Supporting Intelligent Passenger Flows in Airport Terminals

Björn Greßmann, Helge Klimek, Volker Turau
Institute of Telematics
Hamburg University of Technology, Hamburg, Germany
{gressmann,helge.klimek,turau}@tu-harburg.de

Abstract—**In this paper we present a Digital Boarding Assistance (DigiBa) system for passengers in airport terminals. By providing navigation, notification and information services, passengers are enabled to move efficiently through the terminal. Based on functional requirements of such a system, the paper presents a prototype implementation on an embedded mobile device with restricted resources. Challenges concerning channel access in dense networks and indoor navigation on a device with limited hardware capabilities are outlined.**

Index Terms— **Digital Boarding Assistance, Indoor Navigation, Indoor Location Based Services, INLBS**

I. INTRODUCTION

Passengers undergo a high level of stress during the processes in the terminal. They tend to overhear speakers and oversee notification signs. To remedy stress and uncertainty, induced by the unknown environment, disturbed communication channels and unknown processes concepts to realize navigation, direct communication and transparency are used. Passengers will be informed on an individual and location based level at which process step of the process chain (check-in, boarding, security, ...) they are. They will get the information how much time they have left to spend and a navigation system will guide them through unknown areas to their chosen destinations. To achieve this goal, passengers are provided with a cheap and small mobile device, the so called digital boarding assistance (DigiBa).

Passengers can directly and personally be addressed with text messages, either on an individual level or as groups of passengers, for example, to notify all passengers of a flight about a change of the boarding gate. It is made evident for staff sending messages whether the passenger's device received the message. Additionally, messages can be confirmed which makes it also apparent whether the passengers consciously acknowledged the message.

Summarizing, passengers get the information needed at the right time. While they are in the terminal, the time which is left to spend is displayed on the DigiBa and it is always possible to navigate to desired destinations. This way, a passenger is able to move efficiently through the terminal. In case of urgent messages, these can be sent on an undisturbed channel to the passenger, which can consciously acknowledge the received message. If a message is not received by its destined receiver (even though an ARQ protocol is used), this is detected and countermeasures can be taken.

For the operation of the Digiba, two main scenarios exist. First, an existing infrastructure can be used. This allows to implement the functionality of the DigiBa on top of different smart phones or PDAs. This approach requires the implementation of the services for several different software and hardware platforms making it difficult to control the ratio of passengers using the DigiBa.

In the second scenario, a dedicated device is used for the DigiBa and lent to the passengers. In this scenario, it is easier to control the ratio of passenger using such a device. As these devices can get damaged or lost, they have to be cheap. This results in the requirement of low cost for the devices which eventually leads to restricted hardware resources, such as memory, processing power, low bandwidth for communication and a limited user interface due to low display resolution.

In this paper, the focus is on the second scenario: It aims at solving the issues of realizing the digital boarding assistance on a low cost device. In the following, the use cases and the requirements for the DigiBa system are presented.

II. REQUIREMENTS

There are three main use-cases for the system: Information, notification and navigation. The information use case aims at directly informing passengers about important events. Airports or airlines can send text messages to the DigiBa of one or many passengers. In particular, passengers are notified about changes in their flight schedule or boarding gate and their step in the process chain, always telling them, how much time they have left. If messages are of severe importance, their reception can be acoustically signaled to the user. On the other hand, passengers can request information on demand and send predefined requests to the system. Notification means that if users have interest in a special topic or event they can register for such news or events and are informed by text messages if an event is triggered. Another important use case of the system is navigation. The system shall provide passengers the possibility to enter a destination like a restaurant, their departure gate or other points of interest and being navigated there using the DigiBa.

With these use-cases in mind, several requirements of the system can be derived. Wireless communication has to be bi-directional, that is from the backend to the DigiBas and vice versa. From the backend, passengers shall be addressed individually or by a multicast, for instance to address all passengers of the same flight. Additionally, passengers shall be able to send requests from their DigiBa to the backend.

Localization of a DigiBa is a vital requirement to enable the use case navigation. In contrast to outdoor localization where GPS is a de-facto standard, precise indoor localization is still an active research field. The accuracy needed to allow for indoor navigation cannot be specified, but an accuracy of few meters is desirable.

A DigiBa has to be equipped with a graphical display to represent messages, navigation instructions and the user menu. The user interface has to allow to select menu entries and to display text messages. A beeper to signal the reception of messages is also required. The physical dimensions of a DigiBa should be small which restricts the size of the batteries. To allow for a long operation of the devices, the mobile devices should have low energy consumption. For a positive effect on flight delays the rate of passengers using the system should be as high as possible. This results in the requirement of high amounts of passengers being able to use the system at the same time. As human users are involved, the delay of messages should be low.

III. CHARACTERISTICS OF THE TECHNOLOGIES

As presented in Section II, bidirectional communication and localization are two important requirements of the system. There are two options for the technology of such a digital boarding assistance: First, the system can be set up on an already existing communication infrastructure, like WLAN, to reduce installation costs. The second is to pick and install a dedicated infrastructure using a technology which fulfills the requirements. Which approach is taken depends on how well requirements are covered by the different technologies and the total costs of operation for each approach. Communication technologies have different characteristics regarding communication and localization, some of them are summarized in this section.

Possible systems based on GSM / UMTS use SMS or MMS for informing passengers. In the recent past, mobile Internet has gained popularity and is available for the exchange of information. Compared to SMS and MMS arbitrary information can be sent and received. Using GSM / UMTS communication always comes with costs which is a barrier for high pervasion of the system. GSM / UMTS also allow to localize handsets, currently the accuracy is far too low for indoor navigation [1].

Radio Frequency Identification (RFID) refers to tiny transponders which usually store small amounts of data on tags. These devices have no user interface and allow for only cell based positioning whose accuracy is too low for indoor navigation.

Bluetooth is integrated in many mobile devices and is designed for local body area networks. Most devices are equipped with transceivers which allow transmission ranges up to 10m. This would result in a dense infrastructure of base stations in the terminal. Bluetooth does not specifically support localization of the devices. Most existing localization approaches using Bluetooth are cell based, delivering positioning results which are not accurate enough for indoor navigation. Although this technology is integrated in mobile devices, a dedicated infrastructure would have to be installed in most buildings.

An advantage of WLAN is an already existing communication infrastructure in many public buildings. It offers high data rates and transmission ranges for communication, but as Bluetooth it does not support localization specifically. Its disadvantage is the high energy consumption which reduces the life time of mobile devices significantly.

IEEE 802.15.4 is a low cost low energy communication standard with moderate data rates and transmission ranges. It is mostly used in low cost mobile devices and wireless sensor networks. With the 802.15.4*a* [2] extension, a first standardization approaches localization using two way ranging support. Its application requires a dedicated infrastructure in the terminal.

Besides, the suitability of the communication and localization, the heterogeneity of the mobile devices is an important factor regarding implementation and administration costs. As presented in Section I, a dedicated device could be used to support the passenger in the terminal. This reduces the implementation and administrative effort which evolves from using different classes of devices the passengers carry with them. In a WLAN based approach smart phones and laptops have to be considered as target platform. In the smart phone segment, there are five major platforms: Apple iOS, Android, Blackberry, Symbian and WebOS. Additionally, laptops run different operating systems, the most important ones being Microsoft Windows and Linux. This leads to a large number of clients which have to be developed and maintained.

As mentioned above, this paper focuses on the approach to use a dedicated device in order to simplify administration and implementation and to foster a high penetration of the DigiBa in the terminal. As a result the communication technology used in the presented prototype is based on an IEEE 802.15.4 radio combined with a low power micro controller.

IV. DIGIBA HARDWARE

The architecture of the system is composed of three subsystems: The mobile devices (DigiBas), stationary units (base stations) and a central server.

A first prototype DigiBa (see Figure 1) was developed. It is equipped with a monochrome display with a resolution of 128 × 64 pixels, a joystick and a beeper. The transceiver is an Atmel low power RF230 radio chip working in the license free 2.4GHz band offering a gross data rate of 250kBit/s. The micro controller is an Atmel ATMega128 with 8kBytes of RAM, 128kBytes of Flash and a clock speed of about 8Mhz. A second version of the DigiBa integrates ranging capabilities which will be used for localization.

In addition to the DigiBas, the system consists of several stationary base stations deployed in the terminal. They act as gateways between the mobile DigiBas and the wired network to a backend consisting of one or more servers. While base stations are assumed to be connected to the static power supply and can operate unlimitedly in terms of energy use, the DigiBas are battery-powered and energy constraints have to be taken into consideration. The communication between the base stations and the DigiBas is assumed to be single-hop, so DigiBas will not consume energy for relaying messages to other DigiBas.

Fig. 1. First prototype of the DigiBa in front the main screen of the control software

The network is a so called *infrastructure network* [3], in which downlink refers to communication from the base stations to the DigiBas and uplink from the DigiBas to the base stations. While DigiBas use duty cycling to save energy, the transceivers of base stations are continuously active. This leads to different challenges for the downlink and for the uplink which will be described further in Section VI.

V. DIGIBA SOFTWARE

The DigiBa Control Center runs on the backend, a software which is used to initialize DigiBas, handle communication with the DigiBas and to monitor the actual states of the passengers' devices. To initialize a DigiBa, passenger data and flight data is sent to and stored on the DigiBa. After the data has been acknowledged, the DigiBa can be used. From the control center, text messages can be entered and sent to single passengers or to groups of passengers. Different types of messages are supported: Popup-Messages are automatically displayed on the screen. Advertisement messages can be filtered by the device, if the user does not want to receive advertisement information. Finally, messages can be defined to be confirmed by the user. In this case, the user has to consciously send an acknowledgment to the backend system making it evident that the message has been read. Additionally, messages can be sent to a large number of passengers, for example to announce changes in the flight schedule. To allow the administrative staff to easily monitor the status of the communication, it is listed which messages have been received and which have been confirmed by the passengers.

On the DigiBa, the main information for the passengers are displayed on a main screen. This includes the actual process step (check in, security, boarding, . . .), the time left to perform the actual step and flight data like departure gate, departure time and flight number. With the joystick, the user can navigate through the menu tree. This includes an inbox for received messages, a template folder for user requests and a configuration menu.

Received messages are buffered in the inbox. If a message is configured as Popup-Message, it is directly displayed on the screen, otherwise it is buffered in the inbox and a symbol on the main screen indicates the reception of a new message. If messages have to be confirmed, a pending confirm symbol is displayed in the inbox for the respective messages.

As users can not enter free text because of limited input capabilities, they are provided with predefined requests to the system which they can select from the template folder. These requests are forwarded to the backend and processed by the server. Based on the type of request, the reply can be generated by invoking a web service, querying a data base or issuing staff members to take care of the request. Replies are sent asynchronously by the backend to the DigiBa.

In the configuration menu, important settings can be configured by the user. The most important ones are the localization and advertisements. Both are opt-in services to increase the acceptance of the DigiBa system.

VI. CHALLENGES

Based on the limited hardware capabilities (memory, CPU, display resolution, bandwidth), the calculation of routes and the presentation of navigation commands is difficult. One approach is to use textual navigation commands in conjunction with graphical arrows instead of complex maps of the building.

For a real world deployment of the system, the communication channel is a limited resource as potentially all passengers use the system and other networks installed in the terminal might use the same communication channel. This may lead to packet collisions on the wireless channel and results in a data rate reduction. At the same time, the system must provide low latencies and reliable transmission to inform passengers in time and in a dependable manner.

A. MAC protocols

As the system is operating in the 2.4GHz band other technologies like Bluetooth or WLAN installed in the airport terminal will affect the service quality. This is referred to as *external interference* and will not only affect data communication, but also ranging measurements. The effects of external interference on ranging measurements are subject of ongoing research.

Internal interference is caused by the system itself, by the way how multiple DigiBas share the wireless communication channels. As a consequence, internal interference is one parameter which affects how many DigiBas the system can support.

For the uplink, the DigiBas can send as soon as they wake up from their sleeping phase because the receiving base stations are active. The focus is on resolving multiple access to the channel and to avoid collisions. For the downlink, besides access control, the DigiBas need to be awake in order to receive a packet and the sleeping phases cause an additional delay for packet reception. Additional requirements are avoiding the hidden and the exposed terminal problems caused by multiple base stations.

First work in this field considered RiMAC [4] as good candidate for the downlink and CSMA for the uplink, at least in low to moderate traffic situations. Using RiMAC, the receiving DigiBas send a beacon when they enter their active phase to initiate transmission of pending data from a base station and the transmission delay can be minimized. Another advantage is that there is no need of a preamble like in B-MAC or X-MAC by the sending base station. CSMA seems to be a good candidate for the uplink as DigiBas send their data to the base stations as soon as they enter their active phase. Collisions are mitigated by the random back off of CSMA.

Another approach is to design a proprietary protocol which is used for both transmission directions and uses the wired backend for coordination and load balancing between the base stations.

B. Use of multiple channels

External interference due to WLAN or other networks operating in airport terminals is one possible reason for collisions and packet losses. Internal interference caused by other DigiBas within overlapping communication ranges of different base stations with the same channel is another reason. The use of multiple channels within the network is a possible countermeasure for these problems. Base stations shall adaptively select channels for communication with low external interference. Neighboring base stations shall use different channels to avoid internal interference. If DigiBas are within communication range of different base stations, they shall use a load balancing mechanism to select a base station and also consider the quality of the link.

This leads to several challenges: External interference has to be monitored by the base stations during operations as it may change at any time. Neighborhood relations between two base stations have to be identified and established. However, base stations which are not in communication range of each other, may still interfere with each other (hidden terminal problem). Thus, their two-hop-neighborhood has to be established with support of intermediate mobile DigiBas. If neighboring base stations are supposed to use different channels, a graph coloring problem on the topology graph of the base stations has to be solved, minimizing external interference. This can either be done in a distributed or a central approach. If DigiBas consider load balancing and link quality when selecting a base station, these two metrics have to be weighted in an appropriate way.

First tests with a prototype system have been performed [5]. For estimating the external interference, a metric based on the rate of energy measurements larger than zero was developed. Base stations are detected by DigiBas passively receiving periodic beacons sent by the base stations. The beacons also contain the actual load at the base station and optional information about the point of time and target channel of a future channel switch of the base station. This allows DigiBas associated with a base station to follow it to its new channel. When selecting a base station, a DigiBa calculates a score for each base station in range based on link quality and traffic load and chooses the the one with the best score. With increasing traffic load, the impact of the link quality is reduced to prevent connection to congested gateways.

The channel assignment for each base station based on their external interference measurements is centralized in the backend. It is still an open issue how to handle a situation in which it is not possible to allocate different channels to the different neighboring base stations. The scan for channels with low interference is an overhead and causes a delay. One possible countermeasure is the use of an additional transceiver in the base stations to estimate channel quality during operation.

First experiments in a test environment have shown a significant increase of throughput and a reduced impact of interference. Together with a routing scheme, a cross layer design has to be considered for the final design of the system and the presented mechanisms have to be combined.

C. *Indoor Navigation on an Embedded Device*

Navigation is the process of guiding a passenger from the current location to a selected destination. In order to do so, a model of the building is required. In contrast to road maps, buildings are 3-dimensional structures. After selecting a destination, a routing algorithm evaluates an optimal path according to a given heuristic. Once a route is found, it has to be subdivided into several steps from which navigation instructions are generated. Finally, the navigation instructions have to be presented on the mobile device. The point in time when navigation instructions are presented depends on the current location of the user. If the user leaves the predetermined path, the route instructions have to be reevaluated based on the current location. How navigation instructions can be presented depends on the capabilities of the device, of the display as well as on available data to describe the path.

In order to deal with the lack of processing power, the computation of routes is shifted onto the backend servers. The server holds the model of the building which consists of a directed graph for the route calculation as well as other data which describe points of interest (POI) and properties of rooms, hallways, and so on. The algorithm for route calculation is an A^*-algorithm which uses a heuristic for selecting suitable next nodes in the route finding process. Different heuristics can be employed: For example norms, such as the euclidean norm, combined with building properties such as the length of a path.

In a first prototype implementation [6], the DigiBa is primarily used for the presentation of navigation commands and for acquiring position information. Since the DigiBa has a very low display resolution and restricted communication bandwidth, it is not feasible to transmit map images to the device. Instead, textual navigation instructions are displayed. This has been accounted in the heuristic mentioned above, by favoring routes which are easy to describe in textual form.

Consistency problems due to changes in the topology are known from vehicle navigation systems which carry all their data on memory cards. Sending navigation instructions to the client devices mitigates these consistency problems as only a central system has to be kept up to date.

In contrast to vehicle navigation, where vehicles are bound to roads, passengers can walk freely in buildings. For example, in large, open terminal halls a full graph, which connects all the entries to the hall, is not a viable solution as it results in a large number of edges. Intermediate auxiliary nodes acting as center of a star topology reduce the complexity of the graph, but the routes computed along these auxiliary nodes do not represent ways a person would normally walk (e.g. walk straight ways instead of curves). Calculating paths through these open areas is still an open issue.

Currently, the DigiBa has no way to measure the heading of the user directly. The accuracy of electronic compasses inside buildings is low, thus the heading has to be derived from the paths users walk. A zoning concept allows to pre-calculate optimal paths and thus speeds up route finding in building compartments which do not contain points of interest.

Another challenge is the presentation and selection of possible destinations and POIs on the DigiBa. As these have to be presented to the user in a meaningful order, the mobile device requests the next n number of entries from a given start index from the backend, while the backend sorts the POIs by a given criterion like walking distance or alphabetically. This way, the resource constrained device can process possible entries in the system regarding its actual free resources, and further POIs can be requested on demand, if the user scrolls to the last item of the list.

If the passenger leaves the route, it has to be updated. The optimal scheme for this depends on whether the position of the passenger is calculated on the mobile device or in the backend. A periodic backend-side check requires a frequent update of the device's position and results in possibly high data traffic. An alternative is to send a rectangular bounding box to the mobile device which approximately represents the correct route to the next way point. Checking whether the actual position is within the rectangle is a computationally simple operation and the communication overhead of the first approach is mitigated.

VII. CONCLUSION

This paper presents a prototype design for a digital boarding assistance in airport terminals. The focus of the system is on using low cost, energy-efficient devices that allow to directly communicate with passengers and navigation in the terminal. This enables passengers to move self-determined and efficiently through the terminals while also moving efficiently through the steps of the boarding process.

A first prototype of a DigiBa and a control software are presented. The communication is based on IEEE 802.15.4 to allow for long lifetimes and low cost devices. These dedicated devices that can be lent to passengers in order to achieve high user rates to increase the impact of the system and to reduce implementation and administration costs compared to supporting various platforms.

The low cost character of the devices results in various challenges presented in this paper. Limited data rate together with large numbers of users are discussed. How an indoor navigation system prototype for a device with limited processing power and display resolution is implemented is also explained.

Ongoing work will focus on the evaluation of suitable MAC-protocols, use of multiple channels and navigation concepts and their impact on the system performance.

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