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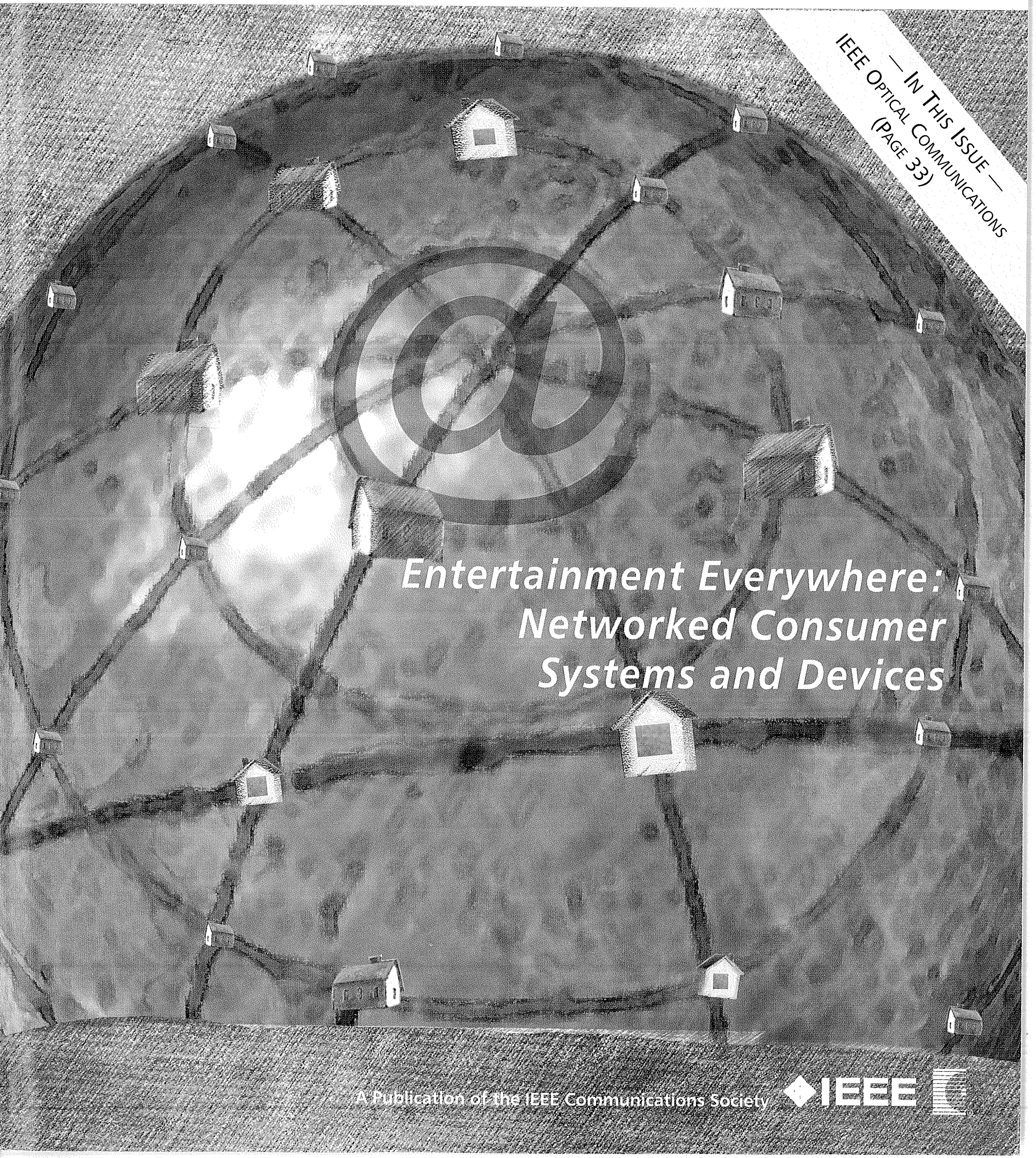

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# Entertainment Everywhere: Networked Consumer Systems and Devices

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# Always-Best-Served Music Distribution for Nomadic Users over Heterogeneous Networks

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## ABSTRACT

The distribution of online music has played a key role in driving the digital multimedia entertainment business to the pervasive extent we know today. The digital music revolution was substantially fueled by the invention of new online distribution models, such as P2P file sharing and online music libraries containing over one million songs in a pay-per-listen fashion. In this context, a new generation of devices that seamlessly integrate multiple radio access technologies is quickly emerging into a market for handheld devices. These devices will contribute to the spread of ubiquitous multimedia for everywhere entertainment, and also strongly influence music consumer habits. New music distribution models will be implemented to offer the user mobile services based on integrated wired/wireless infrastructures. Novel services will allow users to establish or negotiate a music download considering a complex set of access selection criteria, thereby accessing music in the *best possible way*. The user, moving from a *music shower* that distributes digital music contents to a 3G wireless entry point, could also decide to nomadically change the *download and playout* device. An individual who is entering a car while downloading through a cell phone will continue the download using the car radio, and finally end the file transfer on a home theatre. In this article we investigate the architectural requirements to effectively support a ubiquitous and nomadic multimedia entertainment service, and propose a music distribution system that offers a seamless and wandering music delivery service. We present experimental results that show the functionalities and performances of our proposed approach in terms of reliability and effectiveness.

## INTRODUCTION

Online music distribution is transforming the music business from commodity-based to service-based. This is motivating hardware and software producers to develop and offer innovative music download services. Downloadable music was one of the more effective catalysts of the digital multimedia market [1], starting from a killer application such as *Napster*, and continuing with a music distribution service, *iTunes*, that is becoming the main business stream of Apple. A similar role will probably be played by several other music distribution systems in the near future, as predicted by Jupiter Research, which estimates that the 2009 online music market in the United States will reach $1.7 billion. Recently, the advent of diffused high-speed wireless networks, together with the availability of mobile phones and terminals with complex operating systems, is making it possible to glimpse the reality of these download services to mobile and nomadic users. Different kinds of services will be part of this wireless music revolution. When outlining future wireless music distribution, a first scenario is based on *music delivery over cellular networks*. Mobile phones and other terminals equipped with 2.5-/third-generation (2.5/3G) interfaces can become a wireless entry point to music delivery networks, offering mobile users a large collection of music for multiple uses, such as tones or dedications [2]. Another scenario could be outlined for wireless LAN (WLAN) distribution services. In this context, we can hypothesize the presence of WLAN-based music showers that integrate wired/wireless infrastructures to support setup of music distribution points located in specific places to provide digital music to paying customers. Finally, a wireless personal area network (WPAN) scenario would involve *opportunistic music communities* comprising several users sharing downloaded songs using, for example, Bluetooth. The above-mentioned wireless access technologies are complementary when offering the user effective access to music distribution systems, and it is quite clear that there will not be a single wireless access solution appropriate for all music distribution scenarios. On the contrary, as for other wireless applications, we expect that many wireless networks will coexist in heterogeneous contexts, allowing users to access music through the best available access service [3].

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The wireless music consumer will ask for seamless music distribution systems that support mobile and nomadic download services. This leads to the design of future wireless music download systems as always-best-connected (ABC) services. ABC is an emerging model supporting mobile and ubiquitous computing, and its key service is to offer nomadic users the opportunity to choose, from anywhere at anytime, through any network and device, the best connection for an application. An interesting discussion on the general issues of the ABC architecture is provided in [4]. ABC protocols do not have a defined position in the classic Internet Protocol (IP) stack, and are placed from the data link layer to the application layer, depending on context. While [5] suggests placing ABC management at the network level, [6] instead is inclined toward the transport layer; however, neither approach addresses constraints due to nomadic computing. Instead, from our point of view, a better solution for the described scenario is to locate ABC management in a separate session layer.

Two key questions need to be answered when designing and implementing ABC models. The first is related to the meaning of the word *best*, frequently used to refer to just bandwidth or delay, but could be more generally related to a complex set of criteria that together outline a user's perception of the service. The second question arises from more technical issues and concerns basic mechanisms used by ABC applications to realize seamless connectivity. Moving the application from one terminal to another, from a nomadic perspective, worsens the above-mentioned difficulties. We use always-best-*served* (ABS) in this article to refer to applications that allow users to switch terminal and network technology. In particular, we consider users who enjoy downloadable music in a nomadic and ubiquitous scenario, similar to the one that follows. Consider a mobile user, *M*, traveling in a car from his/her office to his/her home. He/she begins to download a music compilation on his/her palmtop computer, temporary connected to the Internet through a Gneral Packet Radio Service (GPRS) interface. He/she stops for coffee at an Internet café, and the mobile system automatically switches to the available WLAN connection. Once back on the road, the device loses WLAN coverage and again uses the GPRS connection. Finally, *M* arrives home and transfers the download back to his/her palmtop and then to the seamless music storage and distribution system located in his/her home theatre and connected to the Internet through wired access. The storage and distribution system completes the file transfer and supplies music using Bluetooth wireless amplifiers placed anywhere in the house.

With this scenario in mind, we have designed, developed, and experimented with a wireless Internet software application that allows users to enjoy wandering music downloads. Different considerations drove the choice to offer a (progressive) download service instead of a streaming one. First, music consumers usually listen to each song many times, and here streaming does not perform well. Second, music consumers ask for a specific quality that is ensured by download but usually not by streaming. Finally, consumers like to "share" music, so they need to "have" songs, not just listen to songs.

The ABS system supports seamless ABC policies on a single mobile device and nomadic download, where device changes can be made. Different criteria could influence a user to leave a network or device, including the obvious wish to complete the download as fast as possible or to save money. The application follows the changing environment of the nomadic user and supports permanence of the download through a variety of places, networks, and terminals. Our ABS system supports end-to-end service continuity without failures due to link outages or handovers.

The reminder of our article is organized as follows. We discuss architectural issues in designing nomadic and mobile ABS services; we briefly introduce our wireless Internet application, and describe its system functionalities and architecture; we present our set of experimental scenarios and describe results obtained; finally, we summarize the approach taken to develop the prototype ABS system and comment on its success.

## Architectural Issues in Nomadic and Mobile ABS Services

Different problems arise when using the IP stack in a wireless and mobile context. This is because the entire IP suite is not designed to handle mobility and correctly manage wireless connections. In particular, the service replication built into IP, which offers the same functionality at different layers, leads to unwanted feature interactions with similar services provided by wireless networks. A well-known example is the very poor performance obtained when coupling the reliability implemented in the radio data link layer and the retransmission-based reliability/congestion control inside the transport layer. Additionally, some features such as support for mobility are not considered in the IP suite [6]. Several approaches have been proposed for integrating mobile hosts into the IP stack through all layers, from custom data link layer add-ons to specifically designed application layer protocols.

In designing a mobile and nomadic ABS music-on-demand application, several issues must be considered. The application would need to provide the following features:

1) Automatically switch connection in case of network failure or handoffs (both horizontal inside a given technology, and vertical among different technologies). This implies that the service ensures end-to-end continuity every possible time.

2) Automatically freeze a download in case of total absence of available networks.

3) Automatically resume a download frozen by total absence of network coverage, restarting the file transfer from the point of interruption.

4) Automatically switch the download among different available connections if some user-defined conditions are true. For example, one simple user-defined condition could be to use

the connection that offers the best bandwidth of all available connections. Conditions need to be monitored to detect context changes and ensure that all constraints defined by the user are met.

5) Freeze a download if required by the user.

6) Resume a download intentionally interrupted if required by the user. Obviously, the download restarts from the point of interruption.

7) Transfer the download to a different terminal if required by the user. The download restarts on the new device from its interruption point, and the music files downloaded on the first terminal are directly transferred between the two mobile devices.

We can consider these requirements as the definition of an ABS music download service. Note that features 1, 2, and 3 are part of the definition of a *seamless service*: these automatic mechanisms guarantee that a user can move about, overcoming handoff and absence of coverage in a transparent way. Features 4, 5, and 6 are related to an extensive *ABC service*. Traditional performance evaluation criteria are the basis of a "better" connection. Other conditions, such as connection price, could be included in the service profile for automatic best service evaluation. Manual freeze/resume mechanisms (features 5 and 6) ensure that it is finally the user who decides which is the best connection, on the basis of his/her perception of quality of service. Finally, feature 7 defines mechanisms to support nomadic download.

It is worth noting that music distribution is actually based on download instead of on streaming protocols; this is principally to give users the opportunity to replay or copy songs (sometimes defining a maximum number of playouts or copies). Maintaining this point of view, we can suppose that a streaming-like (wait and play) reliable mechanism could easily be implemented, starting from the above-mentioned features and adding support for fast forward and rewind.

Considering all seven of the above-mentioned features, an ABS system needs to modify at least a layer of the traditional IP suite, adding support for nomadic and mobile features. Let us briefly consider key approaches. A large number of solutions reach the goal of preserving continuity through the use of Mobile-IP-based architectures [7]. These solutions impose a significant adaptation of the infrastructure, and this characteristic strongly limits their deployment. Moreover, support for connection monitoring is a prerogative of upper levels, and in this context part of the condition and policies could effectively be controlled only at the application layer and are totally ignored at the network layer. Other systems offer similar features by implementing mobility at the transport layer and changing the protocol stack in both end hosts. This approach requires strict coordination between layers to manage constraints imposed by the application and manage IP addressing to ensure continuity [6]. But the main problem of managing mobility at the transport layer comes from portability, a fundamental constraint when implementing nomadic applications. Realizing an effective nomadic service within this approach could impose a change to the transport layer on many different platforms. The solution that

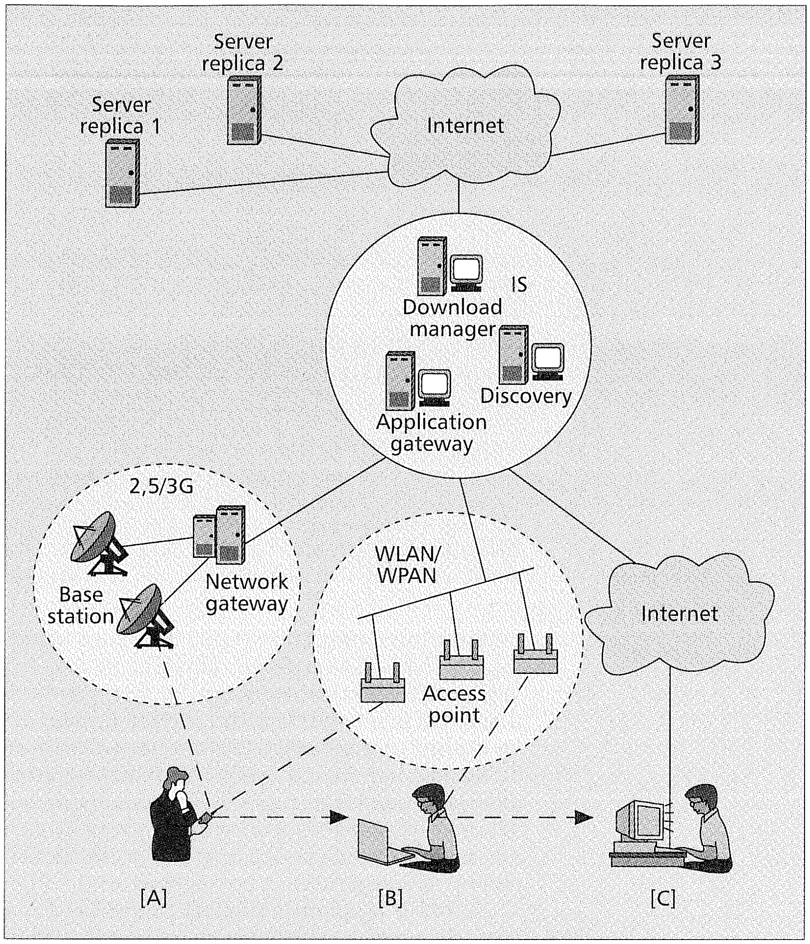


**Figure 1.** *System architecture.*

seems most promising in the context described above consists of building the application on top of a session layer that is placed on top of the transport layer. This approach can leverage all the advantages of a transport layer mobility scheme without requiring deep changes in the classic IP stack. A session layer could offer its services to more than one application; in particular, a session mechanism that supports all seven features mentioned above could offer an effective development framework for a large number of mobile and nomadic distributed multimedia applications.

## An Architecture for ABS Music on Demand

As discussed earlier, a session layer seems to be the most promising approach to adding mobile and nomadic features to Internet-based multimedia distribution. Such a layer could effectively support all the aforementioned issues by using an ID-based mechanism to provide a service toolkit for nomadic and ubiquitous applications. Moreover, the session layer is responsible for starting and terminating user sessions, including login to the service and explicit logout, as well as terminating sessions that have been inactive for too long. The functionalities offered by such a mobile and nomadic session layer (MN-SL) are a subset of those defined for level 5 of the Open

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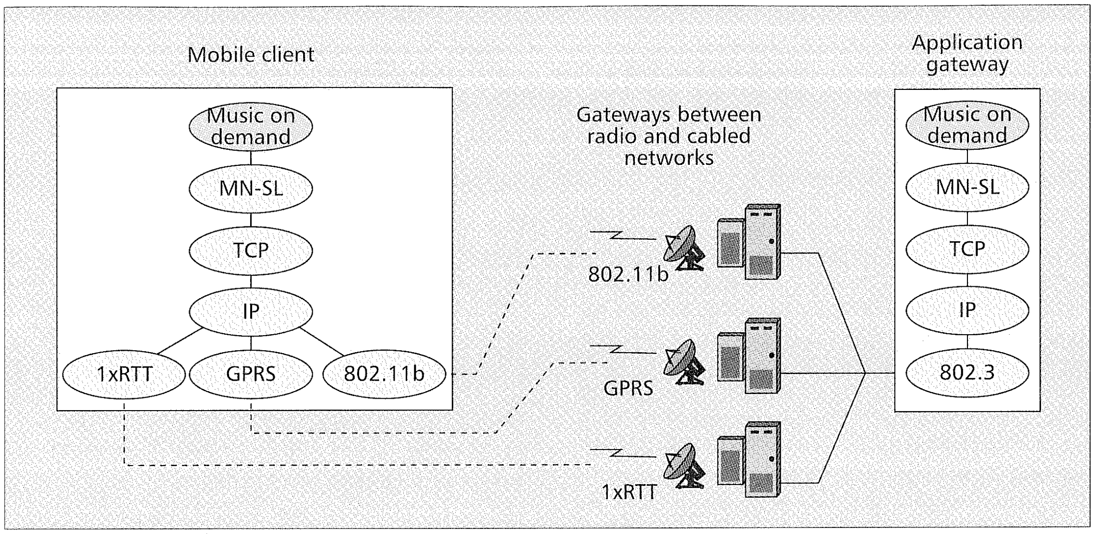


**Figure 2.** *Application gateway-mobile client protocol stack.*

Systems Interconnection (OSI) reference model [8]. The NM-SL uses the session ID:

**To offer service ccontinuity:** Every time a download is interrupted (due to link outages or an explicit user request), the session ID is stored by the client system, together with all the intermediate results (i.e., partially downloaded files). The client restores a download by asking to resume a specific session, unequivocally identified by the session ID.

**To offer support to nomadic download:** To perform a device switch (from one device, A, to another device, B) while in a download session, the application has to transfer the session ID (that unequivocally identifies the session) together with all the intermediate results (including all partially downloaded files). After receiving the ID, device B can restart the download and A concurrently transfers all the intermediate session results to B.

To verify this approach, we have designed, implemented, and tested a software architecture that supports mobile and nomadic music download [9]. The proposed ABS system is based on three main components, as shown in Fig. 1:

- The **mobile client application** (MC) that supports the user while he/she searches and downloads music. The user can select a list of songs (a compilation) and drive his/her client application to start, stop, and resume the download, and move it to a different terminal. The user device could be connected through different wireless interfaces.
- **The intermediate software system** (IS) that is hosted on an Internet server and represents the core component of the ABS system. The IS is in charge of managing all communications between mobile devices and the Internet infrastructures.
- **Replicated Web servers** geographically distributed over the Internet that act as music libraries. In general, different Web servers can be managed and administered by different music service providers, and may also offer a different set of replicated songs. Simply stated, this replication scenario can be thought of as a loosely coupled replication system where, potentially, different servers support different sets of music resources, and each single musical resource may be replicated within a number of geographically dispersed Web servers.

Figure 1 shows the user downloading music using a palmtop computer [A]. This device can seamlessly switch from a 2.5/3G wireless network to a (in this case, infrastructured) WLAN. In [B] the user moves the download to a laptop PC, connected to the Internet through a WLAN. Finally, in [C] the download session is moved to a desktop computer with a wired connection.

The IS component exhibits three main functions that correspond to the following three software subcomponents [9]:

- **The application gateway** that accepts and manages all the songs requested by the user from the mobile device.
- **The discovery system** that identifies and locates all the replicated resources (i.e., the replicated MP3 files) which correspond to songs that have been requested by the user.
- **The download manager** that carries out the activity of downloading songs, identified by the discovery system, from the Web servers to the IS. The download manager does this by exploiting a parallel mechanism called $C^2LD$ [10] that enhances reliability of the file transfer process.

Figure 2 shows the protocol stack we devised to provide support to all communications between the mobile client and the application gateway. As seen in this figure, on the client side different radio technologies may implement the data link layer at the base of our protocol stack. On top of this multitechnology radio layer, a standard TCP/IP stack is mounted. Finally, the classic application layer built on top of the TCP has been designed and constructed from two different sublayers:

- **The (mobile and nomadic) session layer** (MN-SL), devoted to managing the download session
- The **music application layer** that supports the different activities needed to search, download, and play out songs and compilations

As mentioned above, this approach does not require changing standard TCP/IP libraries on the application gateway or client devices. In addition to meeting the goal of nomadicity and augmenting portability of the application, we developed the mobile client software using ANSI C.

## Experimental Assessments

In this section we present an experimental study conducted to evaluate the efficacy of our system for music distribution to nomadic users over heterogeneous networks. In particular, the first part of that evaluation shows the performance of the system in terms of time elapsed in song download while the user is moving along a path covered by different radio technologies. The second part of the evaluation presents experiments in which the user nomadically changes his/her download device.

We conducted approximately 550 experiments downloading a set of different songs (MP3 files) under different conditions. A copy of each song was placed on four different Web servers located in the United States, Brazil, Japan, and Italy, while the intermediate system was located in Los Angeles, California. The client application was running on an HP iPAQ H5450 PDA equipped with the Windows CE 3.0 operating system. We conducted our experiments using three different radio technologies installed on the wireless device: WLAN 802.11b (infrastructure-based), WLAN 802.11b (ad hoc), and cellular GPRS.

### Providing Always-Best-Served Music Download: Empirical Results

This subsection reports on the results obtained when testing the efficacy of the policies for dynamically switching among different wireless technologies during a song download within the experimental scenario described above. These experiments were conducted while the user was in motion along a path in which signal coverage was as depicted in Fig. 3a. The y-axis represents the bandwidth made available to the application from a given wireless technology in a given location on the x-axis of the path. Initially (point **a**) there were two different available wireless networks: an ad hoc WLAN (starting in **a** and ending in **b**) and GPRS coverage (starting in **a** and ending in **d**). A third form of wireless connectivity (an infrastructured WLAN) works from point **c** (together with GPRS) and ends in point **e**. We conducted two different sets of experiments along this path.

**Seamless connectivity:** The system automatically switches among networks in case of link outages. Considering the described path, a first link outage happened to an ad hoc connection in point **b**. The system switched to the GPRS network, and then a second link outage occurred in point **d**. The system reacted by establishing a connection with the infrastructured WLAN.

**ABS service:** The system automatically switches to the connection that offers the best bandwidth of all available connections. To implement the specific meaning of "best," the system monitors download performance on all the available networks. Applying this policy to our path, we determined that the ABS system naturally started with the ad hoc WLAN and met an outage in point **b** (as in experiment 1). The system used the only available (GPRS) connection until point **c**, in which a second network (the infrastructured WLAN) was detected. Measuring performance of both networks, the system automatically switched to the infrastractured WLAN.

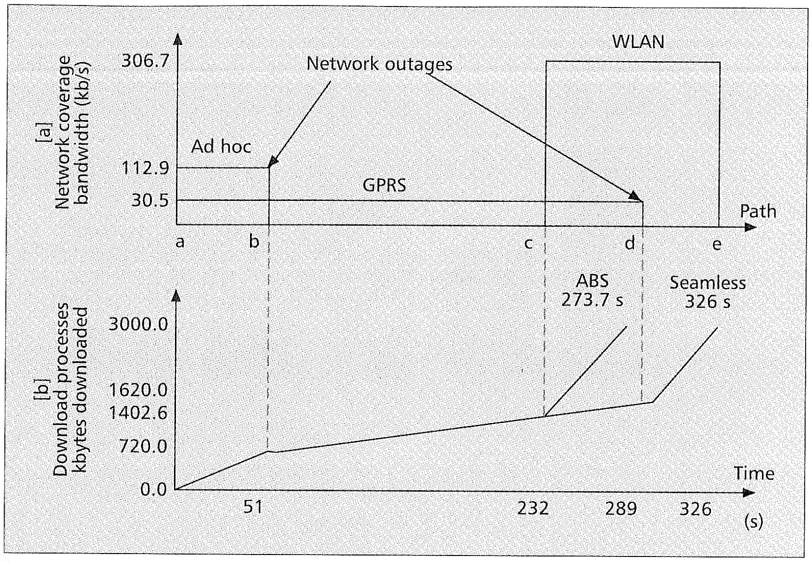


**Figure 3.** *Network coverage and download processes.*

It is significant that the only difference between these two experiments is that the application is handed off from GPRS to the infrastructured WLAN at different points in time. In experiment 1 the system maintained the connection based on GPRS until the outage, losing the opportunity to use a "better" network. In other words, the ABS policy anticipates the switch toward the fastest wireless technology, which obviously results in increased use of the faster network and lower download time. Figure 3b shows the byte download on each path, using the network technologies selected by the client application. Experiments 1 and 2 obtained the same results until point **c**. At point **c** the ABS system increased its performance and completed the download in 273.7 s. The system that used a seamless (not ABS) policy maintained the GPRS connection until point **d** and ended the download in 326 s.

Finally, Fig. 4 shows the download time obtained by separately using each of the available wireless technologies (ad hoc WLAN, infrastructured WLAN, and GPRS) and contrasting it to the time obtained by using the three networks together within the seamless (1) and ABS (2) experiments.

The ABS system provides the best download performance across different network technologies. This evaluation was done under the assumption that each single access technology is available in the experiment according to the percentage of active download time specified by the signal coverage in Fig. 3a. Obviously, in the three experiments the user moved on the described path in a loop, as

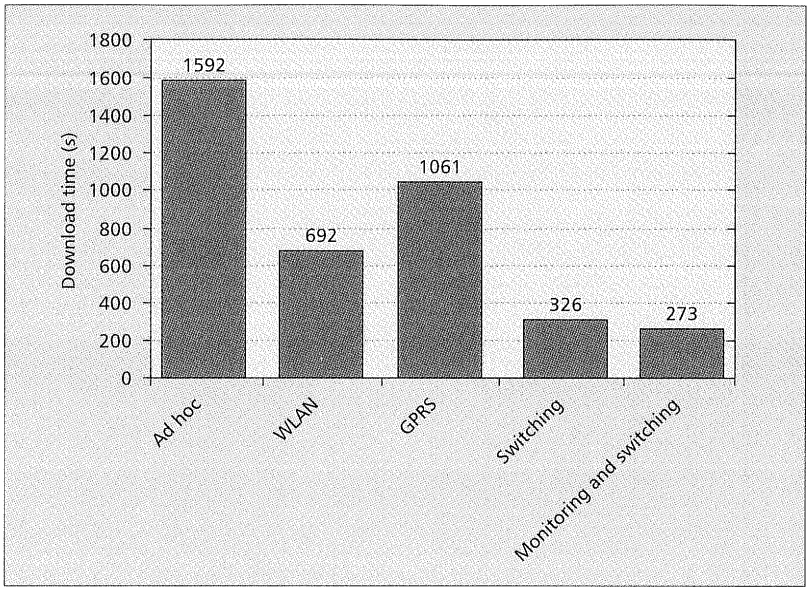


**Figure 4.** *Download time comparison.*

many times as was needed to complete the download. It is easy to see that under these conditions our session-based multitechnology mechanism is able to guarantee completion of the download process in a shorter time than an approach where alternative wireless technologies are used separately.

### PROVIDING NOMADIC MUSIC DOWNLOAD: EMPIRICAL RESULTS

The last goal of our experimental assessments was to verify the effectiveness of the realized MN-SL by moving a session through different devices. We tested the nomadicity of our application by iteratively moving a download of 20 Mbytes through two different devices:

- An HP iPAQ H5450 PDA equipped with Windows CE 3.0 and connected to the music distribution system through GPRS
- A laptop PC connected through an infrastructured WLAN

These two devices used a Bluetooth connection to transfer the session ID and partially downloaded files. The download session correctly terminated in all our tests. Apart from this functional result, we discovered that WPAN-based transfer of intermediate download results may enhance system performance. This improvement is more significant when moving from an iPAQ to the laptop (or, more generally, moving toward a faster connection) and depends on connectivity between the two devices, the dimension of intermediate results to be transferred, and remaining download time.

## CONCLUSIONS

This article discusses wireless multimedia distribution applications and recognizes that service continuity is one of the key quality requirements. The article proposes to design and implement this class of applications on top of a session layer that provides support for mobility and nomadicity of multimedia downloads. The proposed architectural strategy has been used to realize a music delivery service that supports download continuity while users change location, network, or terminal. The implemented prototype reaches our goal of providing users with seamless connectivity while supporting ABC policies and nomadic downloads (as shown by the experimental results described above). Our ABS system completes downloads whenever and wherever possible, regardless of noncontinuous network coverage; hence, ABS may be considered ultra-reliable.

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