decisions, such as auctions, email, and news; entertainment needs; efficiency needs and ambitions; and mobility related needs. Alanen and Autio (2003) categorize mobile services by transactional needs or process facilitation, as well as for consumer or for business needs. Accordingly, mobile services may support:

- B2C/C2C m-transactions services such as stock trading, mobile banking, location based advertising, and m-wallet;
- B2B m-transactions such as access to B2B e-commerce marketplaces, access to bilateral online trading systems, and banking services;
- Personal life management of everyday activities, such as e-mail, chatting, instant messaging, entertainment, and information services;
- Mobile office through email, calendar, groupware, and information services; and
- Mobile operations for sales force support, field service management, fleet management, and remote monitoring.

These frameworks capture a wide range of m-applications, including both push and pull m-services. As mobile channel is becoming an extension of wired e-commerce sites (Chan et al. 2002), contents and functionality of the two channels need to be integrated more effectively. Within this context, adaptive content delivery over the mobile Web poses many challenges for researchers and practitioners.

Constraints for Adaptation

Wireless handheld devices have many inherent constraints when used as a mobile Web browser to interact with World Wild Web. Three common constraints in mobile computing are: wireless communications, device properties, and mobility (Tsalgatidou et al. 2000). Beyond these inherent constraints, mobile user personalization presents even greater challenges because wireless devices are mainly used by individuals. Many established Web personalization techniques such as Web usage mining, content/semantic mining, and structure mining might be well suited for wireless browsing. However, inherent wireless constraints must be addressed before presenting personalized content to a small wireless browser. These constraints include: a) form factor, b) network quality of service (QoS), c) mobility, and d) personalization.

Form Factor Constraints

The physical features shared by wireless handheld devices impose some constraints on Web browsers: a) small content display screen, b) difficult and slow data input, c) scarcity of CPU power and memory, and d) incompatibility among diverse mobile browsers. When deploying the mobile Web over different wireless platforms, these constraints pose serious barriers.

Network Quality of Service

Wireless networks are unable to provide sustained QoS to applications like Web browsers and multimedia due to unreliable wireless media, user mobility between cells, and migration between diverse wireless networks (Bharghavan and Gupta 1997). Network adaptability mainly concerns general data stream optimization according to the underlying mobile computing capability based on MSS (mobile support station)-MH (mobile host) model. MHs could range from laptops with powerful CPU, large memory and large screen, to handheld PDAs with very limited computing, storage, and display capability. It is therefore necessary to consider the limitations of mobile platforms for resources restricted browsing terminals, such as PDAs and WAP phones that have limited content presentation capability. For example, Bharadvaj et al. (1998) present a Perl-coded transcoding proxy named MOWSER, which transcodes HTTP-get requests, image files, video data, and HTML pages on both upstream and

downstream traffic according to the QoS parameters set by MHs. If MHs are powerful laptops, only the underlying network adaptability is of concern.

Mobility

Mobile Web enables users to access their desired information on the go. Nevertheless, mobility causes many problems. For example, network non-reachability and disconnections are often caused by moving into areas without adequate signal coverage. This casts a big challenge to some types of m-commerce transactions that require session consistency.

Personalization

Wireless handheld devices such as WAP phones and PDAs have been used primarily for voice/text communications and information organizer. These devices are highly personal to their owners. This feature could be easily neglected by developers because it is not an obvious physical characteristic of the device. Researchers have emphasized the need for personalization (Anderson et al. 2001c; Lankhorst et al. 2002). However, personalization for the mobile Web involves more restrictive considerations beyond current Web personalization. For example, usability guidelines for small display interface design would play a key role in mobile Web content presentation and navigation (Chan et al. 2002).

A Classification Scheme for Content Adaptation

Several adaptation approaches exist for wireless content presentation. Some have already been incorporated into commercial software. Others are still in the domain of academic research. These approaches have been classified as: mobile-aware versus mobile-transparent approach (Kaasinen et al. 2000), automated conversion versus special language (Gaedke et al. 1998), server-side and proxy-side versus client-side adaptation (Kunz, and Black 1999; Lum, and Lau 2002; Bharadvaj et al. 1998), and static adaptation versus dynamic adaptation (Lum and Lau 2002). Furthermore, Trevo et al. (2001) present four ways of delivering information to small displays: scaling; manual authoring; transcoding; and transformation.

The user perspective is often absent in these classification schemes. A new classification scheme that incorporates mobile user considerations, such as usability and personalization, deems appropriate for improving researchers' and developers' understanding of adaptation approaches. Such a classification scheme may group adaptation approaches into four categories: a) version adaptation, b) template adaptation, c) usability adaptation, and d) personalization adaptation.

Version Adaptation

The most straightforward way to achieve adaptability is to re-author Web content in advance for different handheld devices. Version adaptation is accomplished by generalizing the range of form factors to include both physical appearance and software features, such as the types of operating system (OS) and mini-browser. Current handheld devices are diverse in form factors and are in continuous updates. Creating different versions of a mobile Web site to match specific form factors is costly and difficult to maintain. A common method is to copy existing HTML Web pages and remove any html tags that are incompatible with that particular type of handheld device. However, most current commercial mobile Web sites seem to prefer creating dedicated URLs for their wireless presence on a specific platform, such as the WAP site of the Wall Street Journal is **http://wap.wsj.com** and the United Airlines is **http://ua2go.com**. As shown in Figure 1, user-agent detection module is optional in the version adaptation approach, but is necessary when only one consistent URL identity, such as **http://yahoo.com** and **http://excite.com**, is used to adapt content for multiple wireless platforms.

Template Adaptation

Template adaptation involves the use of XML language suites to overcome the limitation of gateway transcoding. Most proxies or gateways owned by the wireless information service provider (WISP) usually handle on-the-fly content transcoding. As shown in Figure 2, automated transcoding systems, which are sitting in MSS, can do simple programmed syntactic transcoding functions like HTML ➔ HDML/WML/cHTML. Gateway transcoding has very limited adaptability, because Web content providers do

not have control over gateways or proxies which are normally owned and managed by WISPs. XML language suite, as the de facto standard for information exchange over the Internet, has been well adopted in the content delivery for the mobile Web. Unlike HTML's rigid format tags, XML can have user-defined meaningful tags to store, categorize, and label data at desired granularity. By using XSLT (the Extensible Stylesheet Language Transformations) and XPath (the XML Path Language), data extracted by tag names from an XML document can be applied to a desired presentation format (see Figure 3).

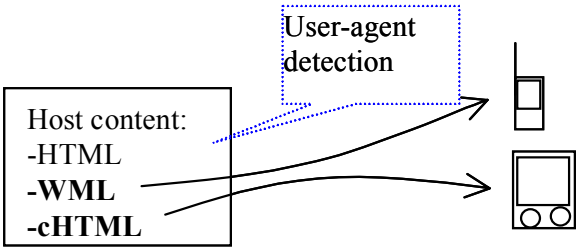

Figure 1. Version Adaptation

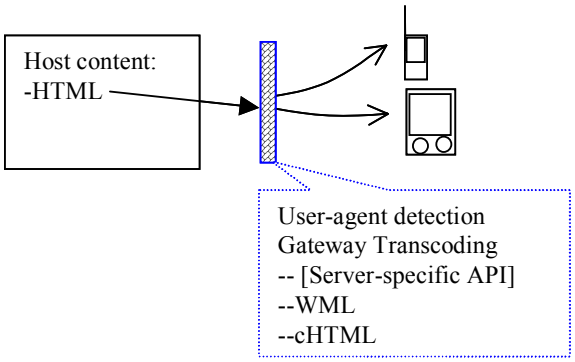

Figure 2. Gateway Transcoding

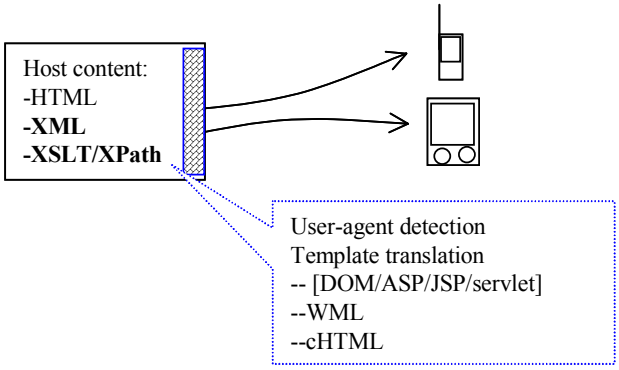

Figure 3. Template Adaptation

Han et al. (2000) have developed a unified XML/XSLT framework, WebSplitter, to facilitate CSCW (computer supported cooperative work) with Web. WebSplitter enables multi-device and multi-user collaborative Web browsing by splitting XML data at the granularity of tags and by grouping tags into independent components and subdocuments, which can then be sent to heterogeneous end users' browsers, including all kinds of PDAs. In order to better represent a prototype or template, Gaedke et al. (1998) propose an object-oriented WebComposition model. Its XML-based description language, WCML (WebComposition Markup Language), enables object-oriented specification of Web content to be easily extracted and adapted to different terminal browsers.

Usability Adaptation

Studies on usability of wireless handheld devices have addressed the use context and tasks of the mobile user and interface design guidelines for small displays. Design guidelines generated from these studies may contribute to adaptive content presentation on wireless handheld devices.

A usability evaluation study by Chan et al. (2002) of ten mobile Web sites on three platforms (WAP phone, Palm and Pocket PC) has yielded several design guidelines. These guidelines include: a) avoid scrolling, especially horizontal scrolling; b) use a flat

hierarchy; c) design navigation system consistent with a regular Web browser; and d) provide a history list for traversed hyperlinks. Schmidt et al. (2000) present several guidelines for the development of WAP interfaces. For example, the input design should: a) use numbers for input where ever possible; b) use common abbreviations; c) prefer first letter on key; and d) offer choices or default values when applicable. The output design should: a) reduce the output by customizing to the user's need; and b) use multiple cards in one deck instead of very large cards or multiple decks. In short, interface design for small wireless browsers should minimize user interaction during navigation by providing with convenient selection and less key entry.

An empirical study by Kim et al. (2002) demonstrates that different mobile use contexts (goal, emotion, hand, leg, visual, auditory, co-location, and interaction) could cause different kinds of usability problems pertaining to presentation, structure, navigation, and content. For example, availability of one or both hands, movement of legs (standing or moving), and the number of people around the user has been found to associate with types of usability problems. Results from this study imply that adaptive data presentation should focus on the primary use contexts, not all possible contexts.

Babaria et al. (2001) have conducted experiments on font size, menu design, and scrolling on small handheld devices to examine the effect of those features on a small display as compared to the effect on a regular PC. The study shows that menu depth should be minimized and menu breadth should be maximized for the most efficient location of an item during a search task. So the design of search menus on handheld devices should have legible font size (medium preferred), scrolling menus, and a small number of buttons or/and menu selections. A usability study by Jones et al. (1999) reveals that 80% of small screen users began by using the search options of the site, and selected search facilities twice as many times as large screen users. Two design guidelines can be drawn for adaptation consideration: a) provide direct access since small screen users seem to choose and prefer direct access strategies, and b) reduce scrolling by placing key information at the top of page and make the content task focused rather than verbose. By applying a text (page) summarization technique, Buyukkokten et al. (2000a, 2001b) show that a progressive browsing style could result in a 57% improvement in browsing speed and 75% reduction in input effort (Buyukkokten et al. 2001b), and a 45% gain in browsing speed and 42% reduction in required pen movements (Buyukkokten et al. 2000a). The combinatory disclosure method of keyword/summary gives the best performance for Web page discovery tasks.

Personalization Adaptation

Personalization adaptation is a content delivery approach based on the user's information needs and preferences. Comparing to previously discussed adaptation approaches (Figures 1, 2, and 3), Figure 4 illustrates the addition of the mobile user in the adaptation approach.

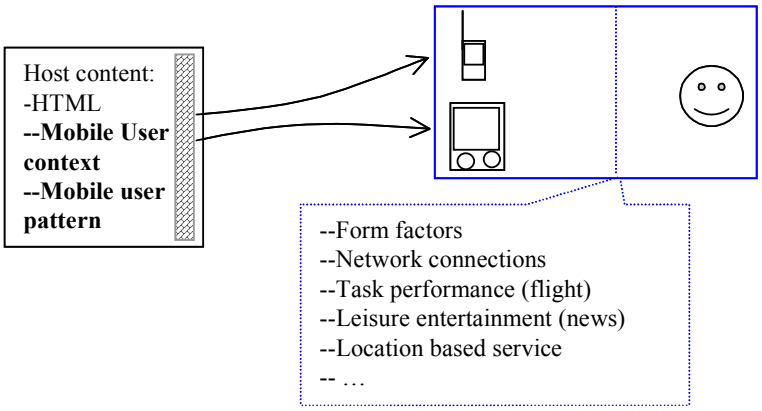

Figure 4. Personalization Adaptation

Technically, personalization approaches often use a client-proxy-server model to embed personalization logic in proxy server. Proxies mainly deal with the syntactical transcoding, system QoS adjustment, and content transformation. Steinberg and Pasquale (2002) present a WebStream customizer that supports adaptive system-based and content-based customization. Lankhorst et al. (2002) propose a holistic approach to the personalization of mobile data services, emphasizing a personal service environment (PSE) to address profile management, service discovery, and service adaptation. From a methodological perspective, personalized and adapted results represent reduced data from the source content. The reduced content should be more concise and directly

related to the user's special interests. Sometimes data aggregation is also applied. Users are interested in a reduced (adapted) result and the ability to control the level of progressive reduction (Heuer and Lubinski 1998).

Nakano et al. (2002) propose a method for user adaptive content delivery over the Web. Its mechanism could be applied to the mobile Web. The transmission time control mechanism automatically adjusts the quality of inline objects, such as images, according to the transmission network bandwidth. The delivery order control mechanism delivers inline objects in a specified order preferred by users. Their study shows the total content delivery time (rendering a complete Web page) with adaptation is 13 seconds versus 26 seconds without adaptation.

WebViews, developed by Freire et al. (2001), allows Web users to record their interested destination Web pages and extract content components in a VCR-style interface from desktops. A user can easily create personalized shortcuts and customized views of Web sites (pages). Such personalized Web Views could be accessed later via the user's mobile browsers. The system's VoiceViews component embeds a simple voice-enabled access mechanism to Web Views. An obvious advantage of such personalized WebViews is the greatly reduced number of required interactions and the amount of data entry and transmission. PersonalClipper in Freire and Kurmar's study (2000) describes a similar idea (VCR-style recording) except without voice-enabled Web views. In the text-to-voice approach, voice contents rely heavily on personalization. Otherwise, users would have to hear much irrelevant information transcoded into voice.

Learning user preference from Web usage data and presenting adapted content automatically by using machine learning and data mining techniques have advantages over demanding user inputs. Mobasher et al. (2000) introduce three different Web usage-mining techniques for Web personalization based on transaction clustering, usage clustering, and association rule discovery. These techniques could be extended to mobile content personalization. The PROTEUS and MinPath (Anderson et al. 2001b) are examples of Web usage mining for mobile users. The personalization process has two steps. First, building a visitor model by mining the access logs and site content. The model includes information about navigation browsing behavior and content interests (and might include geographic location or demographics as well). Second, transforming the Web site according to the user model with the purpose of prioritizing transformation quality in terms of evaluation metrics. Three types of transformation operators are supported: adding shortcuts, eliding content, and swapping siblings. PROTEUS builds its visitor model on the basis of individual user and applies expected utility as the valuation function. MinPath models clusters of visitors and uses expected savings of links as evaluation function.

A Model for Content Adaptation

Based on the above review, we propose a three-dimensional adaptation model to guide research and the evaluation of approaches for adaptive content delivery over the mobile Web. In this model, as illustrated in Figures 5 and 6, adaptation features are represented as vectors in a three-dimensional space of conversion, usability, and personalization.

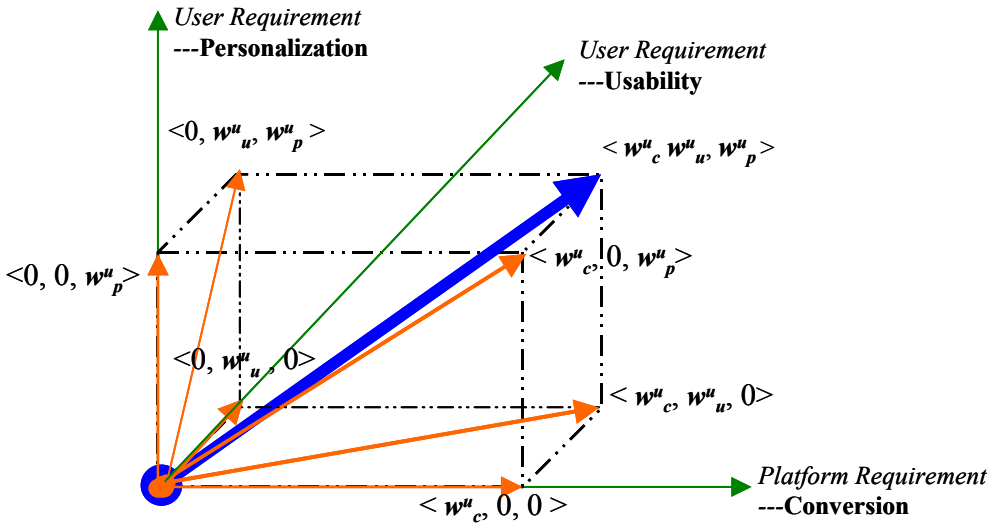

Figure 5. Dimensionality of Adaptation

Dimensionality of Adaptation

The four adaptation approaches reviewed earlier fall into two basic adaptation requirements: wireless form factor oriented adaptation (version adaptation and template adaptation), and mobile user oriented adaptation (usability adaptation and personalization adaptation). The former should be viewed as the basic requirement for content delivery adaptation to wireless handheld devices. The latter is becoming more important for pervasive applications and mobile services, where usability and personalization are critical. Figure 5 shows a comprehensive view of three-dimensional adaptation model: mobile platforms with different browsers would require conversion flexibility; personalized information delivery meets the user's best interests; and usability guidelines would be applied to the converted, personalized presentation.

This model could provide insights for application development and adaptability evaluation. For example, given a particular mobile user

$$u \in U,\ U=\{u \mid \textit{users with mobile browsers}\};\quad U: \leftarrow \textit{user profiles}$$

and a certain type of mobile browsers

$$b \in B,\ B=\{b \mid \textit{WAP phone, palm, pocket PC}\};\quad B: \leftarrow \textit{standard device profiles}$$

If mobile web adaptation features are viewed as a three dimensional vector:

$$ADT = \langle \textbf{C}\textit{onversion},\ \textbf{U}\textit{sability},\ \textbf{P}\textit{ersonalization} \rangle$$

Then the following vector *adt* will represent the combinatory adaptation of different features for a particular mobile user *u* with a certain wireless browser *b*

$$adt = \langle w_C^{ub},\ w_U^{ub},\ w_P^{ub} \rangle \quad u \in U,\ b \in B,\ w \in W;$$

where *W=[0, max]* is defined as the significance scale of each dimension. The determination of this scale value is subject to detailed experiments and evaluation methods. The adaptability value can be computed by taking the norm **||*adt*||.** The difference in effectiveness between different combinatory adaptability can be measured by their distance. Just taking a normalized similarity measure *cosine coefficient* between two vectors as example:

$$sim(adt^A, adt^B) = \frac{adt^A \cdot adt^B}{\|adt^A\| \cdot \|adt^B\|} = \frac{\sum w_i^A \cdot w_i^B}{\sqrt{\sum (w_i^A)^2 \cdot \sum (w_i^B)^2}}$$

Then the distance is

$$dis(adt^A, adt^B) = 1 - sim(adt^A, adt^B) = \frac{\sqrt{\sum (w_i^A)^2 \cdot \sum (w_i^B)^2} - \sum w_i^A \cdot w_i^B}{\sqrt{\sum (w_i^A)^2 \cdot \sum (w_i^B)^2}}$$

In particular, the three-dimensional adaptation model could be extended to *n* dimensional vector space if sub-features are added to each feature dimension.

Increased complexity of content conversion, ranging from scaling, syntactic transcoding, to semantic transformation (Trevo et al. 2001), results in adaptability gains. As shown in Figure 6, more Δs denote increased level of adaptability. Similarly, increased usability and personalization could achieve greater adaptability gain. The exact adaptability value gained could be computed as distance measure. From the perspective of conversion complexity, in order to improve adaptability, linkage or structure rearrangement of content is necessary. Merely scaling down to squeeze the Web content to a mobile browser without usability and personalization considerations has the least adaptability.

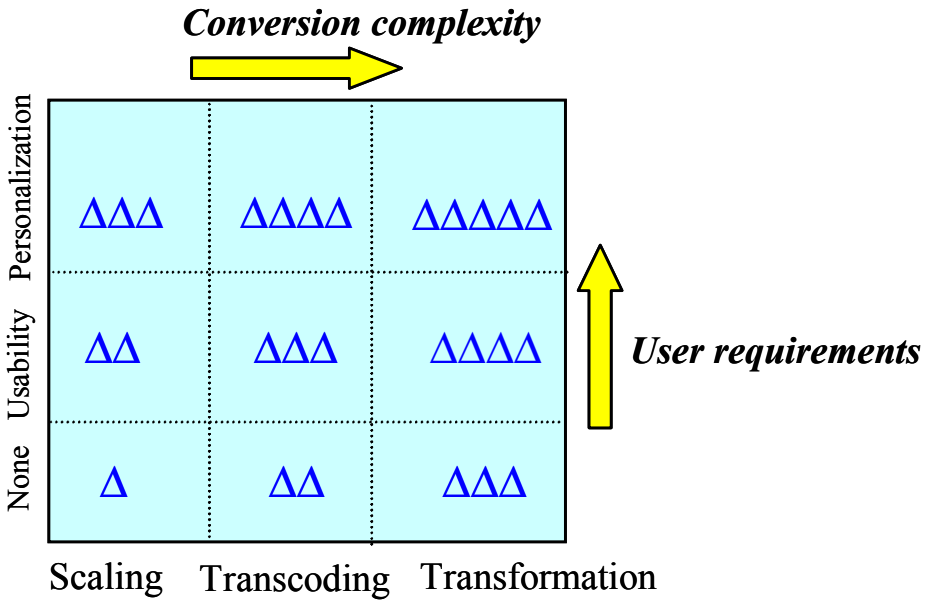

Figure 6. Combinatory Adaptability

Scaling down a full size Web site to fit into small screen is currently seen in Pocket PCs. Pocket PCs usually have relatively larger display window and higher resolutions than PDAs and WAP phones. Nevertheless, a recent research (Chan et al. 2002) indicates such method often leads to awkward rendering effects and poor usability, such as excessive scrolling and malfunctioned scripts. It is clear that content rearrangement is required for small displays. Version adaptation is simple and easy to implement. Once the version is ready, it can quickly respond to the user request to fit a particular platform. An obvious drawback of this approach is the labor involved in re-authoring and maintaining a growing number of versions. Furthermore, *transcoding* for specific (pre-adapted version) version is static. Gateway filtering no longer meets the content provider's flexibility needs either. Diversified browsing clients demand the separation of content and presentation for discriminative information delivery. It is difficult to separate content and presentation in HTML/WML conversion and it is desirable to have metadata to describe HTML elements (Kaasinen et al. 2000). Template based XML (data) /XSLT (presentation) approach is hence a very natural and nonproprietary solution. It allows the separation of data from presentation format and dynamically picks up the relevant template to do the transcoding on the fly.

The need to generate dynamic template and adaptable style sheets on the fly presents new challenges. Just like static adaptation, there will be management and maintenance difficulty with a growing number of XSLT style sheets and XML data files. Lum and Lau (2002) propose a method to achieve an optimal tradeoff between the real-time transcoding overhead (CPU cost) of the dynamic approach and the storage overhead of pre-adaptation (I/O cost) of the static approach. Their hybrid approach selectively pre-adapts a subset of content variants and leaves the generation of the residue to a dynamic algorithm that uses the pre-adapted subset as a base.

Transformation involves significant modification and restructuring on both content and structure in addition to basic syntactical transcoding. (Trevo et al. 2001, Bickmore and Schilit 1997). Usability guidelines and personalization techniques could be applied while content and structure are transformed. The combination of dynamic transformation and personalization could result in greater adaptability for wireless small screen browsers and for mobile users.

Personalization Level

Wireless handheld devices are well suited for personalization. However, how to efficiently obtain the user profiles, or how to discover the most interesting user browsing patterns is still an open research area for both wired and mobile Web personalization.

There are two common approaches to personalization. A common method used by many commercial Web sites is getting the user's profile and preferences by requiring the user to fill out online registration forms or questionnaires and later identifying the

user by his or her sign-in in order to provide recommendations or personalized content. This level of personalization relies heavily on getting human input, and has two drawbacks: a) the input is often subjective and prone to biases; and b) the profile will get outdated quickly (Mobasher et al. 2000). In the mobile Web context, wireless form factors present additional constraints. Either mini-keypad or pen-based Graffiti input method is far less convenient than desktop keyboard. It is necessary to avoid user input as much as possible. The second method is automatically discovering user preference from Web log data by applying appropriate data mining techniques. This method has been broadly known as Web mining (Kosala and Blockeel 2000). Web mining can be applied to the mobile Web to capture the mobile user's profiles and browsing patterns.

As discussed earlier, personalized and adapted results are mostly reduced data from the source content. Inspired by Heuer and Lubinski (1998), two levels of data reduction can be considered: system aware reduction and user intended reduction. Most personalization techniques (e.g., Nakano et al. 2002) are limited to filtering from available content, adjusting inline objects' quality and rearranging content delivery order for individual Web pages. A higher level of personalization with highly personalized profiles needs a querying power just as SQL provides for relational databases (Ozen et al. 2001).

Recent Trends

Hopefully, the emerging W3C standard xHTML (Extensible HTML, **www.w3.org/TR/xhtml1**) could unify the current incompatible structured markup languages supporting heterogeneous wireless handheld devices. At present, 3G-enabled PCS Vision[sm] service launched by Sprint has incorporated xHTML application in selected mobile phones and PDAs since 2002. Smart phones or more composite devices are emerging, which combine some functions of WAP phone, Palm, Windows CE, or other embedded lightweight operating systems. In order to better support and unify graphical display on heterogeneous mobile devices, the W3C SVG (Scalable Vector Graphics, **www.w3.org/TR/SVG**) Working Group has released two Mobile SVG Profiles (**www.w3.org/TR/SVGMobile**): SVGT (SVG Tiny) for low-level highly restricted mobile devices such as mobile phones, and SVGB (SVG Basic) for higher level less restricted mobile devices such as PDAs. Another emerging standard DRM (Digital Rights Management, **www.openmobilealliance.com/documents.asp**), specified by Open Mobile Alliance, is closely related to branded or commercialized content delivery. DRM tries to streamline the value chain of content business and standardize content copy protection mechanism. Whether such convergence would survive well in the mobile commerce market is still uncertain. As long as those constraints like small displays and slow input exist, adaptation techniques have to be applied. Technically, many constraints related to mobile computing infrastructure would be overcome by the advancement of new technologies. Nevertheless, the small display versus the portability convenience is always a trade-off. Voice access to the mobile Web content, embedding voice interface into handheld devices, is becoming a promising approach to alleviating small display restrictions. Advancements in voice recognition and text-to-speech (TTS), combined with the steady increase in computing power, have made the voice access approach viable. The voiceXML application in the WebViews implementation by Freire et al. (2001) is an example. However, research is needed to determine the best balance of the voice versus text and the kind of content suitable for voice presentation for wireless handheld devices.

Conclusions and Future Research

This paper presents a comprehensive review of constraints and approaches for adaptive content delivery over the mobile Web. The proposed classification scheme, the adaptation model, and the concept of dimensionality of adaptation represent a new and integrated approach to studying content adaptation for mobile services. Our ongoing research will: a) clarify and refine the adaptation model, variables, and measurements; b) design a prototype based on the dimensionality study; and c) conduct experiments to accomplish adaptability evaluation. Further research should address:

- How to coordinate and measure the dimensions of conversion complexity, usability, and personalization as featured in our proposed model?
- What new and established mobile usability guidelines could be applied to wireless content adaptation?
- What factors determine the complexity of content transformation?
- How could existing personalization techniques be applied to mobile Web and how effective are these techniques for mobile services?

References

Alanen, J. and Autio, E. "Mobile Business Services: A Strategic Perspective," In Mannecke, B. and Strader, T. (Eds.) Mobile Commerce: Technology, Theory and Applications, 2003, Hersey, PA: IRM Press, pp. 162-184.

Anckar, B., and D'Incau, D. "Value Creation in Mobile Commerce: Findings from a Consumer Survey", Journal of Information Technology Theory & Application, 4 (1), pp. 43-64.

Anderson, C. R., Domingos, P., and Weld, D. S. "Web Site Personalizers for Mobile Devices", Proceedings of the IJCAI Workshop on Intelligent Techniques for Web Personalization (ITWP), 2001b.

Anderson, C. R., Domingos, P., and Weld, D. S. "Personalizing Web Sites for Mobile Users", Proceedings of the 10th World Wide Web Conference (WWW10), 2001c.

Bharghavan, V., and Gupta, V. "A Framework for Application Adaptation in Mobile Computing Environments", Proceedings of the IEEE Computer Software and Applications Conference (COMPSAC), 1997.

Babaria, K., Giacoppo, A.S., and Kuter, U. "Single Item Search and Selection in Handheld Devices: a Pilot Study on the Effects of Font Size and Menu Design", available online: **http://www.cs.umd.edu/class/fall2001/cmsc838s/rust.doc**.

Buyukkokten, O., Garcia-Molina, H., and Paepcke, A "Accordion Summarization for End-Game Browsing on PDAs and Cellular Phones", Proc. of Human-Computer Interaction Conference 2001. Seattle, 2001b.

Buyukkokten, O., Garcia-Molina, H., Paepcke, A. and Winograd, T. "Power Browser: Efficient Web Browsing for PDAs", Human-Computer Interaction Conference 2000, The Hague, The Netherlands, 2000a.

Bharadvaj, H., Joshi, A., and Auephanwiriyakul, S. "An Active Transcoding Proxy to Support Mobile Web Access". Proc. 17th IEEE Symposium on Reliable Distributed Systems, 1998.

Bickmore, T.W. and Schilit, B. N. "Digestor: Device-Independent Access To The World Wide Web". In Proceedings for the Sixth International World Wide Web Conference, 1997.

Chan, S., Fang, X., Brzezinski, J., Zhou, Y., Xu, S., and Lam, J. "Usability for Mobile-Commerce across Multiple Form Factors", Journal of Electronic Commerce Research, VOL. 3, NO. 3, 2002, pp187-199.

Freire, J., and Kurmar, B., "Web Services and Information Delivery for Diverse Environments", VLDB Workshop on Technologies for E-Services, 2000.

Freire, J., Kurmar, B., and Lieuwen, D. "WebViews: Accessing Personalized Web Content and Services", in Proc. of WWW10, 2001.

Gaedke, M., Beigl, M.l, Gellersen, H.W., and Segor, C. "Web Content Delivery to Heterogeneous Mobile Platforms", Advances in Database Technologies, Lecture Notes in Computer Science (LNCS), Vol. 1552, Springer Verlag, November 16-19, 1998.

Han, R., Peret, V., and Naghshineh, M. "WebSplitter: a Unified XML Framework for Multi-Device Collaborative Web browsing", CSCW'00, Philadelphia, PA. 2000.

Heuer, A., and Lubinski, A. "Data Reduction – an Adaptation Technique for Mobile Environments", IMC'98, Rotock, Germany. 1998.

Jones, M., Marsden, G., Mohd-Nasir, N., and Boone, K. "Improving Web interaction in Small Screen Displays", Computer Networks 31 (1999), pp.1129-1137.

Kaasinen, E., Aaltonen, M., Kolari, J., Melakoski, S., and Laakko, T. "Two Approaches to Bringing Internet Services to WAP Devices", 9th International World Wide Web Conference. Amsterdam, 2000.

Kannan, P., Chang, A., and Whinston, A. "Wireless Commerce: Marketing Issues and Possibiliteies, " Proceedings of the 34th Hawaii International Conference on Systems Sciences. Los Alamitos, CA: IEEE Comp Soc., 2001.

Kim, H., Kim, J., Lee, Y., Chae, M., and Choi, Y. "An Empirical Study of the Use Contexts and Usability Problems in Mobile Internet", Proceedings of the 35th Hawaii International Conference on System sciences, 2002.

Kosala, R., and Blockeel, H. "Web Mining Research: a Suvey", ACM SIGKDD Explorations, July 2000.

Kunz, T., and Black, J. "An Architecture for Adaptive Mobile Applications", Proceedings of Wireless 99, the 11th International Conference on Wireless Communications, Canada, 1999

Lankhorst, M., Van Kranenburg, H., Salden, A., and Peddemors, A. "Enabling Technology for Personalizing Mobile Services", Proceedings of the 35th Hawaii International Conference on System sciences, 2002.

Lum, W.Y., and Lau, F. C.M. "on Balancing Between Transcoding Overhead and Spatial Consumption in Content Adaptation", MOBICOM'02, Atlanta, Georgia, 2002.

Mobasher, B., Cooley, R., and Srivastava, J. "Automatic Personalization Based on Web Usage Mining", communications of the ACM, (43:8), pp: 142-151, 2000.

Nakano, T., Harumoto, K., Shimojo, S., and Nishio, S. "User Adaptive Content Delivery Mechanism on the World Wide Web", SAC, Spain. 2002.

Ozen, B., Kilic, O., Atlinel, M., and Dogac, A. "Highly Personalized Information Delivery to Mobile Clients", MobiDE 2001, USA

Schmidt, A., Schröder, H. and Frick, O. "WAP-Designing for Small User Interfaces", CHI 2000 Extended Abstracts, Conference on Human Factors in Computing Systems, 2000.

Shim, J. P., Bekkering, E., and Hall, L. "Empirical Findings on Perceived Value of Mobile Commerce as a Distribution Channel", Eighth Americas Conference on Information Systems, 2002.

Steinberg, J., and Pasquale, J. "A Web Middleware Architecture for Dynamic Customization of Content for Wireless Clients", WWW2002, Honolulu, Hawaii, USA. 2002

Trevo, J., Hilbert, D. M., Schilit, B.N., Koh, and T. K. "from Desktop to Phonetop: a UI for Web interaction on Very Small Devices", UIST, Orlando, FL. 2001.

Tsalgatidou, A., Veijalainen, J. and Pitoura, E. "Challenges in Mobile Electronic Commerce", in IeC 2000, 3rd International Conference on Innovation through E-Commerce, Manchester UK. 2000.

Varshney, U., and Vetter, R. "Mobile Commerce: Framework, Applications and Networking Support," Mobile Networks and Applications 7, PP. 185-198. 2002.