2005 WSEAS Int. Conf. on DYNAMICAL SYSTEMS and CONTROL, Venice, Italy, November 2-4, 2005 (pp445-450)

# Intelligent Data Flow Control by WiFi User Localization – Predictive Data Push Technology Framework

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*Abstract:* - The proliferation of mobile computing devices and local-area wireless networks has fostered a growing interest in location-aware systems and services. Additionally, the ability to let a mobile device determine its location in an indoor environment at a fine-grained level supports the creation of a new range of mobile control system applications. Main area of interest is in model of radio-frequency (RF) based system enhancement for locating and tracking users of our control system inside buildings. The framework described here joins the concepts of location and user tracking in an extended existing control system. The experimental framework prototype uses a WiFi network infrastructure to let a mobile device determine its indoor position as well as to deliver IP connectivity. User location is used to data pre-buffering and pushing information from server to user's PDA. Experiments show that location determination can be realized with a room level granularity.

*Key-Words:* - Mobile device, .NET CF, OpenNETCF, Location-aware services, control system

## 1 Introduction

The usage of various wireless technologies that enable convenient continuous IP-level (packet switched) connectivity for mobile devices has increased dramatically and will continue to do so for the coming years. This will lead to the rise of new application domains each with their own specific features and needs. Also, these new domains will undoubtedly apply and reuse existing (software) paradigms, components and applications. Today, this is easily recognized in the miniaturized applications on network-connected PDAs that provide more or less the same functionality as their desktop application equivalents. The web browser application is such an example of reuse. Next to this, it is very likely that these new mobile application domains adapt new paradigms that specifically target the mobile environment. We believe that an important paradigm is context-awareness. Context is relevant to the mobile user, because in a mobile environment the context is often very dynamic and the user interacts differently with the applications on his mobile device when the context is different. While a desktop machine usually is in a fixed context, a mobile device goes from work, to on the road, to work in-a-meeting, to home, etc. Context is not limited to the physical world around the user, but also incorporates the user's behaviour, and terminal and network characteristics.

Context-awareness concepts can be found as basic principles in long-term strategic research for mobile and wireless systems such as formulated in [8]. The majority of context-aware computing to date has been restricted to location-aware computing for mobile applications (location-based services). However, position or location information is a relatively simple form of contextual information. To name a few other indicators of context awareness that make up the parametric context space: identity, spatial information (location, speed), environmental information (temperature), resources that are nearby (accessible devices, hosts), availability of resources (battery, display, network, bandwidth), physiological measurements (blood pressure, hart rate), activity (walking, running), schedules and agenda settings. Context-awareness means that one is able to use context information.

We consider location as prime form of context information. Our focus here is on position determination in an indoor environment. This indicator is basic level of the predictive data push technology (PDPT) framework described in this paper. Location information is used to determine an actual user position and his future position. When the user position and user track is known, the data which could be needed by the user in the future is pushed to his mobile device. This technique is suitable for data rate increasing between server and user side of existing control system, when the PDPT framework is put on.

Although the framework functionality is useful by itself, it is specifically targeted at being an environment supporting rich mobile applications in the area of control systems computing. Other systems also combine one or

more context elements and incorporate this in a mobile application. We believe, however, that our framework provides a unique combination: the predictive data push technology and location context information as part of an (existing) control system together with an indoor position determination mechanism based on WiFi. The framework's location determination mechanism focuses on applications that need to be able to obtain the user's indoor position with a room-level granularity. We build the framework based on various existing components and technologies and on our own additions and extensions.

We have performed a number of experiments with the control system, focusing on position determination, and are encouraged by the results. The remainder of this paper describes the conceptual and technical details of the framework.

In section 2, we discuss the environment in which the system runs, focusing on basic concepts and technologies. In section 3, we address the framework architecture, followed by the implementation in section 4. Section 5 describes the experiments and conclusions in section 6.

# 2 Basic system concepts and technologies

The proliferation of mobile computing devices and local-area wireless networks has fostered a growing interest in location-aware systems and services. A key distinguishing feature of such systems is that the application information and/or interface presented to the user is, in general, a function of his physical location. The granularity of location information needed could vary from one application to another. For example, locating a nearby printer requires fairly coarse-grained location information whereas locating a book in a library would require fine-grained information.

While much research has been focused on development of services architectures for location-aware systems, less attention has been paid to the fundamental and challenging problem of locating and tracking mobile users, especially in in-building environments. We focus mainly on RF wireless networks in our research. Our goal is to complement the data networking capabilities of RF wireless LANs with accurate user location and tracking capabilities for user needed data pre-buffering. This property we use as information ground for our control system.

## 2.1 Location-based services

Location-based services (LBS) are touted as 'killer apps' for mobile systems. An important difference between fixed and mobile systems is that the latter operate in a particular context, and may behave differently or offer different information and interaction possibilities depending on this context. Location is often the principal aspect determining the context.

Many different technologies are used to provide location information. Very common is the GPS system, which uses a network of satellites and provides position information accurate within 10–20 m. However, due to its satellite based nature, it is not suited for indoor positioning. In cellular telecommunication networks such as GSM, the cell ID gives coarse-grained position information with an accuracy of about 200 m to 10 km. More advanced technologies based on triangulation measure e.g. the angle of arrival (AOA), the time of arrival (TOA), or the enhanced observed time difference (E-OTD), and typically provide an accuracy of < 150 m.

For fine-grained indoor location information, various technologies are available, based on infrared, RF, or ultrasonic technologies often using some type of beacon or active badge. Given the ubiquity of mobile devices like PDAs, however, active badges will probably be superseded by location technologies incorporated in these devices.

In the context of our experimental setup, we need indoor position information accurate enough to determine the room in which the user is located. We must deploy a separate location technology, where we use the information available from a WiFi network infrastructure to determine the location with room-level accuracy. By this information possible user track is estimate.

## 2.2 WiFi - IEEE 802.11

The Institute of Electrical and Electronics Engineers (IEEE) develops and approves standards for a wide variety of computer technologies. IEEE designates networking standards with the number 802. Wireless networking standards are designated by the number 11. Hence, IEEE wireless standards fall under the 802.11 umbrella. Ethernet, by the way, is called 802.3 [3].

The first IEEE wireless standard, adopted in 1997, was simply called IEEE 802.11. This was an RF-based standard operating in the 2.4 GHz frequency band, with a maximum throughput of 2 Mbps. A revision of the standard was originally dubbed 802.11 High Rate for its improved speed (up to 11 Mbps). By 1999, 802.11 High Rate had been renamed 802.11b, and 802.11a, a higher-

speed standard using a different spread-spectrum method, had been added. In 2002, 802.11g joined the ranks of approved wireless standards.

In addition to the three current networking standards, IEEE 802.11 includes task groups that are working on standards that will, when approved and implemented, compliment 802.11a, b, and g. IEEE 802.11i, for example, is aimed at beefing up wireless network security, while 802.11e addresses quality of service (QoS) issues that are important in large wireless networks. Once these standards have been adopted, they can either be folded into one of the networking protocols or simply made available to vendors who want to add features to their 802.11a, b, or g products.

## 2.3 802.11b

As mentioned earlier, 802.11b is an updated and improved version of the original IEEE 802.11 standard. Today, no commercial products based on plain old 802.11 are available. Most wireless networking products today are based on 802.11b. 802.11b networks operate at a maximum speed of 11 Mbps, slightly faster than 10-BASE-T Ethernet, providing a more than fivefold increase over the original 802.11 spec. The 802.11 standard provided for the use of DSSS and FHSS spread-spectrum methods. In 802.11b, DSSS is used.

We use only 802.11b infrastructure so other standards (802.11a or g) is not needed to describe. However, it can be possible to develop a PDPT framework with it.

## 2.4 Pushing in Intranets

Intranets are simply local 'internets' closed inside various organizations. They allow transfer of information between users. Important company news and information can be pushed straight to the Screen of the employees. This could be done in a form of screen savers, tickers (scrolling bars of text) or by some client application. A good example of a useful push application within companies is automatic notification of events. For example, by linking a push system to a database of stocks and components in a manufacturing company a manager could be alerted if the number of a particular component drops below a certain level.

When some intelligence is added to push system, the very useful system may be created. This is what we do. Location information about users is added to server as intelligence for push technology.

## 2.5 Data Collection

A key step in the proposed research methodology is the data collection phase. We record information about the radio signal as a function of a user's location. The signal information is used to construct and validate models for signal propagation.

Among other information, the WaveLAN NIC makes available the signal strength (SS) and the signal-to-noise ratio (SNR). SS is reported in units of dBm and SNR is expressed in dB. A signal strength of s Watts is equivalent to 10*log10(s/0.001) dBm. A signal strength of s Watts and a noise power of n Watts yields an SNR of 10*log10(s/n) dB. For example, a signal strength of 1 Watt is equivalent to 30 dBm. Furthermore, if the noise power is 0.1 Watt, the SNR would be 10 dB.

The WaveLAN driver extracts the SS and the SNR information from the WaveLAN firmware each time a broadcast packet is received. It then makes the information available to user-level applications via system calls. It uses the *wlconfig* utility, which provides a wrapper around the calls, to extract the signal information.

## 2.6 Localization methodology

The general principle is that if a WiFi-enabled mobile device is close to such a stationary device – Access Point (AP), it can "ask" the location provider's position by setting up a WiFi connection. If the mobile device (PDPT framework) knows the position of the stationary device, it also knows that its own position is within a 100-meter range of this location provider. Granularity of location can improve by triangulation of two or several visible WiFi APs as described on figure [Fig. 1].

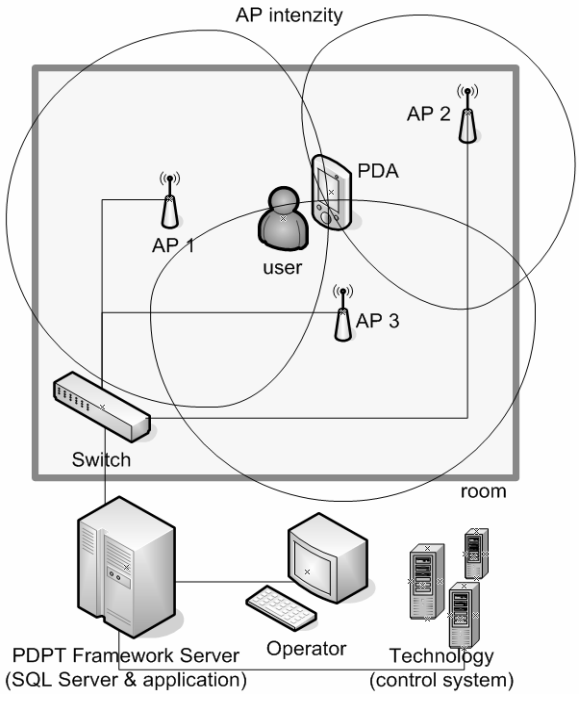


Fig. 1. Localization principle - triangulation.

The PDPT PDA client will support the application in automatically retrieving location information from nearby location providers, and in interacting with the PDPT server. Naturally, this principle can be applied to other wireless technologies.

# 3 The PDPT Framework Architecture

The PDPT framework consists of an infrastructure for handling location context information and an infrastructure for determining indoor position information. The PDPT framework is primarily focused on supporting research and prototype mobile applications enhancement in the area of location-aware and control systems computing. For the handling of location and information from control system, the framework provides a PDPT server as well as a client application. The client application is available for PDAs that run the Microsoft Pocket PC / Windows CE 3.0 operating system with .NET CF support.

The handling of the location information in the framework does not depend on the granularity of the location determination mechanism. The framework can handle any kind of location information from any source, although the focus here is on indoor location with a room-level granularity. The indoor position can be retrieved from an infrastructure of stationary WiFi devices that know their own location. A stationary device has location provider characteristics.

## 3.1 Predictive data push technology

This part of project is based on model of location-aware enhancement, which we used in created control system. These information about are useful in framework to increase real dataflow from wireless access point (server side) to PDA (client side). Primary dataflow is enlarged by data pre-buffering. These techniques form the basis for predictive data push technology (PDPT). PDPT copies data from information server to clients PDA to be on hand when user comes at desired location.

The benefit of PDPT consists in reduction of time needed to display desired information requested by a user command on PDA. Time delay may vary from a few seconds to number of minutes. It depends on two aspects. First one is the quality of wireless Wi-Fi connection used by client PDA. A theoretic speed of Wi-Fi connection is max 825 kB/s. However, the test of transfer rate from server to client's PDA, which we have carried out within our Wi-Fi infrastructure provided the result speed only 160 KB/s. The second aspect is the size of copied data.

The application (locator) based on .NET language is now created for testing. Current application (see figure [Fig. 2]) records just one set of signal strength measurements. By this set of value the actual user position is determined.

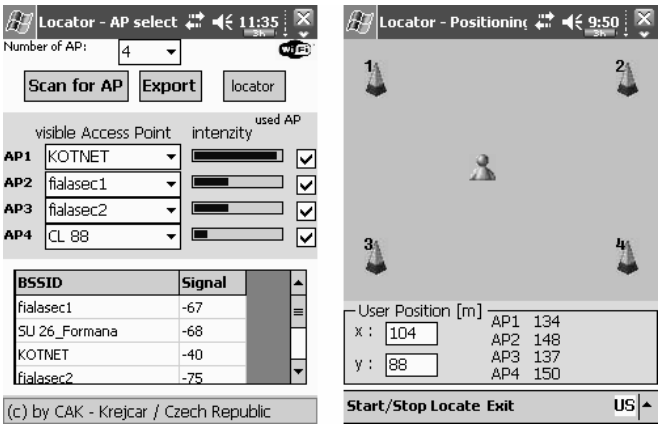


Fig. 2. Locator – AP intensity & Positioning.

## 3.2 Wireless location architecture

Another very important part of the project is design of Wireless Location Architecture (WLA). WLA defines a structure for data store in database. The structure is defined as data levels in building plan for example.

The example of function: User location is determined and analyzed. Server activates the PDPT and pushes data to PDA. As first the data about Building Block will be copied. As next the Block Floor data and finally the data about user occurred cell will be copied.

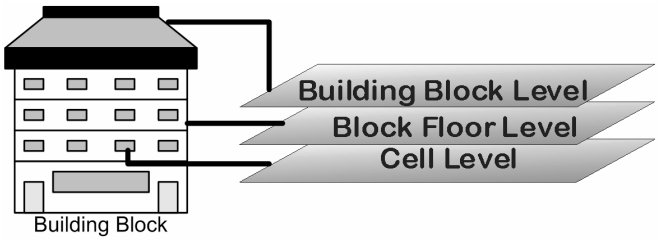


Fig. 3. WLA for building.

## 3.3 Framework design

PDPT framework design is based on most commonly used server-client architecture. To process data the server has online connection to the control system. Data from technology are continually saved to SQL Server database (WLA architecture) [5] and [6]. The part of this database (desired by user location or his demand) is replicated online to client's PDA where it is visualized on the screen. User PDA has location sensor component which continuously sends to the framework kernel the information about nearby AP's intensity. The kernel

processes this information and makes a decision if and how a part of WLA SQL Server database will be replicated to client's SQL Server CE database.

The kernel decisions constitute the most important part of whole framework because the kernel must continually compute the position of the user and track and make a prediction of his future movement. After doing this prediction the appropriate data (part of WLA SQL Server database) are pre-buffered to client's database for future possible requirements.

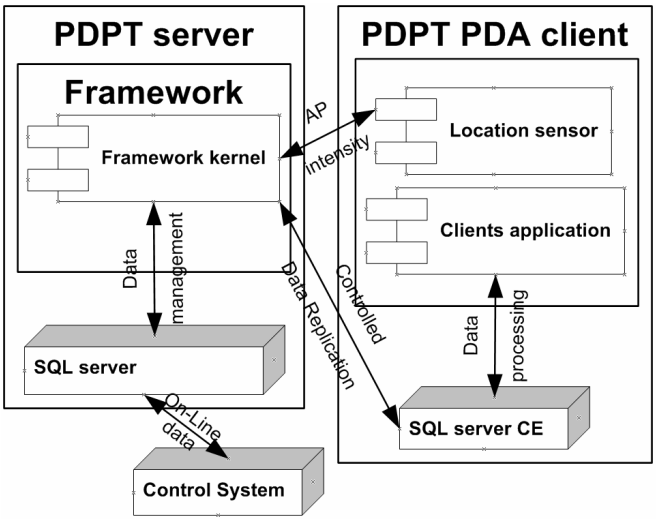


Fig. 4. System architecture – UML design.

# 4 The Implementation

The implementation of the PDPT framework and application consists of a number of components. The PDA client location determination software is implemented by the WiFi middleware.

Basic idea of PDPT framework is in connection between location information and data push technology. When we know user position and user track, the data which could be needed by the user in the future is pushed to his mobile device.

## 4.1 PDA Client

The PDPT PDA client applications provide location and control system functionality to the mobile user. It is implemented in C# using the Microsoft Visual Studio .NET 2003 with compact framework and a special OpenNETCF library enhancement [5] and [9].

OpenNETCF.org is an independent source for Compact Framework development information working under the spirit of the open-source movement.

## 4.2 WiFi Middleware

The WiFi middleware implements the client's side of location determination mechanism on the Windows CE 3.0 PocketPC operating system and is part of the PDPT PDA client application. The libraries used to manage WiFi middleware are listed on figure [Fig. 5].

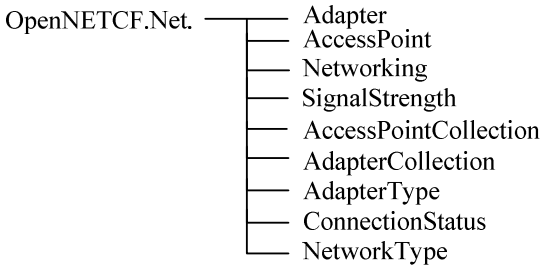


Fig. 5. OpenNETCF network method architecture

Methods from the Net library are used for example to display Visible WiFi AP. See figure [Fig. 6].

```
dtVisibleAP = new DataTable("Visible AP");
DataRow drDataRow;
adptrColection = Networking.GetAdapters();
foreach (Adapter adptr in adptrColection)
{
  Application.DoEvents();
  if (adptr.Type==AdapterType.Ethernet)
  {
    foreach (AccessPoint ap in

adptr.NearbyAccessPoints)
    {
       drDataRow = dtVisibleAP.NewRow();
       drDataRow["BSSID"] =

(ap.Name.ToString());
       drDataRow["Signal [%]"] =

((ap.SignalStrength.Decibels).ToString());
       dtVisibleAP.Rows.Add(drDataRow);
    }
  }
}
```

Fig. 6. Sample code – signal strength from AP

## 4.3 Server

The server application GUI uses the Microsoft Foundation Classes (MFC) with .NET platform. Framework server manages MS SQL Server 2000 with a special WLA architecture. The special search algorithm is implemented in framework kernel to manage user location information used for better server response. This algorithm is the most important part of the framework and much other development work will be spent on this problem in the future.

# 5 Experiments

We have executed a number of indoor experiments with the PDPT framework, using the PDPT PDA application. At different locations in the building, many of WiFi access points were placed in selected suitable rooms. The access point cells partly overlap, i.e. the distance between the location providers was from 40 meters for three visible WiFi AP (We used triangulation of AP intensity to better granularity).

We found that the location determination mechanism selects the access point that is closest to the mobile user as the best location provider. Also, after the loss of IP connectivity, the switch from one access point to another (a new best location provider) takes place within a second in the majority of cases, resulting in only temporary loss of IP connectivity. This technique uses a special Radius server [7] to realize roaming known in cell networks.

Currently, the usability of the PDPT PDA application is somewhat limited due to the fact that the device has to be continuously powered. If not, the WiFi interface and the application cannot execute the location determination algorithm, and the PDPT server does not receive location updates from the PDA client. The client applications, however, provide interfaces to the control system and location information at a level that suits the user in his current environment: in a compact form on the PDA and a visual and animated form for the desktop.

# 6 Conclusion

The main objective of this paper is in the enhancement of control system for locating and tracking of users inside a building. It is possible to locate and track the users with high degree of accuracy.

In this paper, we presented the control system framework that uses and handles location information and control system functionality. The framework provides a model that deals with location. Furthermore, a mechanism for location determination is a part of the framework. The indoor location of a mobile user is obtained through an infrastructure of WiFi access points. This mechanism measures the link quality of nearby location provider access points to determine actual user position. User location is used in core of server application of PDPT framework to data pre-buffering and pushing information from server to user PDA. Data pre-buffering is most important technique to reduce time from user request to system response.

The experiments show that the location determination mechanism provides a good indication of the actual location of the user in most cases. The median resolution of the system is approximately five meters, about the size of a typical office room. Some inaccuracy is inherent to the way location information is obtained using the WiFi infrastructure. For the PDPT framework application this was not found to be a big limitation.

The experiments also show that the current state of the basic technology used for the framework (mobile device hardware, PDA operating system, wireless network technology) is now at the level of a high usability of the PDPT application.

Acknowledgement: This work was supported by the Ministry of Education of the Czech Republic under Project 1M6840770004

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