Towards Smart City Implementations in Sub-Saharan Africa

The Case of Public Transportation in Ouagadougou (Burkina Faso)

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Abstract. Technological progress, in relation with ubiquitous computing, has put forward the concept of ICT-based smart cities. This concept, which is related to the need of facilitating the daily life of citizens in the concerned cities, relies on the use of existing infrastructures of communication to develop adapted digital services. As such, the implementation of mobile services in the framework of smart cities is equally important in developed countries than in the least developed countries. In the latter (more particularly in sub-Saharan Africa), it is however to be noted that the most advanced technologies of communication are not always available. It thus prevents the immediate deployment of digital systems that are available in developed countries. Obviously, the provision of mobile services dedicated to sub-Saharan areas requires the consideration of the ambient environment in terms of social and technological perspectives. In this paper, we discuss the situation of public transportation in Burkina Faso and the needs of users regarding reliable systems to retrieve transit information. We also provide and evaluate a (realistic) SMS-based solution, leveraging the technological and social specificities of the sub-Saharan context, to enhance the dissemination of information about traffic and buses in the city of Ouagadougou (Burkina Faso).

Keywords: Mobile service · Sub-Saharan Africa · Smart cities · Public transportation

1 Introduction

In recent years, the concept of *smart cities* has been put forward by technological progress. In the context of sustainable development, *smart cities* are meant to offer innovative services based on ICT in the domains of transportation, education, commerce and culture. As such, the reduction of financial costs (in terms of evelopment and deployment of digital services), the preservation of energy and

A. Leon-Garcia et al. (Eds.): Smart City 2015, LNICST 166, pp. 78–90, 2016.
DOI: 10.1007/978-3-319-33681-7_7

the mobility (services must be accessible in mobility situations) are key points. Especially regarding mobility, most of digital services are in the form of mobile services that citizens can use via their personal mobile devices.

In developed countries, the technological environment favors the development of innovative mobile services by taking advantage of new mobile technologies. Indeed, the availability of high-end mobile devices and the deployment of infrastructures for efficient communications (4G/5G networks, Wi-Fi hotspots with high bandwidth) have obvious advantages. At European level, collaborative projects have then been initiated to tackle issues related to the design of mobile services that are adapted to the environment of potential end-users. A representative example is the Smart Urban Spaces (SUS) project that aimed at defining new mobile e-services in urban contexts. It also aimed at building a network of cities proposing the same set of ICT-based mobile solutions [2].

In countries of sub-Saharan Africa, unlike eveloped countries, the urban environment is not adapted to initiatives such as the SUS project. Concretely, the major part of the population cannot afford to use high-end mobile equipment. Also, investments in terms of infrastructures of communication are not always sufficient. In addition, the use of 3G/4G networks remains a luxury when they are available. This context changes the perspectives in the development of mobile services. It is then necessary to rely on other elements in the design of digital services so that they can be relevant for end-users. Two key elements are to be considered [21]:

- opportunistic and collaborative networking approaches are reasonable as the organization of societies favors long and frequent encounters between citizens [20]
- "cheap" technologies (i.e. technologies that generate no additional cost) must be privileged as people are more willing to use them [12]

Relatively to the previous points, public transportation represents a relevant domain to be explored for the provision of mobile services. Regarding urban areas of sub-Saharan Africa (more particularly in Burkina Faso), the question that we have then chosen to study is the following: **By taking into account the technological/social environment, how to properly disseminate information about traffic and buses to the attention of end-users?** Based on a survey that we have conducted, our approach has first been to analyze the situation of public transportation in Burkina Faso and discuss the needs of users regarding reliable systems to retrieve transit information. Then, we have designed and developed a mobile solution that relies on existing technologies to support the dissemination of information about traffic and buses. This mobile service is to be deployed in the city of Ouagadougou (Burkina Faso).

The remainder of the paper is organized as follows. First, we present the important role of *smart cities* in the context of sub-Saharan regions. Then, we provide general requirements for a system dedicated to the dissemination of information in public transportation (based on feelings and needs of users with the concrete case of the SOTRACO company in Ouagadougou) and we describe

the solution (in terms of mobile service) that we propose to solve the problem. Finally, before concluding, we discuss the adoption of the proposed service by highlighting the realistic aspect of our solution and by evaluating the prototype that we have developed.

2 Towards ICT-based Smart Cities in Sub-Saharan Africa

The concept of *smart cities* has drawn much attention in developed countries. In the perspective of sustainable development, the ultimate objective is to implement digital services in order to address economic, environmental and governance issues [23]. In this context, the use of ICT is the privileged option to ease the daily life of citizens regarding the different operations to be performed in urban areas [22]. These operations are made possible by taking advantage of the capabilities of personal mobile devices and the efficiency of communication infrastructures.

In regards with sustainable development, the vital aspect of ICT-based *smart cities* for sub-Saharan countries can be highlighted. The universal scope of the concept allows to affirm its relevance for urban areas of sub-Saharan Africa. Indeed, the natural evolution of societies in all parts of the world (in terms of available technologies) encourage public authorities to provide ICT-based services to their citizens. In addition, the high penetration rate of mobile phones in the populations of sub-Saharan Africa (cf. Sect. 4), even if efficient infrastructures of communication are not always available, offers interesting opportunities for the deployment of mobile services. It is then a question of properly analyzing the technological environment in order to determine the most appropriate combination of technologies that is able to support the development of digital services. It is also a question of properly adapting solutions that have already been deployed in developed countries. More generally, we believe that the concept of *smart cities* is in accordance with the topic of ICT for development (ICT4D). ICT4D aims at leveraging ICT in order to promote sustainable development (to move people out of poverty) with an efficient use of the limited resources that are available in poor countries [16]. In the considered regions, there is thus a need to continue identifying priority areas from a societal point of view so that it is possible to initiate innovative (ICT-based) approaches regarding the provision of appropriate services for a smarter urban environment [12]. In this respect, one of the main topics to be studied concerns the domain of public transportation. The exponential growth of cities in sub-Saharan Africa, partly due to rural exodus and political crises, has led to the disruption of public services. This situation has particularly affected the field of transportation. In most of the cases, the public transportation systems fail to meet the needs of users regarding information about schedules and estimated waiting times at stops. Considering for example a country like Burkina Faso, there are no (real) fixed timetables because of the unreliability of the traffic. In addition, it is not uncommon to read stories in journals about commuters complaining of having waited several hours for a (overcrowded) bus when they could have chosen alternative means of transport

if they were informed of the waiting time. In this perspective of implementation of mobile services for *smart cities*, there is an urgent need to provide new solutions to enhance the dissemination of information about traffic and buses. These solutions must be based on the use of technologies that are accessible to the majority of the population. It will allow citizens to adapt their behaviors to the current situation. This could mean that a commuter will decide to stop waiting for a coming bus because it is overcrowded or he will look for alternative means of transport because the estimated waiting time is unusually high.

3 Services for Citizens: Public Transportation Information

3.1 Current Situation and General Requirements

We have carried out a survey among the students of the computer science department at university of Ouagadougou. The aim was to collect the feelings of current/potential/former users within a population which is particularly sensitive to the services provided by public transportation operators (in this case it is the SOTRACO company that operates the network for public transportation in the city of Ouagadougou). The feedback has been collected via a Google form. The results of the survey are presented Fig. 1. Beyond the complaints about the quantity and the quality of the buses, the respondents raised issues concerning the schedules of the buses. Indeed, 97 % of people feel that the waiting times at stops are long or too long and 97 % believe that the (given) timetables are not reliable. Thus, the users "demand" a system so that they can obtain relevant information regarding the estimated transit times of the buses. This analysis is supported by other studies which show that about 70 % of people (in the city of Ouagadougou) are willing to change their travel habits in favor of public transportation provided that improvements are made to the system (especially regarding the compliance of timetables) [18].

From the perspective of end-users, the following points must be considered regarding a system intended to provide information related to public transportation [25]:

- the financial cost for accessing the information should be cheap (for example, it would be a nonsense to pay the same price as the cost of a bus ticket)
- the ease of use and the quick access to the information (so that no complex operations must be performed by the users)
- the relevance of the provided information according to the context (in particular, due to the social organization, the expectations in terms of accuracy of information are somewhat lower in sub-Saharan Africa compared to developed countries)

In our target environment, the option that consists in deploying ICT-enabled equipments at public places is not always reasonable. This situation is linked to the social climate. For example, TV displays at bus stops will probably be

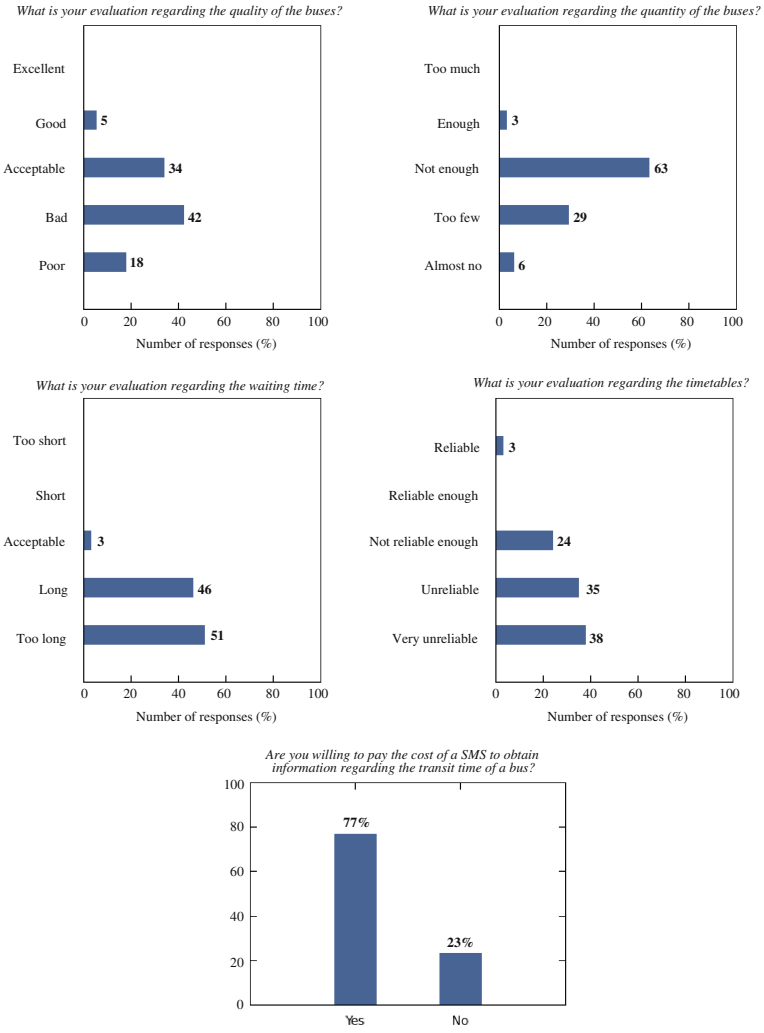


Fig. 1. Feelings of the users regarding the service provided by the SOTRACO company

stolen or broken during the regular strikes. In addition, the high cost of Internet access via personal devices leads to the fact that 3G-based services remain a luxury. In this context, another approach must be considered. It consists in taking advantage of "low-cost" technologies that can be used with the mobile devices of end-users [11,21].

3.2 Our Proposal for an Information Service

The solution that we propose is adapted to the context of the SOTRACO company (public transportation operator in Ouagadougou). We believe this environment represents the situation that occurs in major cities of West Africa.

As a reminder, the goal is to provide the users of public transportation with up-to-date information about traffic and bus hours.

The Fig. 2 presents an overview of the whole system regarding our solution. The process is as follows:

1. Upon the arrival of a bus at a given stop, the mobile equipment (a mobile phone) of the driver receives a Bluetooth signal from a Bluetooth Low Energy (BLE) beacon[1]. The reception of the Bluetooth signal, which consists of the unique identifier of the BLE beacon, triggers the emission of a message to the SMS platform. This message, which is a SMS, contains the identifier of the bus line (corresponding to the identifier of the BLE beacon) as well as the identifier of the current bus stop and it is used to update obsolete information. In order to enable the automatic initiation of this series of operations, each bus stop is endowed with a BLE beacon that is capable of transmitting Bluetooth data in its immediate environment (an approximate range of 70 m). The Bluetooth data is then automatically captured by the mobile device of the driver when the bus comes close to the considered stop. Subsequently, this action activates a mobile application (running on the mobile phone of the driver) that associates the identifier of the beacon to the identifier of the current bus stop and sends the appropriate message to the SMS platform. It is to be noted that the identifier of the bus line, the connection address to reach the SMS Platform as well as the correspondence between the identifiers of the BLE beacons and the identifiers of the bus stops are preloaded in the application. This preloading is performed before the driver begins his journey.
2. When a user arrives at a bus stop, he taps his NFC-enabled mobile phone to a NFC[2] tag. This action triggers a mobile application (running on the mobile phone of the user) that reads the content of the NFC tag before launching the emission of a message to the SMS Platform. The message, which is a SMS, contains the identifier of the bus line as well as the identifier of the current bus stop retrieved from the tag (it is to be noted that the NFC tag also contains the connection address to the SMS Platform). In return, the SMS Platform sends a message with up-to-date information according to the request (e.g. information about coming buses). In case of change in the available information, the user receives on his mobile phone a notification containing the updated details that are sent by the SMS platform. This option is considered when the change occurs in a relatively short time (not exceeding 5 min for example). An alternative solution for triggering the retrieval of the information about coming buses is to make use of a QR code[3] instead of a

[1] BLE beacons are transmitters that use Bluetooth to broadcast small packets of data -http://www.ibeacon.com/what-is-ibeacon-a-guide-to-beacons/.

[2] NFC [15], which stands for Near Field Communication, is a short range wireless technology (about 10 cm) allowing compatible devices to read the content of specific tags (small piece of hardware with electrical circuits).

[3] A Quick Response (QR) code [5] is a type of two-dimensional bar code encoding data and graphically represented (generally) as a set of black squares on a white background.

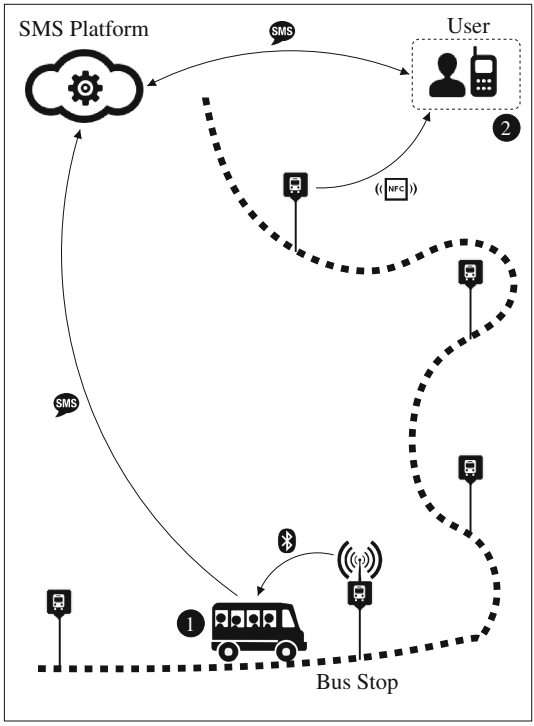


Fig. 2. Keeping commuters up-to-date on bus passage timetables

NFC tag. In this case, the user must "read" the QR code with the camera of his mobile phone. The encoded information is then extracted and the mobile application is activated to perform the requested operations (similarly to the situation in which a NFC tag is used).

According to the description of the process, three main entities are interacting with each other: the SMS Platform, the Mobile Application running on the equipment of the end-user and the Mobile Application dedicated to the equipment of the driver. These entities are illustrated Fig. 3. We detail their main characteristics in the remainder of this section.

SMS Platform. The role of this entity is to receive SMS from different sources, to parse the received messages so that a database can be populated with information regarding bus lines and to answer to requests regarding the information that is stored in the database. The platform, as a traditional SMS platform (i.e. a platform which is able to handle reception and emission of SMS), is accessible via a connexion address which corresponds to a phone number of a mobile operator. The platform also manages the database that stores transit information. Upon the reception of a message, it is parsed in order to be processed according to the following possibilities:

– the message comes from a driver. In this case, the relevant content is inserted in the database to update it with the most recent information regarding a bus line (last stop, transit time at a given stop, current location of the considered bus)
– the message is a request from a user. In this case, the data corresponding to the content of the message is retrieved from the database and it is sent, as a SMS, to the phone number that was used to transfer the request. The transmitted data corresponds to the last time that a bus reached the stop on the concerned line, to the last stop of the approaching bus and to an evaluation of the transit time at the stop of the user (according to the historical data that has been collected)

Mobile Application for the User. The role of this application is to manage the interactions of the user with other entities (or equipments) via NFC and via SMS. The application is able to handle the reading of content stored in a NFC tag (identifier of the bus line, identifier of the bus stop, connection address to the SMS Platform), to format a message with the retrieved information and to send it via SMS to the corresponding platform. The application is also able to handle the reception a message from the SMS Platform (an answer to a request) and to display it for the user. In the case that QR codes are deployed, a module enabling the extraction of data is integrated into the application.

Mobile Application for the Driver. The role of this application is to provide a tool for the driver so that he can transmit information to the SMS Platform (the application works independently and it requires no action from the driver). It concerns the transit times of his bus and its location according to the stops of the journey. The application is then able to handle the reception of signals transmitted by BLE beacons. This data, associated to the preloaded information, is then used by the application to automatically send a message (to the SMS Platform) containing the last stop and the transit time at the stop for the corresponding bus line.

4 Adoption of the Proposed Service

With far more than 650 million users [24], the proliferation of feature-phones and low cost smartphones in sub-Saharan Africa has dramatically increased over the past decade[4]. Moreover, it should be noted that the mobile penetration rate was up to 39 % in 2014 (compared to a global average of 49.9 %) and it is expected to reach 48.7 % by 2020 (compared to a global average of 59.3 %) [10]. It thus highlights the potential of ICT-based systems that rely on the deployment of mobile services. Based on this observation, the following points allow us to anticipate a likely adoption of our solution:

[4] According to GSMA (GSM Association), the number of unique mobile subscribers rose from 146 million in 2008 to 347 million in 2014 [9].

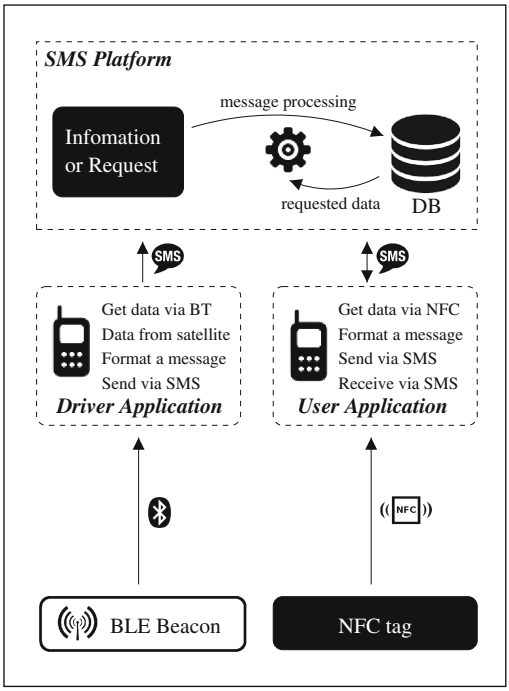


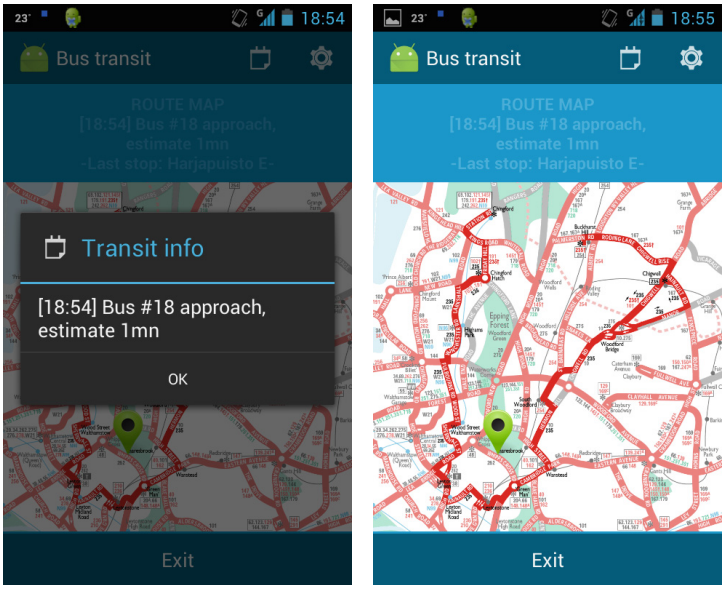
Fig. 3. Overview of the interactions between the entities of the proposed system

- Users increasingly aspire to interact with their mobile phones by taking advantage of productivity and utility applications. This view is supported by a report of a mobile phone manufacturer on *bridging the digital divide* in sub-Saharan Africa [17].
- The availability of feature-phones or low cost smartphones that offer NFC capabilities [1]. This includes for example the Samsung Galaxy Lite S6790, the Alcatel Pop D3 or the Huawei Ascend G300. Obviously, these phones have an affordable price for the people of the concerned areas. It is to be noted that one of the main characteristics of NFC technology is the simplicity of use. Indeed, the user must simply tap his mobile device to the equipment (NFC tags) with which he wants to interact and the corresponding operations are automatically triggered. It is also to be noted that feature-phones and low cost smartphones are equipped with cameras. It then appears realistic to also use QR codes even if this latter option is a little less convenient for end-users (as it has been stated for NFC-enabled ticketing systems [14]).
- In the context of mobile communications, the most popular (and reliable) service in sub-Saharan Africa remains the SMS [3]. Indeed, more than 72 % of the owners of mobile phones use this means of communication on a weekly basis [17]. For the record, the emission of a SMS approximatively costs 0.02

Euro [8] through the networks of the mobile operators in Burkina Faso (compared to the price of a bus ticket which is approximatively set to 0.20 Euro).
– According to the results of the survey that we have carried out, the feelings of users suggest that the people are looking for mobile services dedicated to public transportation. This has to do with the supply of an adapted tool to retrieve relevant information about the traffic of public transportation, especially for the transit time of buses at stops. The survey also suggests that users (more than 75 %, cf. last part of Fig. 1) are willing to pay the *cost of a SMS* in order to get the information they may need. In addition, *SMS Innovation* is seen by the big players as one of the most appropriate means to provide adapted e-services in various domains (e.g. mHealth) for people living in sub-Saharan Africa [6].

We have also performed usability tests with a prototype of our solution. The objective was to collect relevant feedback from potential end-users through the (10-items) questionnaire of the System Usability Scale (SUS) by John Brooke [13]. The System Usability Scale is acknowledged to be an effective tool for the evaluation of perceived usability [7,19]. The group of testers was composed of 34 students of the university of Ouagadougou. Indeed, in the considered environment students represent the type of population that is most likely to use public transportation. As for the prototype, it consists of an Android application that retrieves transit information and a SMS server that performs the operations of the SMS platform. Figure 4 presents screenshots of the mobile application that displays alerts regarding the arrival of a bus. Concerning the scenario of the test, the users simply needed to tap a mobile phone to a NFC tag (or read a QR code) in order to trigger a request (via the emission of a SMS) and they wait to receive in return alerts about transit information. Of course, the Android application was loaded on the mobile phone so that it can interact with the SMS server. By aggregating the answers of the testers (i.e. each set of answers attributes a note on 100), we have obtained an average of 73 out of 100. This result argues in favor of the acceptance of mobile services based on our concept as it corresponds to a good SUS score [4]. As a complement, interviews with the testers have allowed us to get many valuable comments. In particular, we have noted that more than 73 % of the respondents are willing to frequently make use of the proposed service.

The previous elements emphasize the realistic aspect of our system as the social and the technological environment of potential end-users are considered. They also highlight the fact that the system meet the requirements presented in Sect. 3.1. In addition, the implementation of such services may help citizens to benefit from the potential of their mobile equipments and thus make their money worth. However, there is still a challenge in the deployment of the mobile application at the end-user level (i.e. appropriate distribution channel). This topic deserves further studies in order to propose adapted answers. A possible solution will require the establishment of specific customer centers where the people will be able to easily download applications on their mobile phone. Another considerable point concerns the scalability of the system. It should simply be



Transit notification Location on the map

Fig. 4. Reception of alerts within the mobile application of the prototype

pointed that the scalability is an inherent characteristic because of the choices in terms of design and communication technologies. In particular, the use of SMS as the privileged communication carrier is an obvious example. It thus only depends on the level of investments concerning ICT-based infrastructures (e.g. SMS platform).

In view of these observations, a closer cooperation with public authorities is essential to the success of the whole project. As such, we plan to launch a more active phase of the project regarding the collaboration between the university of Ouagadougou and the SOTRACO company (public transportation operator in Ouagadougou).

5 Conclusion

We have proposed a (realistic) system to support the provision of information in public transportation. This system, which is a mobile service, allows the commuters to make use of their mobile equipment to retrieve information about traffic and bus hours. Although initially designed for the public transportation system of Ouagadougou (Burkina Faso), we believe that the solution can be deployed in other cities of sub-Saharan Africa, more particularly in West Africa. The similarity in the structure of the society in these cities allows this extrapolation.

Two main factors militate in favor of the adoption of the proposed service. The sample of opinions that we have collected in Ouagadougou shows

the expectations of users. Indeed, they need and they are willing to use such a system of information so that they can adapt their behavior to the current situation (choose to wait or not for a bus depending on the estimated waiting time). In addition, the service is accessible through "cheap" technologies that are commonly used by the people of the concerned regions (SMS) or that generates no additional costs (NFC or QR codes).

It is reasonable to assume that public authorities can afford some investments (regarding systems such as the SMS Platform of our solution). As such, the current work serves as a basis in the collaboration that is to be set up with public authorities in Burkina Faso. This project is part of initiatives intended to improve the experience of citizens regarding the daily operations that they perform. The expected results will provide useful insights to consider in the development of ICT-based smart cities in accordance with the context of sub-Saharan Africa.

References

1. NFC phones: the definitive list. http://www.nfcworld.com/nfc-phones-list/
2. Smart Urban Spaces website, June 2014. http://www.smarturbanspaces.org
3. Cell phones in africa: communication lifeline, June 2015. http://www.pewglobal.org/2015/04/15/cell-phones-in-africa-communication-lifeline/
4. Measuring usability with the system usability scale (sus), June 2015. http://www.measuringu.com/sus.php
5. QR code technology, June 2015. http://qrcodesdoneright.com/
6. SMS innovation and dynamic mobile content drives mHealth initiatives in Africa, June 2015. http://blog.gemalto.com/blog/2014/07/16/sms-innovation-and-dynamic-mobile-content-drives-mhealth-initiatives-in-africa/
7. System usability scale (sus), June 2015. http://www.usability.gov/how-to-and-tools/methods/system-usability-scale.html
8. TELMOB Mobile Operator, June 2015. http://www.onatel.bf/telmob2/prepaye/tarifs-prp.htm
9. The Mobile Economy - Sub-Saharan Africa. Technical report, GSMA (2015)
10. The Mobile Economy. Technical report, GSMA (2015)
11. Anderson, R.E., Poon, A., Lustig, C., Brunette, W., Borriello, G., Kolko, B.E.: Building a transportation information system using only gps and basic SMS infrastructure. In: ICTD, pp. 233–242 (2009)
12. Bissyandé, T.F., Ahmat, D., Ouoba, J., van Stam, G., Klein, J., Le Traon, Y.: Sustainable ICT4D in Africa: where do we go from here? In: Bissyandé, T.F., van Stam, G. (eds.) AFRICOMM 2013, LNICST 135. LNICST, vol. 135, pp. 95–103. Springer, Heidelberg (2014)
13. Brooke, J.: SUS: a quick and dirty usability scale. Usability Eval. Ind. **189**, 4–7 (1996). Taylor and Francis Ltd, London, England
14. Chaumette, S., Dubernet, D., Ouoba, J., Siira, E., Tuikka, T.: Architecture and comparison of two different user-centric NFC-Enabled event ticketing approaches. In: Balandin, S., Koucheryavy, Y., Hu, H. (eds.) NEW2AN 2011 and ruSMART 2011. LNCS, vol. 6869, pp. 165–177. Springer, Heidelberg (2011)
15. Haselsteiner, E., Breitfuss, K.: Security in near field communications (NFC). In: Proceedings of Workshop on RFID Security RFIDSec (2006)

16. Heeks, R.: ICT4D 2.0: the next phase of applying ICT for international. IEEE Comput. **41**(6), 26–33 (2008)
17. Consumer Insight. How mobile phones are playing a key role in connecting people in sub-Saharan Africa. Technical report, Ericsson AB, November 2013
18. Anicha Adéelaïde Alimatou Kadiogo. Modélisation d'un système de transport urbain de personnes en vue d'une amélioration de la mobilité: cas de la ville de Ouagadougou - Modeling a system of urban passenger transport in order to improve mobility: the case of the city of Ouogadougou. Master's thesis, Institut International d'Ingénierie de lEau et de IEnvironnement - 2iE (2014)
19. Bangor, A., Kortum, P., Miller, J.: Determining what individual sus scores mean: adding an adjective rating scale. J. Usability Stud. **4**(3), 114–123 (2009)
20. Ouoba, J., Bissyandé, T.F.: Leveraging the cultural model for opportunistic networking in Sub-Saharan Africa. In: Jonas, K., Rai, I.A., Tchuente, M. (eds.) AFRICOMM 2012. LNICST, vol. 119, pp. 163–173. Springer, Heidelberg (2013)
21. Ouoba, J., Bissyandé, T.F.: Sensing in the urban technological deserts - a position paper for smart cities in least developed countries. In: International Workshop on Web Intelligence and Smart Sensing, IWWISS, Saint-Étienne, France (2014)
22. Ouoba, J., Siira, E.: Many faces of mobile contactless ticketing. In: Proceedings of the Second International Conference on Smart Systems, Devices and Technologies, SMART 2013, pp. 93–98 (2013)
23. Giffinger, R., Fertner, C., Kramar, H., Kalasek, R., Pichler-Milanovic, N., Meijers, E.: Smart cities - ranking of european medium-sized cities. Technical report, Vienna Centre of Regional Science (2007)
24. Sambira, J.: Africa's mobile youth drive change - cell phones reshape youth cultures. Afr. Renew. Afr. Youth Driv. Innov. **27**(1), 19 (2015)
25. Virtanen, A., Koskinen, S.: Public Transport Real Time Information in Personal Navigation Systems for Special User Groups. Technical report, VTT Technical Research Centre of Finland (2004)