Composable ad hoc location-based services for heterogeneous mobile clients

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This paper introduces a comprehensive architecture that supports adapting a client device's functionality to new services it discovers as it moves into a new environment. Users wish to invoke services – such as controlling the lights, printing locally, gaining access to application-specific proxies, or reconfiguring the location of DNS servers – from their mobile devices. But *a priori* standardization of interfaces and methods for service invocation is infeasible. Thus, the challenge is to develop a new service architecture that supports heterogeneity in client devices and controlled objects while making minimal assumptions about standard interfaces and control protocols. Four capabilities are needed for a comprehensive solution to this problem: (1) allowing device mobility, (2) augmenting controllable objects to make them network-accessible, (3) building an underlying discovery architecture, and (4) mapping between exported object interfaces and client device controls. We motivate the need for these capabilities by using an example scenario to derive the design requirements for our mobile services architecture. We then present a prototype implementation of elements of the architecture and some example services using it, including controls to audio/visual equipment, extensible mapping, server autoconfiguration, location tracking, and local printer access.

1. Introduction

Researchers have predicted that wireless access coupled with user mobility will soon be the norm rather than the exception, allowing users to roam in a wide variety of geographically distributed environments with seamless connectivity [52]. This *ubiquitous computing* environment is characterized by a number of challenges, each illustrating the need for adaptation. One challenge is the continuously available but varying network connectivity [7], characterized by high handoff rates exacerbated by the demands of spectrum reuse. Another is the variability in client devices: impoverished devices need to push computation into the local infrastructure to allow for application-specific adaptation [15]. A third characteristic is the variability in available services as the environment changes around the client.

It is this third feature that has been least addressed by previous research. This paper investigates novel uses of a ubiquitous network, focusing on variable network services in the face of changing connectivity and heterogeneous devices. We propose that providing an "IP dial-tone" is not enough. We must augment basic IP connectivity with *adaptive network services* that allow users to control and interact with their environment.

In developing this architecture, we have designed, implemented, and deployed in our building the following example services:

- untethered interaction with lights, video and slide projectors, a VCR, an audio receiver, an echo canceller, motorized cameras, video monitors, and A/V routing switchers from a wirelessly connected laptop computer;
- automatic "on-the-move" reconfiguration for use of local DNS/NTP/SMTP servers, HTTP proxies, and RTP/multicast gateways;
- audited local printer access;
- interactive floor maps with a standardized interface for advertising object locations;
- tracking of users and other mobile objects.

In realizing this architecture, we employ a few key techniques:

- augmenting standard mobility beacons with location information, scoping features, and announcements from a service discovery protocol;
- using interface specifications that combine an interface definition language with the semantics of a model-based user interface; and
- hosting scripts in the infrastructure that
  - ∗ map exported object interfaces to client device control interfaces,
  - ∗ compose object interactions, and
  - ∗ automatically remap the destination of object invocations to changing server locations.

The testbed for our experiments [26] includes Intel-based laptop computers with access to a multi-tier overlay network including room-sized diffuse infrared cells (IBM IR), floor-sized wireless LAN cells (AT&T WaveLAN), and a wide-area RF packet radio network (Metricom Richocet). We also leverage facilities in two seminar rooms, a laboratory, and a student office; all contain devices that can be accessed and/or controlled via our software. The physical components of the testbed in one of the seminar rooms (our first prototype, 405 Soda Hall) are illustrated in figure 1.

Our infrastructure builds on and extends the substantial work in mobility support provided by the networking