Web Mapping-Based Architecture for “Dakar Dem Dikk” Buses Fleet Management

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***Abstract*—The national public transport *“Dakar Dem Dikk” (DDD)* owns an active automobile fleet of approximately 675 buses in order to provide interurban transport and run a shuttle between Dakar region to $AIBD$ airport. Nevertheless, DDD operates 24 lines with roughly 100 buses per day for $120,000$ passengers. The lack of punctuality and the amount of time wasted at bus stops are a big concern. The existing information system, called *DDDT (“Dakar Dem Dikk Tracking”)* based on Short Message Service (SMS) requests can predict only bus position with respect to a number of remaining bus stop. Nevertheless, DDDT is not scalable due to the huge number of sent SMS as well as their cost price. Therefore, we propose a new fleet buses management based on web mapping technology and Internet connectivity. In contrast to previous DDDT architecture, the communication between target passengers and the system is based by default on $3G$. Each passenger is able in real time through a mobile application or a navigator to plan its trip and get updated schedule information. Furthermore, DDD staff can monitor the overall network from a dashboard that depicts buses in motion.**

***Index Terms*—smart transport, web services, geographic localization.**

I. Introduction

Dakar is the smallest and the most populous region in Senegal with 4 million of inhabitants for an area of $550km^2$. 80% of the country’s economic activities and most urban infrastructure are located in Dakar-downtown. Every day, workers need to transported from suburb to Dakar-downtown as well within the Dakar city’s. Traveling on Dakar roads has become a real ordeal during workday. Furthermore, we note an increasing number of new private cars and clandestine vehicles that are used as means of transport. The main reason is due to the lack of punctuality and the time wasted when passengers use public transport. Indeed, the long waiting time at bus stops dispirit passengers and thus make them unwilling to take public transportation. Consequently, the use of private cars increase traffic jam and then the wasted time can go up to 4 hours during workdays. Meanwhile, the lack of punctuality and the waiting time at bus stops are the main concerns of national public transport *“Dakar Dem Dikk”* (DDD).

So far, a real time information system enabled DDD passengers to enquire about bus schedules and delays due to traffic jam are available [1]. This tools called *“Dakar Dem Dikk Tracking” (DDDT)* is based on *“Short Message Service”(SMS)* and enables to know the actual geographic position of circulation buses. The passenger sends a SMS request to the server which contains bus line, bus stop number and target direction. After server processing, it sends back a SMS to the passenger the number of remaining bus stops and the distance between its position and the targeted bus passenger. However, $DDDT$ is a SMS-based communication architecture. Consequently, the interface is not very intuitive and user-friendly. Indeed, in Senegal SMS costs is very expensive. Moreover, SMS is not user friendly and not convenient for a couple of passengers category like students.

Therefore, efficient transport management becomes a big concern in order to motivate the use of public transport. Nowadays, Internet and mobile phone are become essential for everyday life: mobile payments, social networks, smart cities, smart transport. In Senegal, 81% of the population own a mobile phone and among them 13% have a smartphone [2]. The number of mobile cellular subscribers is estimated at $15,765,524$ and the mobile operators have switched their network from $2G$ to $3G$ [3]. It is worth noticing that during June 2016 (respectively June 2015), the mobile penetration rate in Senegal was estimated to 116.71% (respectively 109.70%). This growth is not over yet. Indeed, the penetration rate is up to 100% due to the fact that cellular subscribers own several SIM cards.

By leveraging Internet connectivity or cellular network we design new solutions that are mobile applications-based. In fact, among the $8,965,676$ Internet links estimated in the second quarter of 2017, 96.81% of users are connected by using $2G$ and $3G$ cellular mobile network [3]. At the same time, SMS traffic is following a downward trend [3]. By taking into account this new dawn, it is mandatory to overcome the limitations of $DDDT$ [1] tool which is SMS-based and not user-friendly.

Web mapping or map broadcasting by way of the Internet network is a important domain thanks to the development of Web Open Source solutions [4] [5]. *Web Mapping* approach is adapted to a wide non-specialist public. It provides a simple user-friendly, ergonomic, oriented interface and on-line *“Geographic Information System” (GIS)*, low-cost and low-connection, independent according to browsers.

Therefore, we design a web mapping-based architecture which is low-cost and provides an ergonomic navigation system for DDD fleet management. In contrast to other countries, we do not have an unique position of bus driver-fare collector in Senegal. In other words, bus driver and bus fare collector (or tickets seller) take up two distinct positions. It should be noted that “fare collector” and “tickets seller” are used interchangeably.

The proposed Internet-based architecture is formed by:

(i) a mobile application deployed on smartphone which is connected into the system through mobile Internet; (ii) a smartphone hosted within the bus and managed by bus fare collector transmits to a remote server, by using Web services, several information such as the actual geographic bus position according to its destination; (iii) servers that collect either data transmitted by buses or process passenger's requests.

In this paper, we aim to provide smart travel applications as well an efficient fleet monitoring tool. Thereupon, each customer that owns our mobile or $HTTP$-based applications can plan its trip, get updated schedule information, besides knows the optimal path between its current position and nearest bus stops. Furthermore, DDD staff by leveraging our DDD fleet buses management can monitor the overall network from a dashboard that depicts buses in motion.

The remainder of the paper is structured as follows. Section II presents the related works. Section III illustrates the different components that forms our web mapping architecture. Next, section IV shows obtained results through a real testbed. Finally, section V concludes this work.

II. Related Works

Major concerns of urban transport is to satisfy its passengers by reducing long time waits in bus stops likewise to give an efficient information system. To achieve these goals, intelligent transportation system should be considered [6] [7] [8]. Data retrieved from Global Positioning System (GPS) enable to estimate distance between objects and their relative speed. By considering GPS coordinates as speed estimation, we need to figure out how to determine the distance from longitude and latitude. The shortest distance between two GPS points A (lat_A, lon_A) and B (lat_B, lon_B) is given by the *Haversine* formula [7] [9] [10]:

$$\begin{cases} D_{AB} = 2 \times R \times b \times tan^{-1}(\sqrt{b}, \sqrt{1-b}) \\ b = sin^2(\frac{lat_A - lat_B}{2}) + c \\ c = cos(lat_A) \times cos(lat_B) \times sin^2(\frac{lon_A - lon_B}{2}) \\ R = \text{earth radius} \end{cases} \quad (1)$$

The traveled distance by bus between two points A and B along the road is often upper than the one estimated by equation 1. These two distances are equal if, and only if, the path between these two points is linear or very short. Thus, Aradhya et al [10] in order to overcome this limitation, propose a micro-segmentation based approach. The goal of the micro-segmentation is to splits the path into several short and linear micro-segments, making it possible to increase the precision of distance estimation. Summing up micro-segments enable to obtained estimated distance that is near to the actual traveled distance. Fig. 1 depicts a given path between two bus stops operated by DDD public transportation. It is worth noticing that micro-segmentation approach is more efficient compared to the the distance as the crow flies.

More recent work proposed a landmark-based and polygon-based heuristics that provide location estimation within a given confidence region [1]. The traveled path is split into a linear micro-segments with well known geographic position called landmarks. For each received GPS coordinates, their heuristic estimates a confidence region where we can localize a given target with high confidence. By considering a confidence region bounded by a set of nearest landmarks, the landmark-based approach proposed by [1] mitigates computational time compared to previous work [10] that consider the overall landmarks. According to the polygon-based approach, the set of selected landmarks act as polygon's vertices. Afterwards, polygon's centroid is estimated, and thus, the nearest landmark with respect to this center is chosen as the estimated position of the bus. The landmark-based heuristic locates 70% of targets with an error distance less than 100 meters [1]. Furthermore, both approaches enable to know the remaining bus stops according to target bus. Nevertheless, the proposed geolocation technique is based only in SMS communication.

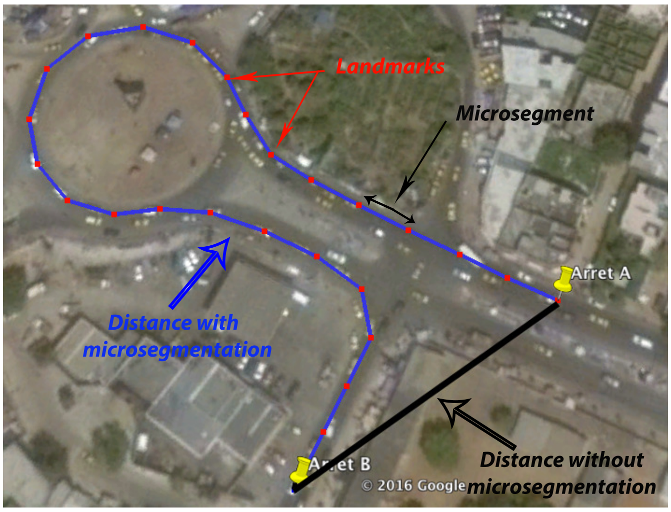


Fig. 1. Geographical distance estimation

Kasture et *al* [11] propose a multi-tracking system based on GPS, $GSM/GPRS$ and $GoogleMaps$ for vehicle. The system offers a heterogeneous platform taking into account a variety of applications such as tracking vehicles and people. A GPS device is deployed within vehicles and sends the vehicle position to a server through GSM network. The vehicle position can be viewed through *Google Maps*. Nevertheless, the proposed tool is not deployed on user's smartphone and suffer from a lack of bus status real time management. In addition, their tool do not provide the possibility to seek the nearest bus stops with respect to a given position.

A tracking system using a device that leverages GPS and *GSM/GPRS (Global Packet Radio Service)* technology, embedded in vehicles is proposed in [4]. The tracking system uses the GPS module to obtain geographic coordinates at regular time intervals and $GSM/GPRS$ to store and update the vehicle position in a database. A smartphone-based application is used in order to display the geographical position of vehicles on *Google Maps*. Like [11], this approach presents the same drawbacks.

Manini et *al* [5] send vehicle's coordinates at regular time intervals by $GSM/GPRS$ towards a database. Passengers can access to this information by choosing a couple of source/destination. The server returns a list of buses from the database and then passengers can select with respect to their itinerary. It is worth noticing that bus positions are displayed on *Google Maps* interface.

The authors of [4] [5] [11] consider same approaches by transmitting only geographical position of vehicle to a remote server and displaying the vehicle position on *Google Maps*. They do not take into account SMS for data transmission. It should be noted that in underserved areas there is a lack of full coverage according to $GPRS$ network. Therefore, in such countries for a good penetration rate it is a mandatory to keep SMS option. Furthermore, they do not take into account bus status management when anomalies such as bus breakdowns or deflection arrive. Additionally, these approaches do not consider the use of their tool by a smartphone-based application.

III. Components of the Web Mapping-Based Architecture

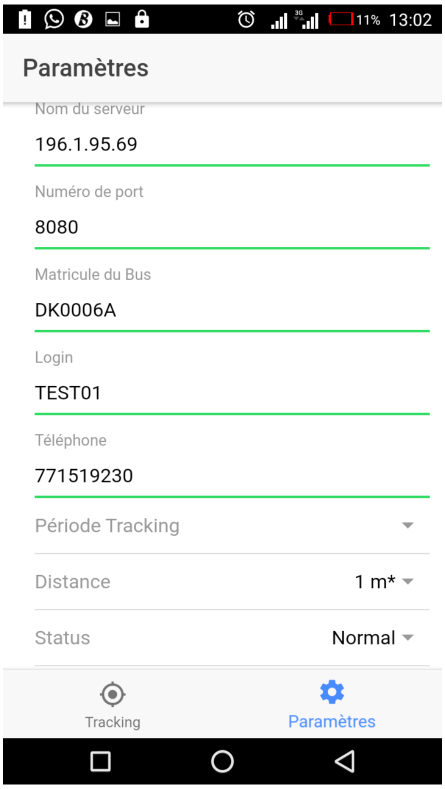
A. Smartphone-embedded bus kit

The smartphone-embedded bus kit is an application developed under $Android$ platform with $Ionic3$ [12], $Angular4$ [13] and $Cordova$ [14] technology. The mobile application is deployed on Android smartphone equipped with GPS sensor and mobile Internet connection ($3G$). When Internet connection is down, the collected bus information can be sent by SMS. Fig. 2(a) illustrates the displayed Graphical User Interface (GUI) that enables the mobile application to log into a $MySQL$ database located in a remote server. It should be noted that this smartphone is owned by the tickets seller who can configure the following parameters:

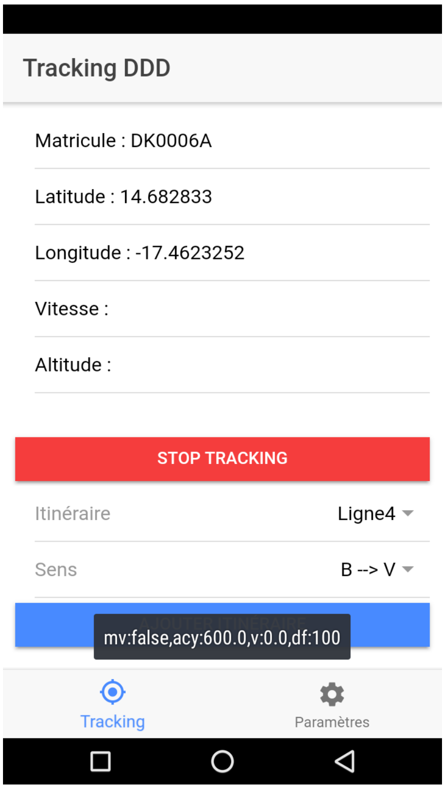
- **Internet-based transmission:** IP address, Port number, Bus ID and login connection.
- **SMS-based transmission:** telephone number of the GSM gateway
- **Transmission interval rate:** the interval time at which the actual bus position should be sent. By default, an interval of 1 minute is chosen.
- **Cumulative traveled distance:** this parameter is tuned. For instance, it can be sent whether a distance of 100 meters is traveled by the bus or much more.
- **Anomalies detection:** several status like "normal", "deflection" or "disruption" due to unexpected obstacle, "flat tyre", "crash", "mechanical failure", "flooded road" can be sent for real time monitoring.

For each new starting itinerary, the tickets seller configures bus direction (Fig. 2(b)). After validation, the smartphone-embedded bus kit sends to a remote server through Internet network several parameters such the actual bus position (latitude, longitude), altitude, line number, direction, and timestamp.

By default, Internet connection is considered, but in areas where we do not $3G$, the smartphone-embedded bus kit uses

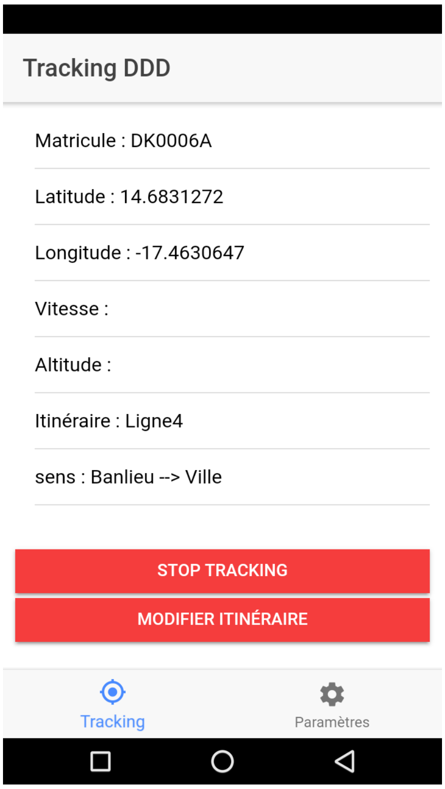


(a) Server settings

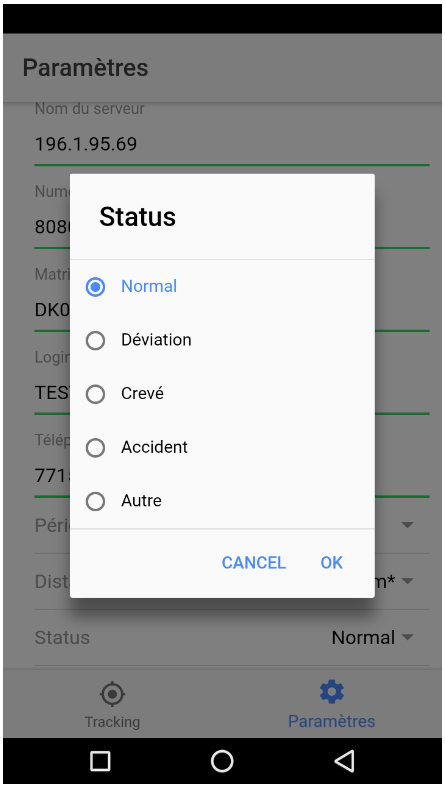


(b) Route settings

Fig. 2. Bus kit configuration



(a) Roadmap settings



(b) Real time anomalies detection

Fig. 3. Web mapping-based information system

$2G$ cellular network to send by SMS previous information. We considered keep alive approach where probe requests are sent during a fixed interval time in order to check Internet connectivity. However, SMS will be not sent with respect to periodic interval. It will be rather in correlation with bus motion. Indeed, when traffic jam occurs, it is not necessary to send the same bus position.

For instance in Fig. 2(a), every minute the smartphone-embedded bus kit collects all informations related to the geographical position of the vehicle and estimates the traveled distance. The last position is sent to the $kannel$ server, only if the cumulative traveled distance is at least upper than 100 meters.

In the event of either accident or deflection due to unexpected obstacle, or mechanical failure, the tickets seller has the possibility from its mobile application to trigger an alert by changing bus status as illustrated in Fig. 3(b). Therefore, notifications are sent to our server. Thereupon, DDD staff can take decision by scheduling a new route or inform maintenance personnel.

B. *Web mapping-based architecture*

Fig. 4 illustrates the proposed Web mapping-based architecture system for DDD fleet management. The infrastructure is divided into four bricks:

- **A measurement kit located within the bus**: the smartphone-embedded bus kit which is kept and managed by the tickets seller collect several parameters such as : latitude, longitude, altitude, speed, bus direction, timestamp, bus status (normal, mechanical failure). These information are sent by default through Internet to a server by using Web services and collected data are save into a $MySQL$ database.
- **A Kannel server**: in case of Internet failure, the smartphone-embedded bus kit sends by SMS the collected data to a $Kannel$ server that acts as a SMS gateway. Afterwards, by using Web services, the $Kannel$ server stores the different information contained in the SMS into a $MySQL$ database.
- **A server**: it is use as data storage and requests processing. The landmark-based heuristic [1] is considered by the server in order to estimate the geographic bus position. Also, the server hosts a $MySQL$ database, a *J2E* $OpenGTS$-based, a $Tomcat$-based server, and toolkit applications based on $PHP5$, *geocoding*, *Javascript*, $GoogleMap$. We designed three web services which are programmed on *J2E Springboot* for the:
  - **"Smartphone-bus" module**: the first web service is used in order to send the actual geographic bus position to a $MySQL$ database.
  - **"Kannel gateway"**: the second one aims to relay the received SMS from the $Kannel$ server to a MySQL database
  - **"Smartphone-bus" passengers**: the last one seeks the nearest bus stops with respect to a given radius

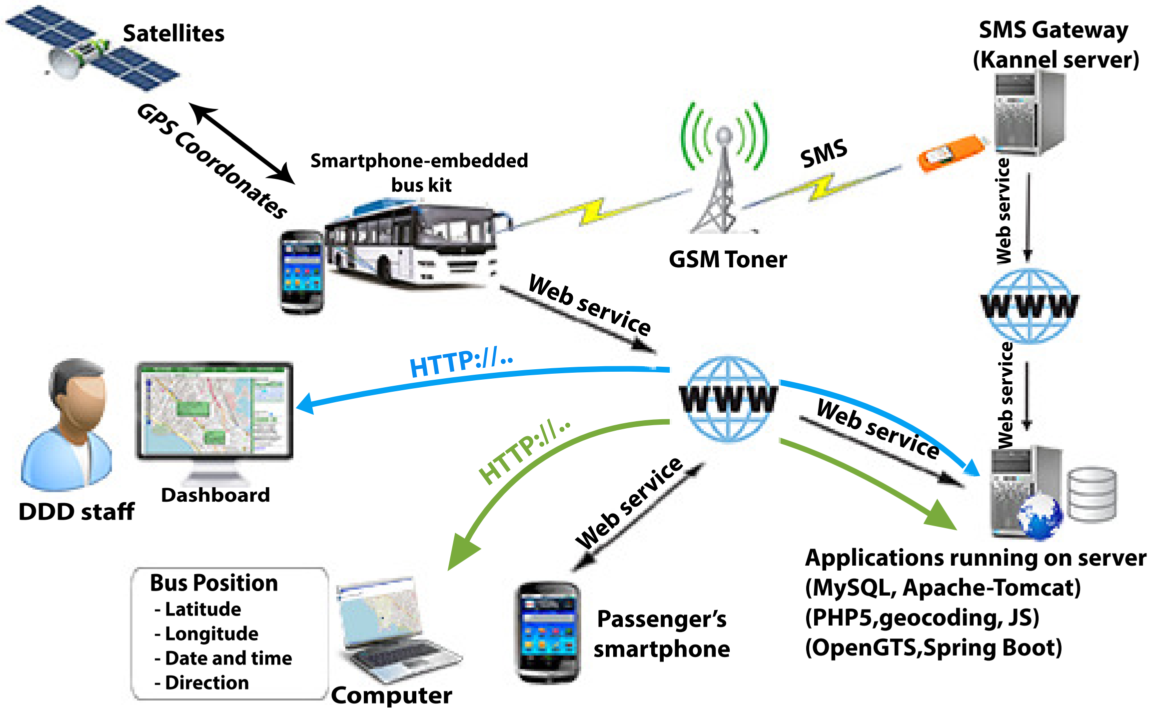


Fig. 4. Web mapping-based architecture system

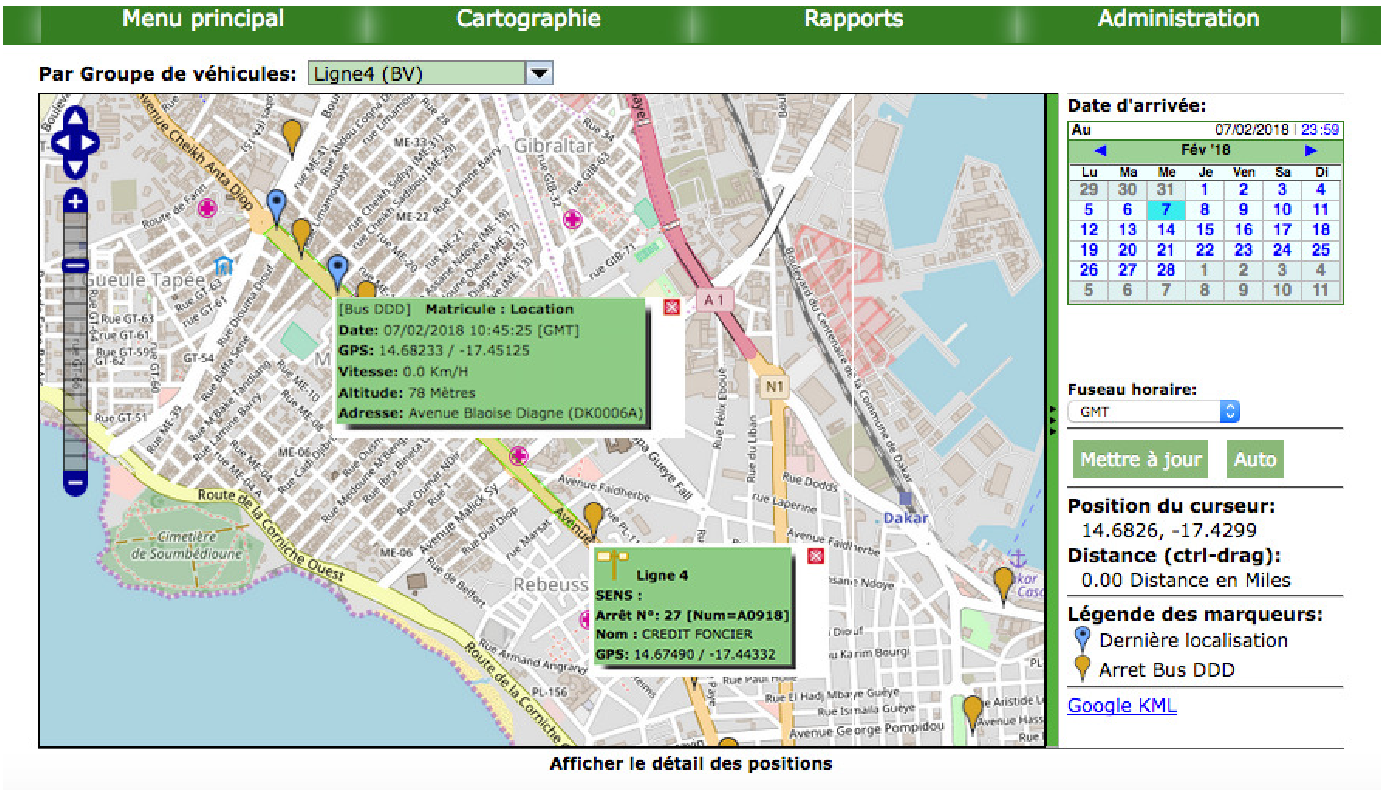


Fig. 5. *DDD* fleet buses management

as well the overall geographic bus position according to given travel plan.

- **A GUI deployed at the level of application's users**: this geographical information system is able to show bus position by considering Web Mapping of *Google Maps*.

Fig. 6. *HTTP*-based web mapping

IV. Designing a web mapping-based applications

The proposed *DDD* fleet management application which is based on *"Open GPS Tracking System" (OpenGTS)* [15] is depicted in Fig. 5. In fact, *OpenGTS* is the first open source application, designed specifically to provide a web-based *GPS* tracking service for vehicles fleet. *OpenGTS* is written in *Java* with technologies such as *Apache*, *Tomcat* for web service deployment and *MySQL* as database system. *OpenGTS* is highly configurable and scalable.

It provides a customizable mapping service that supports *OpenLayers/OpenStreetMap* also *GoogleMaps*, *MicrosoftVirtualEarth* and *Mapstraction*. Other existing mapping services can be easily integrated through *OpenGTSframework*. Therefore, our designed three web services (Section III-B) interact with *OpenGTS* when requests are sent either from user's smartphone or tickets seller's smartphone or *SMS* gateway.

The *OpenGTS* Internet-based application acts as a dashboard and it is used to monitor the overall moving buses. It is accessible from through a web browser. Therefore, DDD staff have a global overview on the car in motion and their status.

A. Data collection

The 930 bus stops geographic position (latitude, longitude) according to the 24 operated lines by *DDD* are stored in a *MySQL* database. Each bus position has a an unique identifier. In fact, several meta data related to the bus stop are also collected. For instance, we figure out whether a bus stop hosts a bus shelter, a bench area. It should be noted that each bus stop is located within a cluster which refers to a well-known place or district. Therefore, cluster's name that hosts a bus stop is saved. Finally, the number of bus lines that cross a given bus stop with respect to bus direction is available.

B. HTTP-based bus tracking

The main goal of this a application is to enable an access into our platform for passengers that do not own the mobile application. With just a web browser connected to Internet, we can receive feedbacks about the actual network status or plan you trip. Fig. 6 illustrates our *HTTP*-based web mapping application which is developed by *PHP*, *JavaScript* and *GeocodingAPI* from *Googlemaps*. According to this tool, we can localize the overall buses within the network through the *GoogleMaps*-based application. This application ensures that passengers know either about new and existing services and how they can utilize them, or how they can get smart trip in their daily lives.

C. Smartphone-based bus tracking

Fig. 7(a) and Fig. 7(b) show a real case of where a smartphone-based web Mapping is used by a given passenger. The tool is an *Android*-based application. This application highlights travel solutions that work within an individuals lifestyle. The following items are available on the passenger's GUI which is based on the *Google Maps*:

- bus stops within a given radius
- all itineraries
- all buses position
- nearest bus stops within a given coverage
- travel path between passenger's position and a given bus stops.

Fig. 8 illustrates a user case diagram where a given passenger chooses a travel path and a confidence region. Afterwards, he receives the overall bus stops within the target area as well the current set of buses that cross this route (Fig. 7(a)). Finally, the passenger can select a bus stop in order to receive the route between his position and the target stop (Fig.7(b)).

V. Conclusion

We proposed a geographical information system that enables *DDD* fleet buses management and a smart travel mobile applications-based for bus passengers. *DDD* management staff owns a dashboard which provides a global overview of the overall network. In case of mechanical failures, flat tyre, road flooded, disruptions, maintenance services are informed in real time. A toolkit designed for bus customers is provided. Firstly, a web browser, connected to Internet where we can receive feedbacks about the actual network status or plan you trip, is available. Secondly, a mobile application, deployed on customers smartphone which are connected into the system through mobile Internet, enable to search the nearest bus stops and to compute an optimal itinerary.

As ongoing work, we would like to send notification on passenger's bus smartphones about disruptions, updates and changes to the transit services you take. We plan to improve bus tour circulation according to the amount of collected data by considering machine learning approaches. Besides, a circulation plan based on traffic jam is aimed.

Acknowledgement

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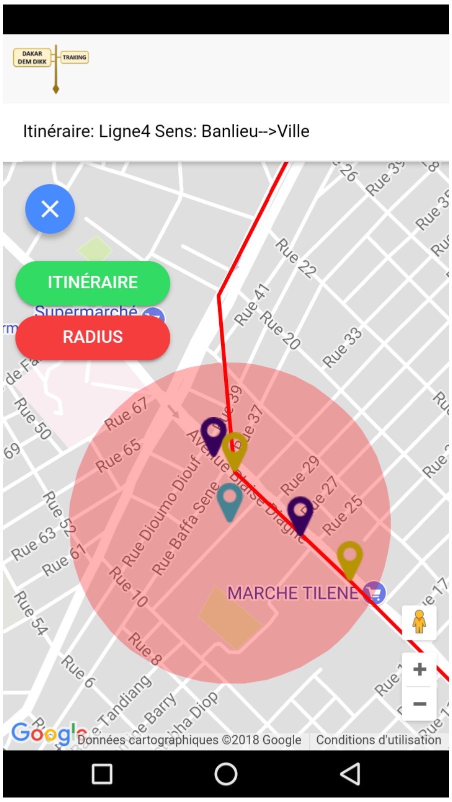
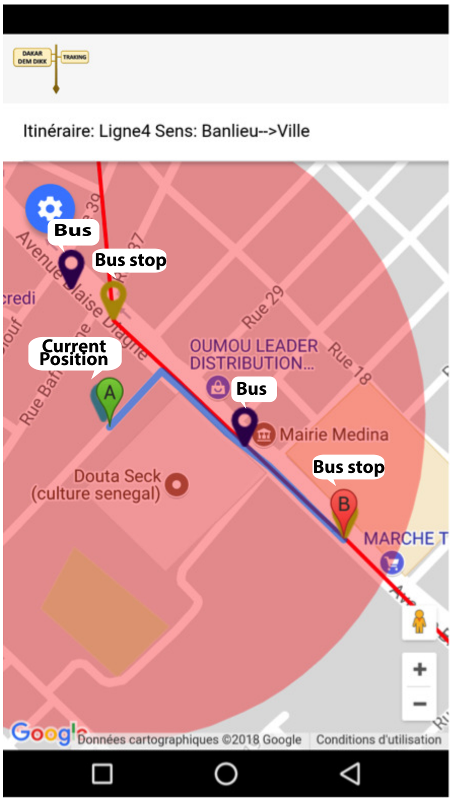


(a) Searching nearest bus stops



(b) Itinerary computation towards bus stops

Fig. 7. Passenger's smartphone

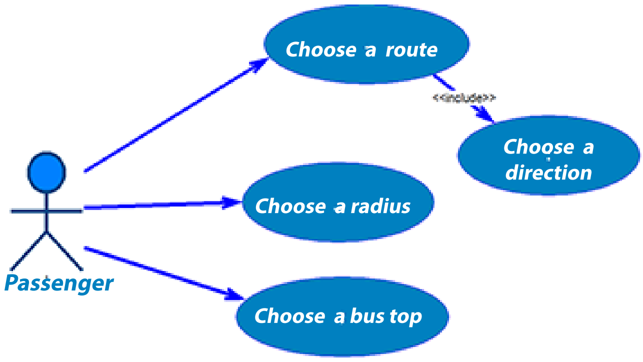


Fig. 8. Use case diagram

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