Towards an Ubiquitous and Context Sensitive Public Transportation System

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***Abstract*—Transportation systems deal with dynamic and sometimes inconstant scenarios, which could involve events like traffic jams or accidents. Intelligent Transportation Systems (ITS) should be projected in a way that their behavior changes according to the real world that can be pictured surrounding it. Context is what allows the understanding of this dynamicity and how it impacts the way people decide to use the available transportation. This paper presents UbiBus, a system that aims to integrate the concepts of Computational Context and Ubiquitous Computing into the ITS domain. It considers the mobility of people and vehicles and the occurrence of dynamic factors that could affect the transportation and provide passengers with advanced information about the available public transportation in a city (e.g. the estimated arrival time of a bus, according to its current location and a given bus station, or route and bus recommendations according to the different needs of a passenger at a certain time). To verify the viability of the proposed ideas we developed an application that provides the current location and estimated arrival time of a bus. This application was evaluated after real data collection involving a route created for the city of Salvador, Bahia, which showed the potential of the proposed solution.**

Keywords- ITS, Context, Ubiquitous Computing

I. Introduction

Intelligent Transportation Systems (ITS) investigate how to apply well-established technologies of communications, control, electronics and computer hardware and software to the surface transportation system, in order to improve its quality [1]. The implementation and improvement of passenger information automated systems is one of the targeted goals of a subarea of ITS named APTS (Advanced Public Transportation System). APTS aims to provide real time information that can assist users on planning their trips by choosing times and itineraries more appropriate to their needs and the currently availability of transportation. This information includes the types of transportation available, the estimated departure and arrival time of the vehicles and their itinerary.

A better accessibility to information concerning the public transportation in a city makes this option a more attractive mean of transportation to its potential users [2]. This interaction can occur by using different devices, such as information centers, bus or bus station displays, the internet, smartphones, interactive TV, and others.

This kind of technological solution, although already operational in first world countries, is very hard to implement on big cities of developing countries (e.g. Brazil), where the buses don't have exclusive lines to operate and traffic jam occurs all the time. The estimated arrival time of a bus, previewed on its schedule, almost never is accomplished in real life. The result is that, in practice, it is very common for people to stay, for a long time, in a bus station waiting for their bus without having a single information about its current location or when exactly it is supposed to arrive.

Ubiquitous systems are those that allow the availability of services and information "anytime, anywhere, from any device" [3]. Understanding the current context of transportation vehicles, route, passengers and devices is an essential factor to assist those systems on achieving their goals. Static information, stored in databases, related to the predetermined schedule of buses is not enough. It is necessary to consider dynamic information that characterizes the context of a bus trip. Context information can be related to the transportation (e.g. current location, speed or availability), the route conditions (e.g. traffic jam, accidents, obstructions), time of the day (e.g. rush time), meteorological conditions (e.g. rainy days, natural disasters), alternatives for integrated transportation, among others.

This paper presents a proposal for a ubiquitous, context-sensitive public transportation system, named UbiBus. UbiBus aims to specify and implement technological solutions (e.g. models, algorithms and tools) to ease the access to information about public transportations. It uses real time dynamic context information collected from different sources, considering the mobility of vehicles and passengers, and dynamic factors that can affect the transportation. Different services are provided to passengers, such as route prevision and recommendation, estimated arrival time of a transportation, among others. These services should be accessed from different devices (e.g. desktops, terminals on bus stations, displays inside a bus, ormobile phones).

UbiBus investigate different aspects related to the development of: (i) acquisition, processing and management techniques for context information either static or dynamic; (ii) algorithms and mathematical models to calculate travel times and to define better routes; (iii) techniques for visualizing and interpreting geographical information, considering large volume of data from transportation and routes; (iv) a middleware to support building context-sensitive ubiquitous applications; (v) different context-sensitive applications to support passengers, adaptable and available on different devices; and (vi) route and transportation recommendation systems. The focus of this paper is on presenting the overall ideas about the UbiBus project, and its preliminary results with an application that provides estimated buses arrival time in a bus station.

The paper is organized as follows: Section II introduces concepts related to context and ITS and discusses our approach with related work; Section III presents the UbiBus proposal; Section IV illustrates the UbiBus usage through an implemented application and presents some results from the application evaluation; and, Section V concludes the paper with some final remarks and future work.

II. Context and ITS

A. Definitions

Context-Sensitive Systems (CSS) are computer systems that use context to provide more relevant services or information to support users performing their tasks. Context appears as a fundamental key to enable systems to filter relevant information from what is available, to choose relevant actions from a list of possibilities, or to determine the optimal method of information delivery. In the literature, we can find several context definitions. According to the Merriam-Webster dictionary [4], context is “the interrelated conditions in which something exists or occurs”. As defined in [5], context is any information that can be used to characterize the situation of an entity (e.g. person, place, object, user, application). Context is defined in [6] as “what constrains a step of a problem solving without intervening in it explicitly”. In a broad sense, context is anything that surrounds a situation, in a given moment, and that allows to identify what is or is not relevant to interpret and understand that situation [7].

A definition for Intelligent Transportation Systems (ITS) is given by Sussman [1], for which the ultimate goal of ITS is “to combine high technology and improvements in information systems, communication, sensors, and advanced mathematical methods with the conventional world of surface transportation infrastructure". The technical world is described as the one involving areas such as: information systems, communication, sensors and advanced mathematical methods.

A classification for the ITS area provides six categories of applications [1]: i) ATMS (*Advanced Transportation Management Systems*), related to the network management, including incident management, traffic light control, electronic toll collection, congestion prediction and congestion ameliorating strategies; ii) ATIS (*Advanced Traveler Information Systems*), information provided to travelers pre-trip and during the trip in the vehicle, such as location of incidents, weather problems, road conditions, optimal routings, lane restrictions and in-vehicle signing; iii) AVCS (*Advanced Vehicle Control Systems*), a set of technologies designed to enhance driver control and vehicle safety, e.g. intelligent cruise control, which automatically adjusts the speed of the vehicle to that of the vehicle immediately ahead, or collision warning systems that alert the driver to a possible imminent collision; iv) CVO (*Commercial Vehicle Operations*), technologies to enhance commercial fleet productivity, including weigh-inmotion (WIM), pre-clearance procedures, electronic log books, interstate coordination, directed to private operators of trucks, vans and taxis; v) APTS (*Advanced Public Transportation Systems*), passenger information and technologies to enhance public transportation system operations, including fare collection, intramodal and intermodal transfers, scheduling, headway control; and vi) ARTS (*Advanced Rural Transportation Systems*), mostly safety and security technologies for travel in sparsely-settled areas. The UbiBus project is associated to the APTS category.

ITS and context have aspects that suggest a potential connection between these two areas. ITS often involves situations and objects related to issues such as navigation, mobility and traffic, i.e., aspects that have a constant behavior variation, which justifies the development and implementation of CSS solutions for this domain. However, there is still a lack of approaches that explore this cooperation between ITS and CSS [8]. Next subsection describes some works that uses context information on ITS solutions.

B. Related Work

We investigated the relation between context and ITS in the literature and found some works (e.g. [9-13]). In [9], authors propose a mobile application called UbiGreen that aims to increase ecological awareness related to users’ transportation habits. It considers context information, collected from three basic sources: a mobile sensing platform, the cell phone GSM signal and the user itself. Context is used to infer the transportation of the user (e.g. bicycle, train, car, walking) and to calculate the amount of CO_2 s/he is emitting in such activity.

The BPN system (BMW Personal Navigator) [10] receives context information from three main sources: web services, the user and GPS locators. Context is used to support navigation (e.g. driving in the traffic, walking on a street or looking for a room in a building). The application functionalities are adaptable to three different conditions: in an indoor environment via a desktop, in a car via GPS equipment, or walking via a mobile device. Thus, it considers design limitations and offered services to modify its behavior depending on the current context.

A method for dealing with the safety issue on roads is addressed in [11], which proposes the combination of bayesian belief Nnetworks and multi-agent systems to process real-time information about the qualifications of a particular highway. Context information, such as, traffic volume, road network characteristics and climatic conditions, composes the basic input for estimating the probability of accidents.

The Mobility-for-All project [12] addresses the difficulties faced in current public transportation models for people with cognitive disabilities and proposes a social and technical architecture to support them. The Personal Travel Assistant application, for instance, checks a user’s context for information such as his/her current location, the next activity s/he will accomplish and the location of a bus in a given area.

The application provides instructions about what the user should do to reach the venue of his/her next activity.

In [13], it is presented a prototype application that aims to provide data related to traffic flow and journey times on roads in Ireland. Context information includes vehicles location and speed, weather conditions and other events(e.g. accidents and obstructions). Processed information are available to transit authorities for acting on issues such as safety and mobility on the monitored highways.

Performing a comparative analysis of the presented works with our proposal, we noticed a major difference related to the focus. Our project aims to provide smart solutions to support public transportation systems, particularly those in urban areas, unlike other studies that focus on sustainable transport [9], integrated navigation [10], road safety [11] and road characterization [13]. The main difference regarding to [12] is the target audience and the purpose of each system, being users with cognitive disabilities in the first and a broad range of users in our approach. In UbiBus, we intend to provide different kinds of information that can be accessed by a variety of devices to any passenger, assisting them on their daily decisions concerning the usage of public transportation systems in a city (their own or a city they are visiting).

III. The UbiBus System

This section presents an overview of the proposed UbiBus System. A scenario of use is shown in Section A. The UbiBus architecture is described in Section B.

A. A motivating scenario of use

To exemplify the UbiBus use, let's consider the following scenario. Peter is a student who is visiting his colleague John in downtown to make a scholar group activity. From there, he is intending to go to Ann's (his girlfriend) house. So, he decides to check on John's desktop, via Web, the best alternative to take a bus, since downtown has selective bus stops, i.e. only a few lines stop at certain stations. The system verifies Peter's current location and informs him that the best station is the number 12, just 200 meters away from John's house.

Peter say goodbye to John, and while walking to the station 12 he decides to check through his 3G phone if everything is OK and if that is still, in fact, the best one. He receives from the system the updated information showing that the desired bus is stuck in a traffic jam, and the best alternative now would be the station number 14, 300 meters to the right, where he can get another bus line. Peter does what the system suggests and when arriving at the bus station he checks through a visualization screen available there, which confirms that the bus will arrive at the station in about 3 minutes.

Once the bus arrives, Peter enters into the bus, and there, using a Bluetooth connection between his cell phone and the computer placed in the bus, whose screen is available for passengers, Peter verifies the bus itinerary, the best station for Ann's house and the estimated arrival time to that station. Using a WiMAX connection, the bus frequently accesses the database of the Society of Traffic and Urban Transportation searching for updated information concerning the traffic on its route. Upon reaching the destination station and getting off the bus, Peter took the opportunity to buy flowers for Ann in celebration of one more month of their recent dating.

B. UbiBus Architecture

Figure 1 presents an overview of the UbiBus Architecture. It is divided into 5 main layers: *Data*, *Communication*, *Acquisition*, *Processing* and *Application*.

The *Data Level* is responsible for managing the data processed by the system, including data representation, storage and retrieval. The database contains georeferenced spatial context for the trajectories of moving objects (e.g. buses, cars, subways, trains and people). Different types of data and information may be considered, as shown in Figure 1: bus location, bus speed, bus route, bus station location, passenger location, traffic jam information, maps and locations, lines and schedules, and others. Traffic jam information includes the existence of obstructions or delays in the bus path and the traffic jam level (slow, moderate, high). Data on the positioning of mobile objects undergo continuous updates for representing their movements over time.

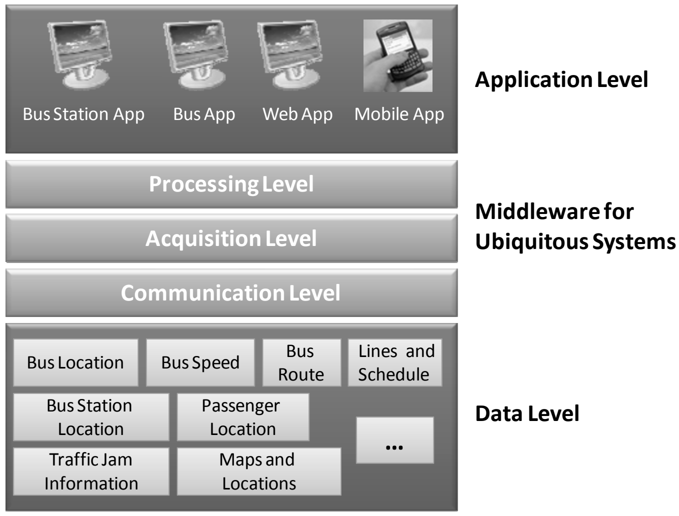

Figure 1. UbiBus Architecture Overview

The *Communication Level* allows the connection between the static and dynamic elements that compose the transportation infrastructure, allowing information exchange in real time between managers, operators, users, drivers, vehicles and other elements nearby the roads. The advances and standardization of wireless communication technologies such as WiFi, Bluetooth, WiMAX, GPRS and 3G, allows the short and long range communications. Terminals and panels installed at strategic points (e.g. bus or bus station) present traffic conditions and estimated time schedules. Such services may also be offered directly to users, considering the wide availability of connectivity, based on wireless communication technologies between mobile devices and laptops.

The *Acquisition Level* is responsible to gather static and dynamic context information from different sources, sending them to the *Data Level*. Bus location and speed, for instance, can be acquired from GPS or RFID systems available on the bus or at a bus station; traffic information can be provided by cameras, monitoring traffic systems or by inference using mathematical models; weather information can be provided by external meteorology systems; passengers' information (e.g. current location or next destination) can be provided by a GPS system embedded in a personal mobile device or by the user itself.

The *Processing Level* uses acquired contextual information along with mathematical and algorithmic solutions to calculate planned routes and temporal functions that indicates the approximate bus arrival time. This layer is also responsible for pre-processing acquired information to increase the accuracy of found locations, ensuring compatibility between different positioning systems (e.g. GPS and RFID) and the incorporation of semantics to the trajectories generated by mobile transportation units. Incorporating semantics to trajectories can be done from the collection, representation and use of dynamic contextual information and/or through trajectories patterns identification based on the analysis of geometric properties [14].

The *Application Level* contains the different types of applications developed on the top of the UbiBus infrastructure. These applications should be adjusted to different platforms and devices (e.g. Web, desktop, mobile devices, terminals at bus stations or displays inside a bus). Features offered by each application process the data from the Data Level and provide up-to-date information to users regarding routes and buses s/he intends to use. Applications should be adaptable since different devices have different requirements and limitations for interface, usability and contents.

Web applications enable an easy dissemination of the contextualized data related to the transit. A web application should provide: i) arrival times for each bus at each station; ii) definition of the best route based on priorities (cost, time, comfort); iii) traffic level in each area, route or region; iv) time history of travels and patches; v) map with the traffic intensity in different regions; vi) bus lines that pass at a given bus station and bus stations on a route; among others. *Mobile applications* have the great benefit of being portable, so the user can make a decision about his/her trip anywhere, even not being at a bus station or at home. Such applications are similar to web applications, but with interface adaptations for mobile devices and also the possibility of using the device's georeferenced position to generate more contextualized information.

Bus applications are terminals available inside the buses that provide information about their current situation. Passengers can, while inside the bus, visualize information about the trip and make new decisions due to unforeseen events. Some features that can be available in these applications are: i) estimated arrival times of the bus on each station in the route; ii) previous and next stations; iii) traffic at each patch in the route; and iv) alerts for a bus station stop to aid disabled people. *Bus Station applications* provides information to the passengers that are waiting for a bus in a bus station about the buses s/he can take, the estimated arrival time of each bus and its location in a route map. Section IV presents a prototype for a Bus Station application developed in the context of the UbiBus system.

To support the development of the different types of applications, UbiBus proposes a multiparadigm, extensible and message oriented middleware for Ubiquitous Systems. This middleware embodies the activities presented on the Communication, Acquisition and Processing levels. A middleware plays an important role in developing context sensitive and ubiquitous applications since it facilitates the communication and coordination of distributed software components dealing, in a transparent way, with the difficulties and complexities introduced by mobility and wireless communication [15].

The middleware is multiparadigm and extensible because it must support a set of communication paradigms, which can be adapted and extended to meet different types of applications. To optimize resource usage of mobile and embedded devices, the project adopts the approach of software product line. Thus, the paradigm is modeled as variation points that share and reuse a set of components that comprise the middleware reference architecture. The middleware uses the asynchronous interaction model, considered the most suitable for mobile environments, since it adopts an architecture in which software components are loosely coupled. This model is provided by middleware platforms oriented messages (MOMs) [16], in which communication is established from message production and consumption, instead of directly invoking methods or operations.

IV. The Your City on Time Application

This section presents the prototype of a Bus Stop application entitled Your City on Time [17]. Section A describes the application while Section B discusses some results found in its evaluation using real data collected in the city of Salvador, Bahia.

A. Application Description

The **Your City on Time** (YCT) application objective is to use contextual information to estimate a bus arrival time at a given bus station. The prototype interface (Figure 2) was designed in a way that a user can easily understand the presented information concerning the location, distance and estimated arrival time of a bus. A map is used to contextualize the location data, whereas a table shows the legend, estimated arrival time and current distance between the bus and the bus stop. A countdown, in the lower left side, lets users know when an updated set of information will become available. The name of the bus station is shown in the lower right side ("Comercial Ramos", in the example)

The final user does not interact directly with the system, which means that s/he can only passively look at a set of information which might offer some idea about the arrival time of the bus s/he is waiting for. That allows the user to plan her/his schedule towards the next appointments in a better way and under more appropriate conditions. To calculate the estimated arrival time, the system considers contextual elements such as: bus identification and location, bus station location and the traffic jam level in certain stretches of some routes.

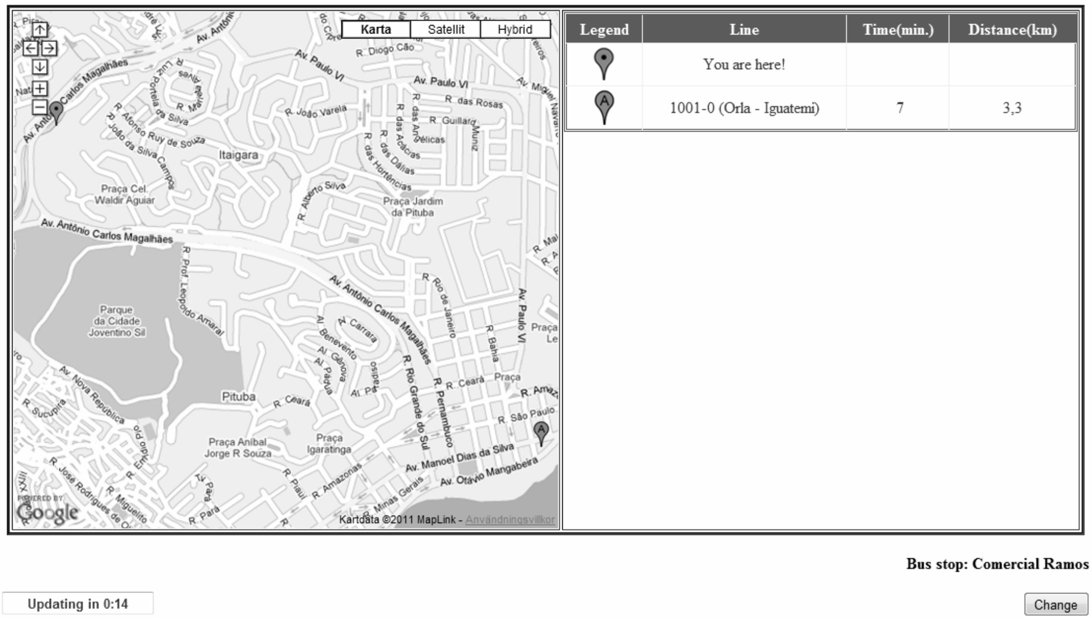

Figure 2. Main Interface for the Prototype of the Your City on Time Application

Table I lists the contextual elements used in YCT and provides some considerations about its acquisition/processing. For instance, bus location and speed are dynamic information acquired from GPS installed inside the buses. Traffic level is a dynamic information inferred from the buses and stretches average speed values using an incremental weighted update algorithm of average travel speed.

TABLE I. CONTEXTUAL ELEMENTS FOR YOUR CITY ON TIME SYSTEM

Contexual Element	Description
Location (Station)	Georeferenced location of a bus station. Acquired from GPS (Static).
Location (Bus)	Georeferenced location of a moving bus. Acquired from GPS (Dynamic).
Speed (Bus)	Current speed of a moving bus. Acquired from GPS (Dynamic).
Avg Speed (Bus)	Average speed of a bus calculated from a set of previous stretches he passed. Calculated (Dynamic)
Avg Speed (Stretch)	Average speed of a stretch calculated from the buses that recently passed by. Calculated (Dynamic)
Traffic level (Stretch)	The traffic level intensity on a stretch (low, moderate, high). Calculated (Dynamic)
Line (Bus)	Current line a bus is attending to. Provided by bus operator (Static/Dynamic).
Last Station (Bus)	Previous station the bus has just passed by. Acquired by sensor (Dynamic)
Distance next station (Bus)	Distance from a bus to the next station in its route. Calculated (Dynamic).
Time next station (Bus)	Estimated time from a bus to arrive on the next station in its route. Calculated (Dynamic).

Once all needed information are acquired or inferred, the system carries on with the processing and usage of that information. Knowing the bus and bus station location the system calculates the distance between them. Knowing the bus average speed, the stretch average speed and the distance to a station, the system calculates the estimated arrival time to that station. To support distance measure, the application uses the Google Maps API Family [18].

The YCT prototype is composed by a service, which handles the UbiBus Acquisition and Processing Levels activities, and by a web application that will run on a terminal located at the bus station. The Communication and Data Level were simulated according to a real world scenario as described in the next section.

B. *YCT Prototype Evaluation*

In order to evaluate the YCT prototype, we simulated a scenario with conditions similar to those found in the real world. We used real data from the city of Salvador, Bahia, by defining a bus route composed by existing bus stations, whose georeferenced location information were acquired using a GPS equipment and registered in our database.

To simulate the dynamic bus movement in our defined route we installed a GPS equipment in a car, which was driven throughout the route in different times of the day performing speeds and stops similar to those performed by a bus. The first time of the day was in a high traffic level situation and the second time was in a low traffic level one. Information collected from the GPS equipment during these trips simulations was analyzed and results are shown in Table II. The table exhibits the distance to the next station, the estimated arrival time (in minutes) and the difference between the estimated time calculated by the system and the real time collected by the GPS equipment. These measures include the two simulations performed (by day and by night).

By analyzing found data in comparison with other possibilities (e.g. the estimated time offered by Google API) we found that contextual information is a key player when estimating bus arrival time. As expected, estimated times behaved differently on the two traffic level scenarios and they presented values closer to the reality as new samples were received throughout the time.

TABLE II. EVALUATION RESULTS IN DIFFERENT TEST SCENARIOS

Distance to the next Station (km)	Day		Night	
	Estimated Arrival Time (min.)	Difference Estimated x Real (mm:ss)	Estimated Arrival Time (min.)	Difference Estimated x Real (mm:ss)
3,3	6,8	01:48	4,9	00:28
2,9	6,2	00:24	-	-
2,3	4,6	00:00	-	-
1,9	-	-	2,5	00:04
1,3	2,2	00:24	-	-
0,5	1,2	00:36	-	-
0,4	-	-	0,6	00:10

V. CONCLUSIONS AND FURTHER WORK

The UbiBus Project has as main contribution the integration of methods and techniques from several areas (e.g. Ubiquitous Computing, Context Sensitive Systems, Middleware, and Geographical Information Systems) in order to build a computational solution that, through personalized information and recommendations, allows a more efficient usage of public transportation systems. The proposed solution differs from existing ones by its focus on the passengers of public transportations and by the usage of context and different devices to support a ubiquitous and context-sensitive usage.

This paper presented the overall idea of the project and preliminary results found concerning the Your City on Time system, a bus station application that provides information for users in a bus station regarding the available buses in that station, their current location, distance to that station and estimated arrival time. Preliminary experiments using real data from the city of Salvador, Bahia, showed that context information aids providing more accuracy in estimating a bus time arrival.

We are currently working on the specification and development of the five levels indicated in the UbiBus architecture (Figure 1), the Middleware for Ubiquitous Systems and building additional applications regarding the Web, Bus and Mobile devices.

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