FUTURE WIRELESS APPLICATIONS FOR A NETWORKED CITY: SERVICES FOR VISITORS AND RESIDENTS

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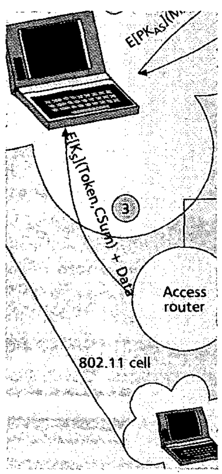


In its entirety, the Lancaster GUIDE system comprises a citywide wireless network based on 802.11, a context-sensitive tour-guide application with, crucially, significant content and a set of supporting distributed systems services.

ABSTRACT

Future wireless networks will offer near-ubiquitous high-bandwidth communications to mobile users. In addition, the accurate position of users will be known, either through network services or via additional sensing devices such as GPS. These characteristics of future mobile environments will enable the development of location-aware and, more generally, context-sensitive applications. In an attempt to explore the system, application, and user issues associated with the development and deployment of such applications, we began to develop the Lancaster GUIDE system in early 1997, finishing the first phase of the project in 1999. In its entirety, GUIDE comprises a citywide wireless network based on 802.11, a context-sensitive tour guide application with, crucially, significant content, and a set of supporting distributed systems services. Uniquely in the field, GUIDE has been evaluated using members of the general public, and we have gained significant experience in the design of usable context-sensitive applications. In this article we focus on the applications and supporting infrastructure that will form part of GUIDE II, the successor to the GUIDE system. These developments are designed to expand GUIDE outside the tour guide domain, and to provide applications and services for residents of the city of Lancaster, offering a vision of the future mobile environments that will emerge once ubiquitous high-bandwidth coverage is available in most cities.

INTRODUCTION

It is widely anticipated that future mobile users will have near-ubiquitous access to high-bandwidth wireless communications. While this connectivity may take many forms, such as 3G public networks or semi-private high-bandwidth access points based on technologies such as 802.11 (e.g., [1]), the overall effect will be to enable new classes of communications-oriented mobile applications.

In parallel with the emergence of high-bandwidth wireless communications, significant progress has been made in the field of location technologies. In particular, sensor technologies such as GPS and network-based services such as those required to support the location of 911 callers make it likely that, in addition to good connectivity, future mobile users will have access to accurate positional information.

These developments in communications and location technologies have led to significant interest in the field of location-aware applications. Such applications exploit location information to provide services that are tailored to a user's physical location. Examples from the literature include Electronic Post-It Notes [2], applications from the Active Badge project [3], and Cyberguide [4]. Since these applications often take many factors of the user's context into account (not just location), they are usually referred to as context-aware or context-sensitive [2, 5] applications.

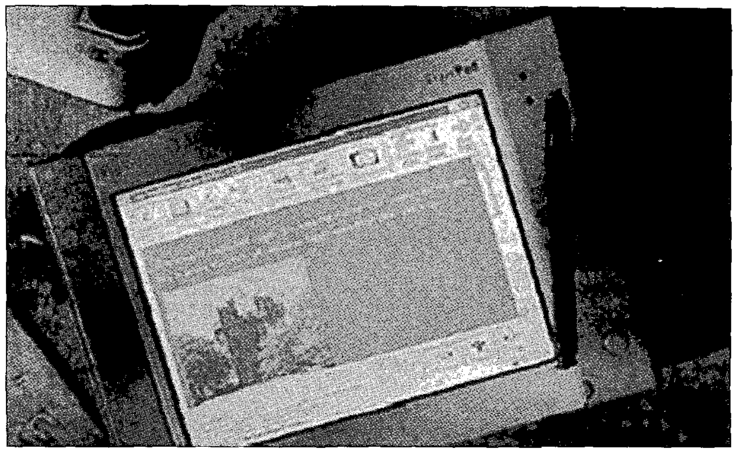
In early 1997 we initiated a project called GUIDE to investigate the development of context-aware applications. The overall aim of the GUIDE project was to develop a context-aware tour guide for visitors to the city of Lancaster. Such an aim was not in itself novel: early work by researchers on the Cyberguide project had already produced a tour guide application for a limited geographic area. However, the GUIDE project, as it was conceived, had two unique characteristics. First, we decided to rely heavily on a high-bandwidth wireless communications infrastructure for information dissemination. This was in sharp contrast to the approaches adopted by other projects at the time, in which data was either held locally (e.g. [4]) or transmitted using low-bandwidth public wireless networks. Second, and somewhat more significant, we decided to build a working prototype system that we would deploy in the city of Lancaster for use by members of the general public. As a result, it was envisioned, we would be able to explore both architectural issues and usability issues and report on these in the literature.

Between 1997 and 1999 we designed, developed, and deployed the GUIDE system, culminating in a field-trail involving members of the general public. The results of this project have been widely reported (e.g., [6, 7]). The experience of working with GUIDE and, in particular, of conducting a field trial involving members of the public has given us a unique insight into the role of context-aware applications in a city environment. In this article we describe a number of future wireless applications and supporting services that have been motivated by this insight and collectively form part of the GUIDE II system, the successor project to GUIDE.

THE GUIDE SYSTEM

The GUIDE system has been developed to provide city visitors with a hand-portable context-aware tourist guide. The system enables tourists to discover information about the city, interact with online services (e.g., to make hotel reservations), and obtain walking directions, either to a single destination or as part of a tour of attractions in the city.

The end systems used by tourists are tablet-based PCs (Fujitsui TeamPad 7600s [8]) equipped with Lucent Technologies ORiNOCO 802.11 wireless networking cards (Fig. 1).

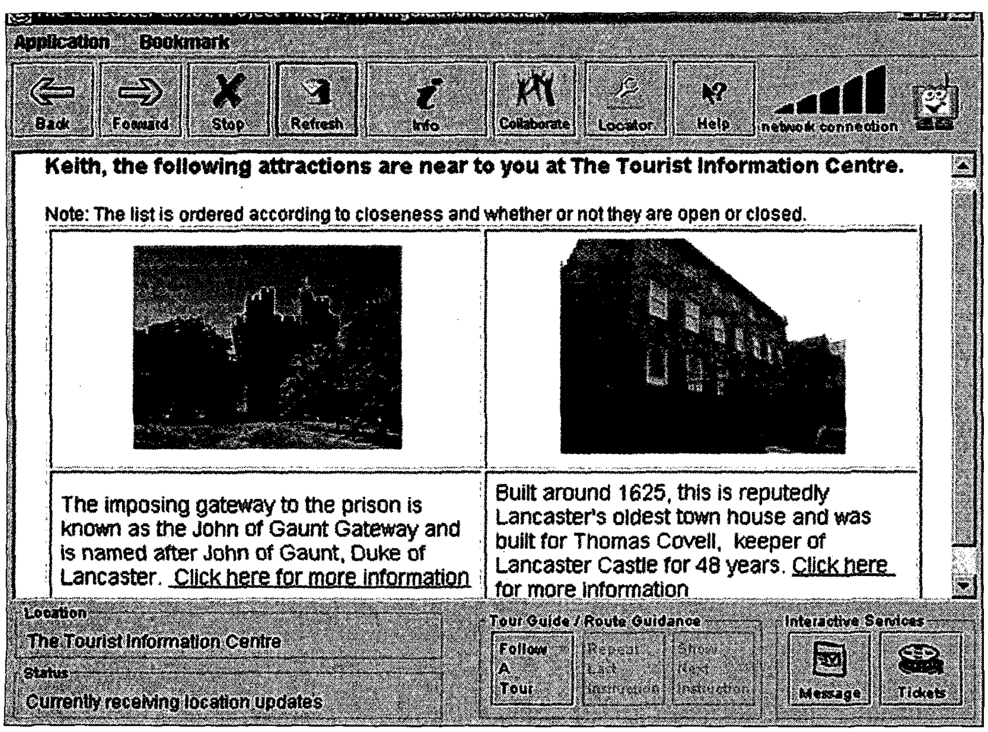


■ Figure 1. *The GUIDE end system.*

The end systems use the wireless network cards to communicate with a series of base stations we have deployed in the city of Lancaster. These base stations perform two distinct functions. First, they are responsible for disseminating information to the GUIDE units. This is achieved using a broadcast protocol that repeatedly transmits pages of information frequently accessed by users in the geographic area covered by the cell [7]. These pages are cached by the end systems and used to serve user requests. This technique is used to improve the scalability of the GUIDE system: most user requests are for pages that are in the end system's cache and hence do not require an explicit http request. Cache misses cause a request to be sent from the client to the cell server and the requested page to be added to a future broadcast cycle, enabling the new information to be disseminated to all users in the cell.

Cell servers also provide location information to the GUIDE units by periodically broadcasting beacons containing their cell identifier.

Figure 2 shows a sample screen from the GUIDE application.



■ **Figure 2.** *An example of a dynamically created page.*

LARA++ routers have been developed to provide a flexible platform for introducing new services into the network. More specifically, each router contains a lightweight component framework and a high-performance packet classifier, allowing the dynamic introduction of new network services through the instantiation of service components.

In the current version of the system we have information on approximately 120 distinct locations in the city including tourist attractions, restaurants, and shops. Full details of the GUIDE system can be found in [6].

Analysis

In order to evaluate the GUIDE system we used a series of expert walkthroughs and field trials. The expert walkthroughs provided an opportunity for members of the HCI community to evaluate early versions of the GUIDE system and provide feedback. Following these walkthroughs and the associated revisions to the GUIDE system, we conducted a field trial using members of the general public.

The field trial lasted for a period of four weeks and involved approximately 60 subjects. The results of this field trial were previously reported in [6]. For the purposes of this article we simply highlight the main findings:

- The majority of users appreciated the location-based nature of the system, even though this information was not always accurate.
- The provision of interactive services and access to the Web allowed us to create appealing services.
- Children and teenagers were particularly active users of the system (as measured by the level of interaction recorded).

As a result, we believe that in the future there will be significant interest in wireless applications that are both location-based and oriented toward supporting user communications. Whether the systems will be more generally context aware is still open for debate.

Furthermore, we take the active involvement of young people in GUIDE to be evidence that many of these applications will be adopted first by the younger generation (mirroring the uptake of the GSM short messaging service, SMS).

In the second phase of the GUIDE project (GUIDE II) we are exploring the issues raised by these findings in more detail. In particular, we are attempting to answer the following questions:

- Do our findings generalize beyond the tour guide domain to applications aimed at residents of Lancaster?
- Can we successfully develop applications that use context, including location, to enhance social communications?
- Given that computer-based access to services and information was popular with tourists, how should we integrate existing bricks and mortar shops and services for the benefits of residents and visitors alike?
- What further extensions can be made to the existing GUIDE system to improve the overall user experience?

In the remainder of this article we consider these issues, describing our current ideas not only for applications, but also for the system services necessary to support them.

Future Applications: Design, Implementation and Support

Infrastructure Developments

One major shortcoming of the existing GUIDE system is that the communications infrastructure is designed to support only the GUIDE application. More specifically, we do not support general IP access from GUIDE units and, since we need to restrict access to the wireless network, only GUIDE end systems may be connected. However, there are clearly many interesting applications applicable to city residents that are not currently supported by GUIDE. In order to experiment with such applications it is clear that we need to "open up" the existing network infrastructure to support full network layer routing of IP datagrams without compromising the integrity and robustness of the existing GUIDE system. In addition, in GUIDE II we envisage using a richer set of communication technologies (e.g., Bluetooth for small picocells), thus creating a heterogeneous networking infrastructure.

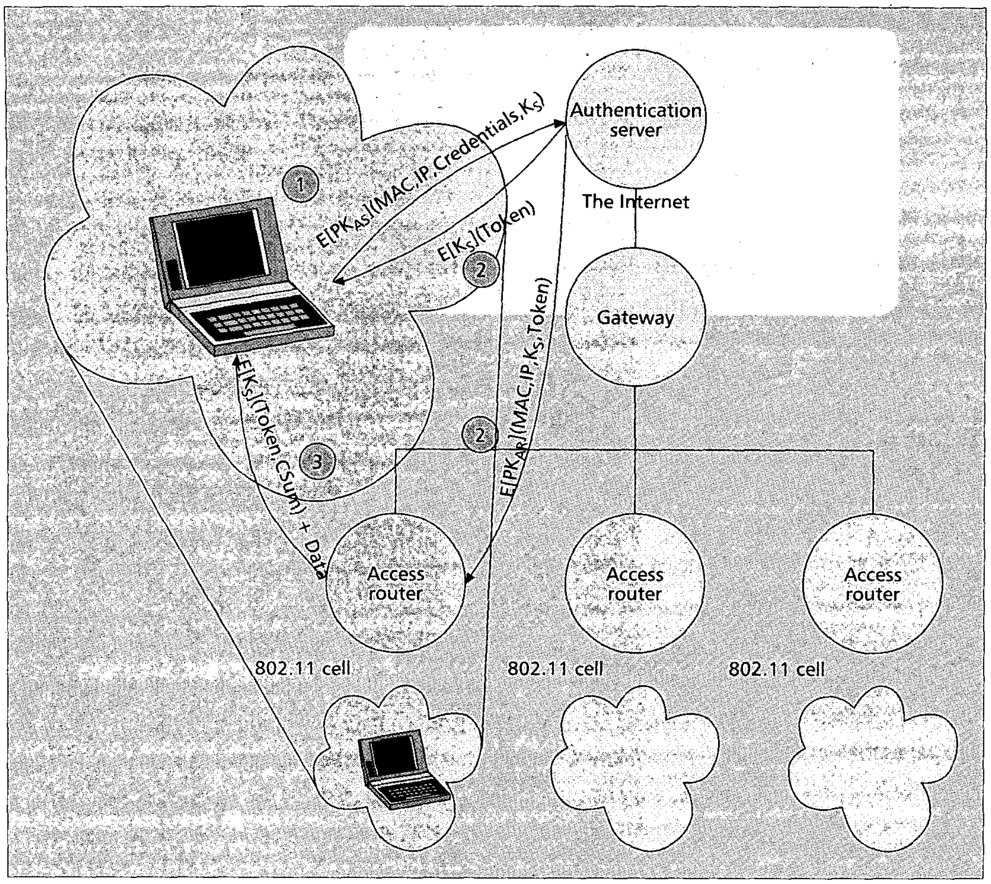
In making this transition from a closed network to an open one, we are also proposing to move from IPv4 to IPv6. This will provide us with a more realistic test environment for future mobile applications since it is widely anticipated that these will be engineered using IPv6. Furthermore, in addition to the issues of access control described above, we are also keen to explore the development and deployment of network services such as proxies and filters that exist at the edges of the fixed network and are designed to improve utilization of the wireless link. In general, these services have been difficult to evaluate in the wide area since they rely on access to the fixed/wireless network interface. However, in GUIDE we control this interface on a citywide scale and hence can evaluate these services in a realistic setting.

In short, the new requirements for the GUIDE II network are for a wireless IP network that can offer secure, accountable, and controllable access with the option of adding new functionality at the edges of the fixed network. Our approach to this problem is based on the introduction of programmable routers into the GUIDE II infrastructure. These routers are based on the LARA++ programmable router architecture [9].

LARA++ routers have been developed to provide a flexible platform for introducing new services into the network. More specifically, each router contains a lightweight component framework and a high-performance packet classifier, allowing the dynamic introduction of new network services through the instantiation of service components. Components are run in user memory and are thus separated from the router's core functionality (in kernel space). Virtual memory mapping techniques are used to support zero-copy operations between the router core and the component services.

While in fixed networks the issue of performance normally dictates that specialized hardware be used for routing, at the edge of the fixed network the overall throughput of the router is of less concern and the flexibility afforded by the LARA++ system outweighs the overhead. In particular, using the LARA++ routers enables us to experiment with the introduction of edge services as discussed earlier in this section.

In the first instance these routers will be used in the implementation of a secure access solution for the GUIDE infrastructure, as described



■ **Figure 3.** *The access network architecture.*

It is clear that any "pubic access" IP network must provide fine-grained access control, traffic monitoring and mechanisms to enable the enforcement of network management policy and accounting.

in the following sections. However, the routers also provide a useful point at which to introduce new services into the live network, such as charging, differentiated services, and traffic filtering.

Requirements for Secure Network Access

Based on the above discussion, it is clear that the requirements for the GUIDE network infrastructure have now changed; rather than the focused requirement to support one context-aware application with a single objective, the GUIDE II infrastructure must support a range of additional context-sensitive services and, potentially, a number of legacy IP applications.

However, permitting general IP access to networks that include technology available to a wide user base (the IEEE 802.11 family) has a number of implications for GUIDE II. In particular, our current system uses a broadcast-based approach to data dissemination in order to allow the system to accommodate large numbers of tourists in a single cell [7]. Once support for general-purpose IP traffic is enabled, the range of applications that can be deployed by users can no longer be controlled, and specialist protocols that assume complete control of the wireless channel (e.g., the one we currently employ) will become impractical. Moreover, such a network could offer a haven for miscreants since dynamic addressing makes identifying and tracking a specific host more difficult. Potential abuses of the system might include using our network as a staging post for malicious activity; the setting up of illicit Web services (e.g., exchanging unlicensed software or music, or data of an unsavory nature); or simply using the system to act as a gateway for free Internet access (abuse of this facility could effectively lead to denial of service attacks on the GUIDE II system). It is clear therefore that any "pubic access" IP network must provide fine-grained access control and traffic monitoring, and mechanisms to enable the enforcement of network management policy and accounting.

Access Network Architecture

The components of the GUIDE II public access wireless network are illustrated in Fig. 3. To gain access to the network the client end system must first authenticate itself with an authentication server. The client generates a session key and passes this together with its MAC and IP addresses, user name, and password to the authentication server, all encrypted with the server's public key.[1] If the user name and password are known the user is issued a valid access token, encrypted with the session key. This dialog between the client and the authentication server is the only traffic permitted from a client that does not hold a valid token.

Once the authentication server has issued the token it updates the appropriate access router with the current MAC address, IP address, and

[1] *Note that while this approach is more than adequate for the limited numbers of users participating in our trial system, we may need to integrate support for more scaleable identity (e.g., PGP keys or Microsoft Passport) and authentication services at a later date.*

Our approach is further differentiated by the ability to dynamically deploy and reconfigure network's services into the running network configuration, which is crucial in providing us with the generic research facilities we require.

session key binding for the client. Thereafter the client must include the token (and a digest calculated from the dynamic fields in the IP packet) as an extension header with all user datagrams.

We describe each of the three key architectural components: an authentication server, a gateway router, and one or more access routers (typically one per wireless cell) in more detail below.

Authentication Server — The authentication server is responsible for verifying the credentials of a user requesting access to the network. Access is granted by distributing pseudo-random tokens to each client as they authenticate based on their username, password, IP, and MAC addresses. The token and an SHA1 message digest of the user data and IPv6 header fields form a custom IPv6 extension header that is added to each user as a sign of validity (analogous to a certificate of authenticity).[2] Each user is forced to authenticate when entering or roaming into a wireless cell. Re-authentication is triggered in the client IP stack by the Mobile IPv6 neighbor discovery process. The credentials passed by the user not only ensure that a user is registered with the system, but additionally enable us to associate specific credentials to a known set of MAC addresses (particular end systems) and cells (to tie services to a specific set of cells etc.). The IP address allows us both to strengthen security (each MAC address should have a single IP address within the system at any one time) and track an end system's whereabouts (for location-based services).

Gateway Router — The gateway router sits between the core of the access network and the campus backbone. The role of the gateway router is to ensure that only traffic forwarded by valid access routers is permitted onto the network. The gateway router is preprogrammed with the MAC addresses of the access routers and acts as a firewall; blocking traffic from unknown sources. In addition, we can implement specific packet filters within the gateway router designed to protect key services (e.g., the authentication server) from attack; for example, only permitting traffic up to a particular rate limit on certain destination ports.

Access Router — The access router will initially contain active packet filter components, responsible for enforcing the access policy of the network. A modified protocol stack on the client end system ensures that the client's authentication token is attached to each datagram. The router forwards only packets bearing a valid access token. Each router maintains an access control list that is updated by the authentication server each time a client in that router's cell is awarded an access token. Access credentials can be *optimistically* distributed to ensure smooth handover between neighboring cells.[3] The access tokens are only valid for a short time (10 minutes) before the client must re-authenticate, in order to complicate the process of obtaining, and limit the usefulness of, intercepted credentials. The combination of per-cell filtering and soft state at the routers enables us to enforce a wide range of access policies (e.g., users may be constrained to use the network at specific locations, time intervals, or durations).

It should be noted that controlling access to a public network is not a new problem, and a number of solutions have already been proposed (examples include the SPINACH system from Stanford [11], MS CHOICE developed at Microsoft Research [1] and the CMU NetBar system [12]). Furthermore, commercial access points such as the Orinoco AS-2000 [13] are now available, and there have been a number of recent developments in IEEE 802.1x standardization specifically designed to address the known issues with the 802.11 WEP [14].

However, none of the systems thus far developed offer us the set of services required for GUIDE II. More specifically, none of the above approaches have been designed to support Mobile IPv6 in heterogeneous networking environments. Our approach is further differentiated by the ability to dynamically deploy and reconfigure network services into the running network configuration, which is crucial in providing us with the generic research facilities we require. A full comparison between the GUIDE II access architecture and other solutions can be found in [15].

Access to Existing Services

In the preceding section we considered how to facilitate access to people and electronic services within our local city. However, currently there are significant numbers of services (e.g., restaurants, cafes, and taxi services) people wish to have access to electronically (e.g., using the GUIDE infrastructure) that have no online presence. Moreover, it seems probable that such services are unlikely to be in a position to accept online reservations, bookings, and orders for some time to come. In deploying GUIDE II we do not wish to contribute to the creation of a "digital divide" in the city between those services that have an online presence and those that do not.

To address this issue we have constructed an *interactive services gateway* system that aims to broker electronic requests for services with "legacy" human-centric services that currently provide no Internet access to their facilities. In essence, GUIDE users interact with the gateway via a set of Web pages while traditional service providers interact with the gateway via a conventional phone interface. The key is for the gateway to adequately interface between these two domains, addressing issues such as the possibility of GUIDE users losing network connectivity during the process.

Gateway Overview

The gateway utilizes prerecorded messages and text-to-speech to relay requests for service via a standard telephone line to each client organization. The recipient of the call uses DTMF (or touch) tones to navigate the booking options and choose whether or not to accept each request.

Each interactive service to which a GUIDE user has access comprises the following elements:

- An *interactive service logic* (ISL) state machine denoting the sequence of options, DTMF tones, and recorded messages that realize the booking of a particular service.

[2] A similar packet tagging and filtering approach is employed by the Microsoft CHOICE system. However, using extension header processing we are able to forward our protocol traffic through existing routers, allowing us a more flexible network topology (i.e. access routers do not have to be first hop routers).

[3] Note that recent advances, such as the context transfer protocol [10], may soon provide a standards compliant mechanism for smooth handover support within our network.

- The set of hypertext pages presented to the GUIDE user. These pages contain special markup tags that represent the parameters of the specific request (e.g., number of people, time of booking).
- A corresponding set of *check objects* that perform client-side validation of the parameters entered by a user to make sure they fall within the acceptable bounds for a given request (e.g., ensuring that the date and time entered corresponds to the opening hours of the restaurant).

To ease the development of these sets of elements (an instance of each element is required for each new café etc. added to the system), we have developed an *interactive service editor* that allows us to swiftly generate the service logic and templates for the hypertext pages and check objects.

Gateway Components

The components of the interactive services gateway that execute service requests are illustrated in Fig. 4.

Client-Side System —To support interaction with the gateway we have introduced a new component into the GUIDE client unit called the *interactive service view* (ISV). The ISV is responsible for validating the user's requests using the corresponding check objects for a given service and presenting status update requests to the user as their request is processed by the server-side system. The ISV thus ensures that the service provider is not interrupted by requests they could never satisfy (due to the requirements specified in the check objects). Also, the client is kept informed of the status of their requests whenever connectivity is available (e.g., the request might be queued at the server behind other requests, or the telephone may be engaged at the service provider).

Cell Server — As previously discussed, the current GUIDE system does not support IP routing; GUIDE units are assigned nonroutable class A IP addresses and the cell servers do not support routing between network interfaces. In order to support interactive services, where a user's service request may outlive the time the user spends in a given cell, we must address the IP routing limitations at the application layer.

Each cell server runs an *interactive service cell agent* (ISCA). The ISCA acts as an intermediary for interactive service requests and status messages, ensuring that the client's movements are tracked for the lifetime of the request so that status updates continue to reach the client as their request progresses (akin to the home and foreign agents used by Mobile IP). The ISCA may present the status updates to the user by pushing hypertext pages to the GUIDE client browser or through interactive dialog boxes. This component was developed for the existing GUIDE network infrastructure and will not be required as we migrate to the GUIDE II system.

Server — Requests for the GUIDE client units pass via the ISCA to the interactive service gateway server. The server is attached to the public switched telephone network (PSTN) via one or more voice-capable modems. As requests arrive at the server they are queued pending processing and are scheduled in a round-robin fashion as each of the modems become available.

As each request arrives it is assigned its own thread that instantiates the ISL (a set of Java classes in the current implementation) to interact with the specific service provider.

The ISL threads report state changes back to the clients via the ISCAs (e.g., "waiting for telephone resource," "calling provider," "connected"). Termination of a particular ISL thread occurs when the ISL reaches a terminal state (the request has been accepted and the booking made, or the request cannot be fulfilled). Each request is assigned a unique identifier to allow tracking and cancellation of requests as necessary.

In order to begin evaluating this system service logics have been defined for a small number of restaurants and takeaways in the city. We hope to field trial this aspect of the GUIDE system in the near future.

New GUIDE Services

The existing GUIDE system enables members of the general public to enhance their visit to the local city with a wealth of additional context-sensitive information — this is, in a sense, an augmented reality system, overlaying the physical world with virtual content. Based on the GUIDE concept there are a number of extensions we believe would enhance the visitor's experience with the system.

The existing GUIDE system enables members of the general public to enhance their visit to the local city with a wealth of additional context-sensitive information. This is, in a sense, an augmented reality system, overlaying the physical world with virtual content.

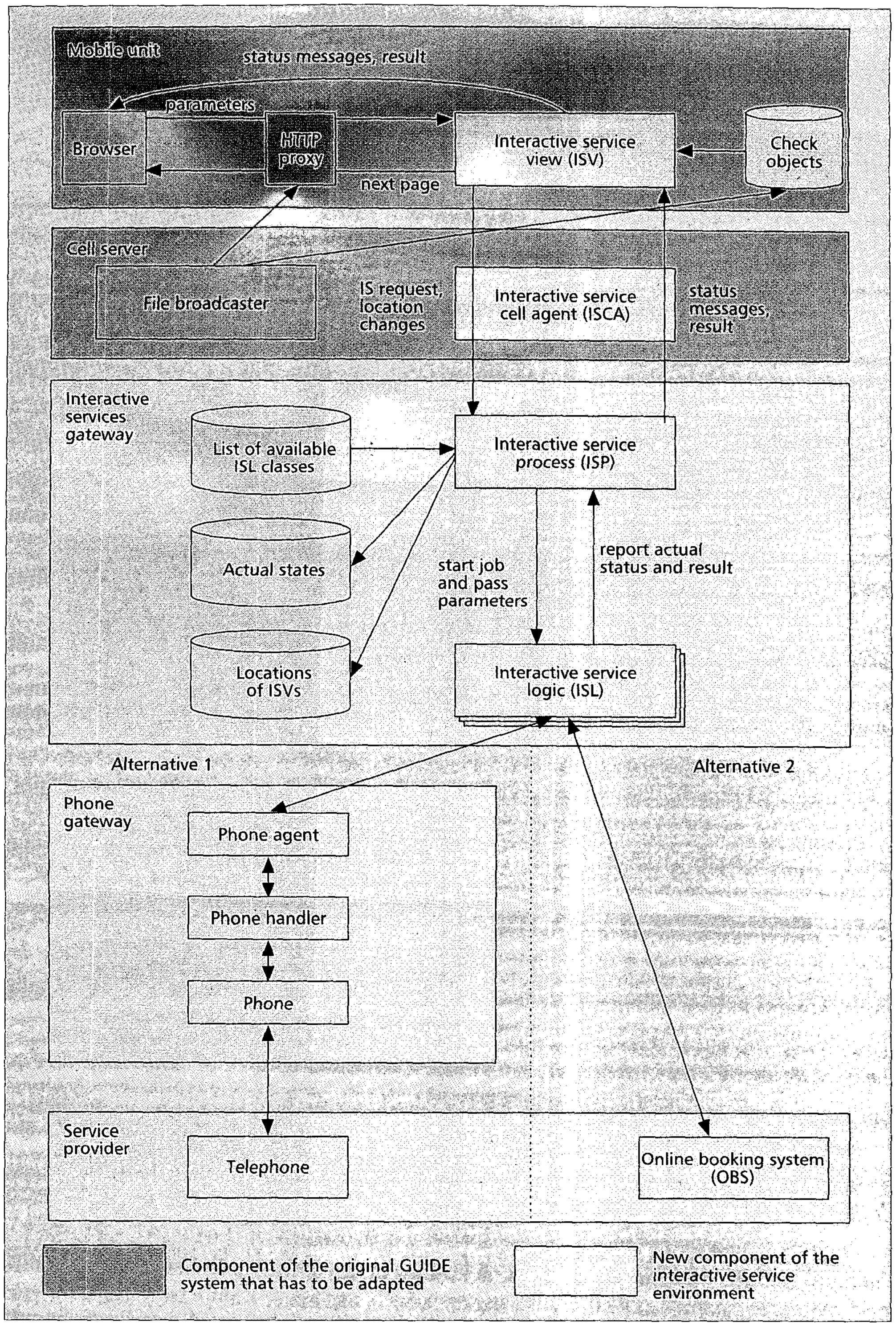
Educational Tours through Time — The current GUIDE system presents tourists with a view of the city as it exists now, in the 21st century. A technically trivial enhancement (although one that would require a significant body of authoring work), would be to add the facility to "travel through time." For example, users could be provided with a scroll bar that allowed them to set the GUIDE system to a particular point in time, and see information and directions pertaining to that time (within practical limitations of course).

"Famous" Tours of the City — GUIDE currently allows tourists to select between one of a number of predefined tours (e.g., short, long) or the bespoke custom tour wizard to choose their tour. One possibility for extension would be to track where people go and allow them to volunteer to have their tours "exported" so that others might follow their paths at a later date. Such a system might aggregate tourist movements to extract the "most popular" tours of the city, proving a model for visitors to provide each other with help navigating the city [16].

A further possibility (although one that may not apply so strongly to Lancaster) might be to allow users of the system to follow predefined tours of famous people (e.g., the path taken by a famous historical figure or an actor in a popular film).

Supporting Advance Reading by Tourists — With the current GUIDE system users are not predisposed to using the tour generation facilities [6]. In particular, visitors do not like to spend the time necessary to supply all of the information required for their GUIDE unit to generate optimum tours. We would

The current GUIDE system provides *interactive messaging* systems to allow groups of tourists to send messages to each other, to arrange to rendezvous and so on. A possible enhancement would be providing a simplified facility to allow users to "track a loved one."



■ **Figure 4.** *The interactive services gateway.*

like to capitalize on some tourists' willingness to research an area before visiting it by enabling potential visitors to the city to interact with the GUIDE system prior to their arrival. For example, visitors could read about and bookmark attractions. When they arrived in the city they could pick up a GUIDE unit and have their profile and bookmarks automatically downloaded to the unit, creating a tour that encompasses those attractions they found interesting before their travel.

Keeping in Touch with Loved Ones — The current GUIDE system provides interactive messaging systems to allow groups of tourists to send messages to each other, to arrange to rendezvous and so on. A possible enhancement would be providing a simplified facility to allow users to "track a loved one"; that is, let the system track a user's location and provide update information, explicitly promoting awareness of each other's movements (the loved one being tracked may also want to be aware that they are being tracked, which may promote a sense of security or togetherness).

A family group might be able to exploit such a system to allow the whole group to pursue their interests while retaining awareness of the movements of the remainder of the group, in the certain knowledge that they can regroup whenever they wish.

Virtual City Games — A further augmentation of the GUIDE units could allow for context-sensitive games to be enacted within the city. For instance, virtual objects or characters from a game could be positioned (or move) within the city. Players of the game would move through the physical space of the city, perhaps experiencing some alternative reality described by the information presented to them by the GUIDE units, meeting these characters and enacting roles within the game.

Use of Streaming Media — The existing GUIDE system's user interface is based on a Web browser with text and static images rather than an approach that makes use of streaming media. This reflects both the social attitudes and technology available at the time of development (i.e., the late 1990s). More specifically, the widespread use of cellular telephones and hands-free kits has made people more accepting of interacting using audio within city environments, while the emergence of lightweight yet powerful portable devices such as the Compaq iPAQ make it possible to deliver good quality video to mobile users. As a result of these developments we plan to reinvestigate the use of streaming media within the system's user interface, a notion that was discarded during GUIDE's first development cycle. This will enable us to design and evaluate alternative interaction metaphors, such as an avatar-based approach, which may be more suited to the limited screen real estate available on a compact PDA.

We are in the process of exploring these ideas further under the auspices of the GUIDE II project.

Context Sharing

Motivation

Following on from the previous section, in our work we also aim to determine the extent to which the sharing of personal context (e.g., location or activity) can be used to support and benefit the activities of both city visitors and city residents.

One type of context that may be shared is of location; this could be used, say, in order to help visitors or residents to determine the current hot spots in Lancaster. Alternatively, the information could be used to notify people when a friend or colleague is in a nearby café. Other types of context that may be shared include the activity of users or their opinions regarding attractions or events taking place in the city.

To date, there are few examples of systems that make explicit use of context sharing in order to support cooperation between users. Furthermore, the examples that do exist tend to be situated in the work domain, the most comprehensive research being that carried out by Olivetti Research Laboratories [17, 18]. In our work we hope to gain a strong insight into the various human factors issues likely to arise when sharing personal context in the leisure domain.

> The obvious type of context that may be shared is that of location and this could be used in order, for example, to help visitors or residents to determine the current "hot spots" in Lancaster. Alternatively, the information could be used to notify people when a friend or colleague is in a nearby café.

An Illustrative Scenario

By way of an illustrative example scenario, consider the following problem: a geographically distributed group of tourists wishes to reunite at a café within the city. However, the group is unfamiliar with the layout of the city and requires some assistance from GUIDE.

The following two approaches illustrate how the sharing of location context could be used in order to facilitate the group's reunion:

- The system could take an *active* role by, for example, providing an assistive agent that recommends a café as a rendezvous point based on a collection of context, including the current location of each group member and the layout of the. On calculating the most suitable café the system could then guide each group member there.
- The system could take a *passive* role by simply providing each group member with an awareness of the current location of the rest of his/her group. The onus would then be on each individual to use this information in order to select a suitable café.

This simple scenario reveals an interesting dimension for considering the way in which context may be shared (i.e., the extent to which the system takes on an active or a passive role in facilitating the group's task). In this scenario, when the system adopts an active role, the group members are not required to consider the actual location of each other (but are required to trust the judgment of the system). Alternatively, when the system adopts a passive role, the completion of the group's task requires some form of social negotiation.

Human Factors Issues

The aforementioned scenario clearly introduces one of the key human factors issues associated with the sharing of personal context: privacy. In more detail, one can envisage difficulties with the passive approach if certain group members do not wish their own location within the city to be made known across the group. However, with the active approach (and given an appropriate level of trust in the system), users might be prepared to share their location with the system agent in order to facilitate the group's reunion.

The experiments conducted at Olivetti involved workers being asked to wear "active badge" position sensors. One use of the badges was to provide colleagues with an awareness of the location of coworkers. However, in general, workers found this lack of privacy unacceptable, and many stopped wearing their active badges in order to prevent the tracking and disclosure of their location from taking place [17, 18].

It is clearly important to provide users with sufficient flexibility to control the trade-off. However, at a usability level the difficulty becomes one of empowering the user with sufficient control while maintaining a system that is not overly complex to configure and use.

In effect, there is actually a dual trade-off between awareness of the activities of others and privacy, and between awareness and the level of disturbance or disruption to a user this awareness causes [19]. It is clearly important to provide users with sufficient flexibility to control the trade-off. However, at a usability level the difficulty becomes one of empowering the user with sufficient control while maintaining a system that is not overly complex to configure and use. Our attempts at developing a user interface to tackle these conflicting requirements are described in [20].

Concluding Remarks

In this article we have presented our plans for the development and deployment of future wireless applications for tourists and residents of a city equipped with a high-bandwidth wireless infrastructure. These plans are based on an analysis of the present GUIDE system and include:

- Provision of public access points to allow city residents to use the GUIDE infrastructure
- Development of a new gateway to integrate existing city services into the GUIDE system
- Extensions to the original GUIDE application to include new features that improve the overall user experience
- A detailed investigation of the social and human factors issues arising from the sharing of context

To date we have completed the interactive services gateway and are working on finalizing our access routers ready for deployment.

We believe our system provides a good insight into the types of high-bandwidth environments that will be deployed in the future, and the issues described in this article will become increasingly relevant as these environments become more widespread.

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Biographies

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