Leveraging GPS and SMS-Based Bus Tracking Architecture for an Efficient Transportation

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Abstract. Nowadays, we note a huge population growth in Dakar Region due mainly to the drift from the land. Therefore, the suburbs keep growing and daily workers need to be transported since economic activities and most urban infrastructures are located in Dakar-downtown. The lack of punctuality and the amount of time wasted at a bus stop are big concerns for the national society of transportation "*Dakar Dem Dikk*" (*DDD*). We aim to enhance the communication system by allowing the bus passengers to know either how many bus stops it remains for a given bus to reach a fixed bus stop; or the estimated distance between a target bus and its position. The proposed architecture is based on GPS sensors and mobile networks that relay bus position towards bus passengers that request the information. Relying on two heuristics, Landmark-Based and Polygon-Based approach, the obtained results show that 70% of targets are localized with an error distance less than 100 m.

Keywords: Geolocation · Tracking · Sensors networks
Internet of thing

1 Introduction

During last decades we note a huge population growth in Dakar Region due mainly to the fact that economic activities and urban infrastructures are located in Dakar-downtown. Dakar Region, which is a peninsula, is the smallest and most populated region in Senegal. The population is estimated roughly to 4 millions of inhabitants for an area of 550 km^2.

Since daily workers need to be transported in Dakar-downtown, Dakar roads are in chaos during workday. This chaos is accelerated since everyday the number of new private vehicles and the clandestine exploitation of private vehicles as means of public transportation increase. Consequently, diurnal traffic jam occurs and during rush hour, the wasted time can be up to 4 h from Dakar-downtown to suburbs. The big concern with the increased number of cars is air pollution. Indeed, the car pollution is high since most of vehicles are bought in second hand from European countries.

The national society bus transportation "*Dakar Dem Dikk*" (*DDD*) has no Information System and it operates 17 bus lines that cover 352.4 km within

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Dakar Region. Bus Passengers suffer with the lack of punctuality which is increased according to traffic jam. Therefore, the time wasted while waiting for the bus is a big concern for potential bus passengers. Potential bus passengers prefer to use private bus transportation even if it is more expensive. The number of customers is reduced as well as the company's revenues.

To overcome these limitations, intelligent transport system should be used by the DDD society [1–3]. We propose an information system, called *DDDT* (Dakar Dem Dikk Tracking) that can predict buses arrival in order to help bus passengers in their choice when they travel. The DDDT architecture system is based on a *GPS*, Short Message Service (*SMS*), and Web Services technology. From a SMS sent by a target bus passenger and having as inputs the bus number line and its direction, the information system is able to provide either the remaining bus stops from a fixed bus stop, or the distance between the target and the bus.

The remainder of the paper is structured as follows. Section 2 depicts the different components of the DDDT architecture. In Sect. 3, we design the Landmark-Based and Polygon-Based bus geolocation technique and the DDDT methodology to localize target hosts. Following that, we present in Sect. 4 our experimental results. Finally, Sect. 5 concludes this work.

2 Components of the Bus Tracking Architecture System

2.1 Data Acquisition Module

The core embedded data acquisition (*DAQ*) system is based on an *Arduino Uno* board (*AUB*). Figure 1 illustrates the set of components which is connected to the AUB. The used Global Positioning System (GPS) hosts a high performance receiver and a low power consumption *Arduino* GPS shield *V.1.1* of *ITead Studio* with an internal GPS Antenna. It can track up to 20 satellites at a same time and performs fast Time-To-First-Fix (TTFF) during weak signal environments[1]. The DAQ system collects through the GPS shield the latitude, longitude, velocity, altitude and bus direction. In order to send the collected information to a SMS gateway, a GSM shield[2] with a compact right angle antenna type is also connected to the AUB.

Furthermore, due to unpredictable road conditions, it is not suitable to send SMS periodically [2,3]. For instance, in situation of traffic jam, it is not necessary to send SMS continuously since the bus is not in motion. Therefore, it is mandatory to deal with congestion on the transport network. To overcome the limitations of previous works, we propose to send SMS even if the bus is moving in respect of a given distance (Fig. 2). In order to mitigate the number of transmitted SMS, every τ seconds the AUB collects the geographic location of the target bus. Afterwards, the AUB computes and adds up the distances travelled along the road. However, a SMS with the last collected information will be sent

[1] http://store.iteadstudio.com/images/produce/Shield/Shields/gpsshield/ArduinoGPSshield_DS.pdf.
[2] http://www.embeddedartists.com/products/acc/cell_2g_shield.php.

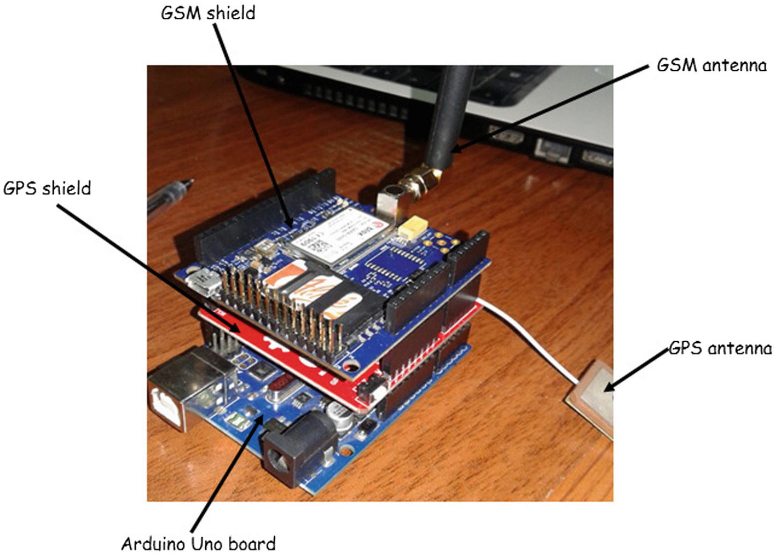


Fig. 1. Data acquisition components.

only if the cumulative distance D exceeds a threshold distance D_l. The distance D_l is estimated with respect to our micro-segmentation heuristic which splits the paths into several short and linear micro-segments. The values of τ and D_l depend on several factors such as distance between bus stops, roads condition, and rush hour. According to the illustrated algorithm in Fig. 2, we are able to mitigate the numbers of transmitted SMS.

2.2 Bus Tracking Architecture System

Figure 3 represents the bus tracking architecture system where the SMS sent by the embedded system are analyzed by the *Kannel* server which is used as SMS gateway Server. Afterwards, we consider web services in order to fetch the latitude, longitude, velocity, time and date from retrieved messages and store these data in a MySQL data base.

The communication between target bus passengers and server is also based on SMS services. When a target bus passenger needs to use our service, he will just send a SMS to a *Kannel Server*. In order to estimate the bus arrival, the server needs to receive the target bus stop name or number, and the bus direction. It is worth noticing that the geographic position of bus stops along the used route is well-known. Furthermore, a mapping between each bus stop and its corresponding geographic position is done. At each received SMS, a tracking process is done in order to retrieve bus position and its direction. Next, the bus tracking system will respond by sending back a SMS to the target host. It should

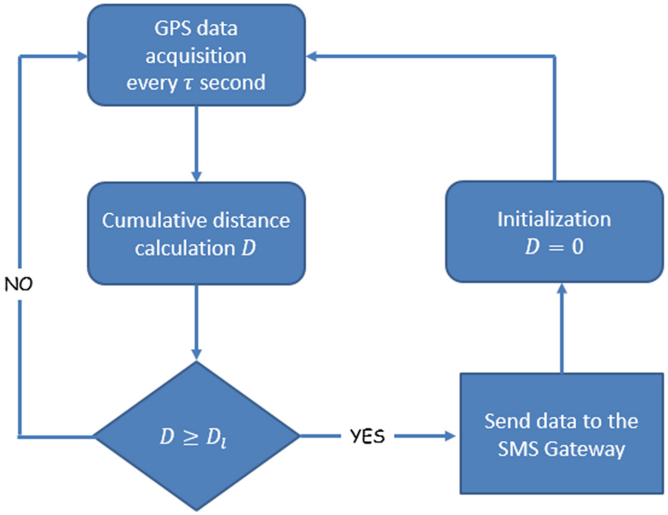


Fig. 2. SMS transmission process.

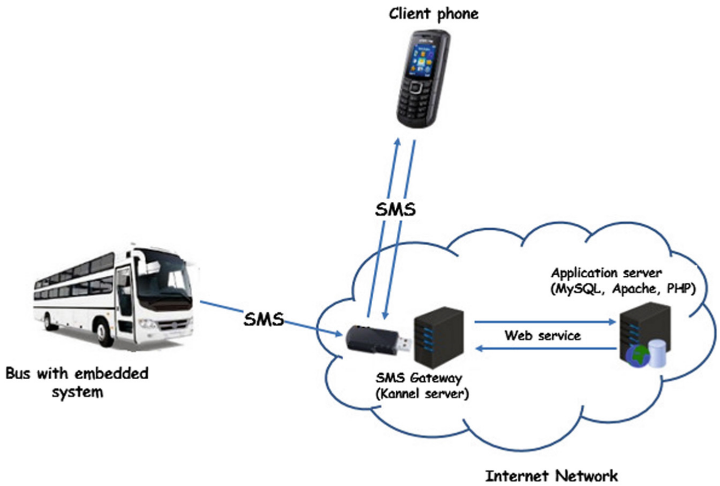


Fig. 3. Bus tracking architecture system.

be noted that the SMS flows back the passengers through the SMS gateway. The SMS contains the number of bus stops that will be crossed with respect to your actual bus stop as well as the geographic distance between your position and the targeted bus.

3 Bus Geolocation Approaches

3.1 Overview on Distance Estimation

The shortest distance over the surface of the earth between two GPS trace points A and B is given by the *Haversine formula* [2,4,5]:

$$D_{AB} = 2Rbtan^{-1}(\sqrt{b}, \sqrt{1-b}) \quad (1)$$

where $b = sin^2(\frac{lat_A - lat_B}{2}) + cos(lat_A) \times cos(lat_B) \times sin^2(\frac{lon_A - lon_B}{2})$, R is the radius of the earth and $lat_A, lon_A, lat_B, lon_B$ are respectively the latitude and longitude of the GPS trace points A and B.

However the distance travelled by a bus between these two points along the road is often greater than that the distance given by Eq. (1). These two distances are equal only if the path that relies these two points is linear or very short. By proposing a micro segmenting approach Aradhya et al. [4] try to overcome this limitation. The goal of micro-segmentation, which splits the path into several short and linear micro-segments, is to increase the accuracy of the distance estimation. By so doing, the add up micro-segments is then closer to the actual distance travelled by the bus. For instance, Fig. 4 shows the path between to bus stops crossed by the line bus number 10 of DDD transportation. On can easily see that the micro segmenting approach is more suitable.

In this paper, we design and evaluate two geolocalization techniques based on micro-segmenting approach. Therefore, the travelled path along the road bus

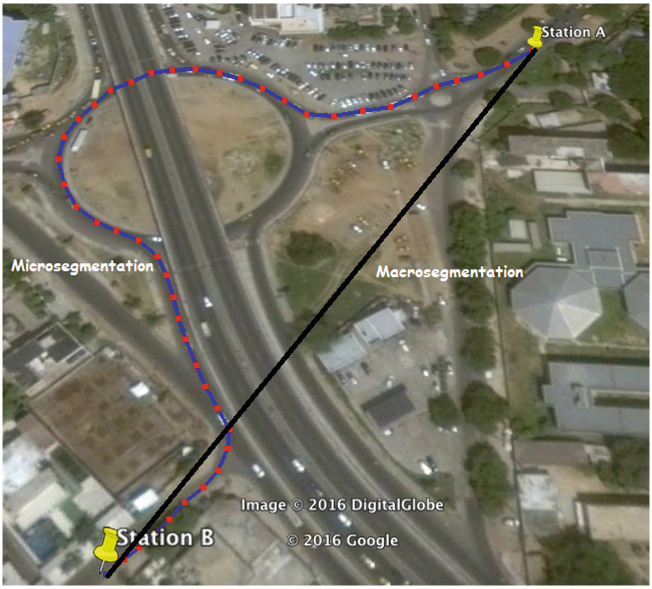


Fig. 4. Geographical distance estimation.

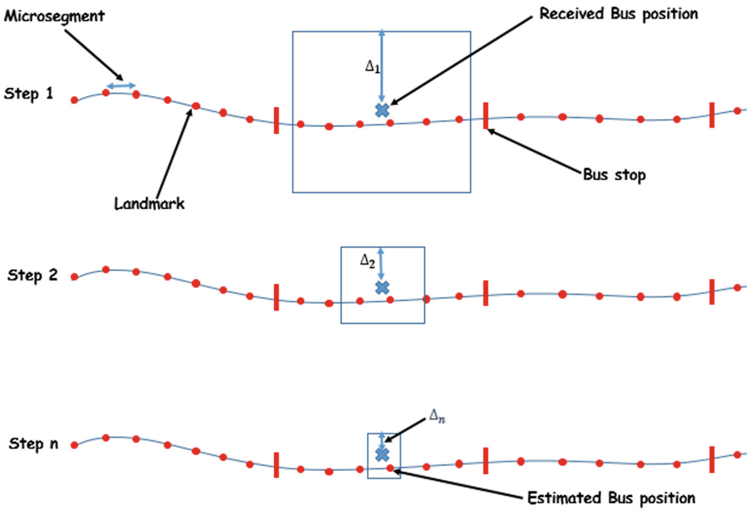


Fig. 5. Locating a host with landmark-based geolocation approach.

is split into micro-segments (l) having equal distance. Each micro-segment has an unique identifier called ID. Our proposed heuristics aim to accurately match each received GPS trace point into a micro-segment along the road.

3.2 Landmark-Based Geolocation Approach

Figure 5 illustrates the Landmark-Based geolocation (LB) process. The LB heuristic localize the bus position by performing a correlation between each received GPS trace point and the set of landmarks. It should be noted that a landmark is a well known geographic position point (latitude, longitude) along a given bus line. Afterwards, the closest landmark with respect to the received bus position is considered as the bus estimation position.

Indeed, at each received GPS trace point, the LB heuristic seeks a confidence region. The area of the confidence region is given by a square surface as follows;

$$\begin{aligned} lat - \delta_{lat} \leq lat_1 \leq lat + \delta_{lat} \\ lon - \delta_{lon} \leq lon_1 \leq lon + \delta_{lon} \end{aligned} \tag{2}$$

where (lat, lon) are the latitude and longitude of the received GPS trace point and $(\delta_{lat}, \delta_{lon})$ are used to find the boundary of our confidence region. The center of the square is the received GPS trace point and the values of $(\delta_{lat}, \delta_{lon})$ can be tuned in order to obtain Δ_1 as shown in Fig. 5. Next, the number of landmarks within the square surface is determined and will be used as testbed. By considering the confidence region, we reduce the computation time compared to previous work that verifies the distance between the whole set of landmarks [4].

Thereby, the micro-segment ID is known if the number of landmarks is equal to 1. Otherwise, the same process is repeated by considering $\Delta_i < \Delta_1$ until the micro-segment ID is not found. As soon as the micro-segment ID is known, our bus tracking tool can determine either the bus geographic bus position, or the remaining bus stops with respect to a fixed bus stop, or the distance between the bus stop and a target bus passenger.

3.3 Polygon-Based Geolocation Approach

Figure 6 depicts the different steps of locating a host with a Polygon-Based (PB) heuristic. Firstly, the PB approach selects the nearest set of landmarks according to the received GPS trace point. Afterwards, the selected set of landmarks will form the vertices of a polygon which area represents our confidence region. Next, the centroid of the polygon is determined and the nearest landmark with respect to the centroid of the polygon is chosen as the bus estimation position. The same process Like LB approach is considered in order to determine the closest landmark with respect to the centroid of the polygon.

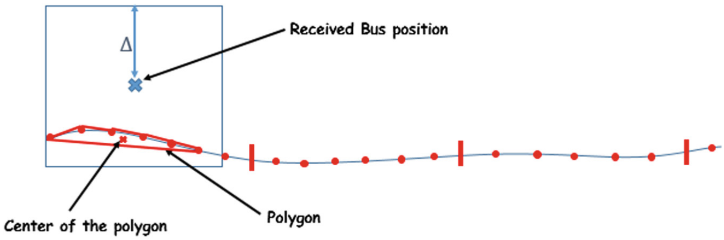


Fig. 6. Locating a host with polygon-based geolocation approach.

During weak signal environments, when the received GPS trace points is far away according to the bus road, as illustrated in Fig. 6, by considering the centroid of the polygon, we are able to shift the potential wrong location towards the landmarks. However, with respect to the number of turnings or curvatures along the bus road, as shown in Fig. 7, an error may happen on distance estimation. Nevertheless, the PB approach will be more suitable in case of weak signal environments.

4 DDD Tracking Evaluation

4.1 Experimental Settings

To analyze and compare the performance of the two proposed detection methods, simulations are carried out the line number 10 of DDD transportation over a distance of 15.5 km. We collected the GPS trace points of all the bus stops which are 28 in each direction. Also, we realized the micro-segmentation of the 15.5 km with two three sampling distance equals to 65 m, 130 m, and 195 m.

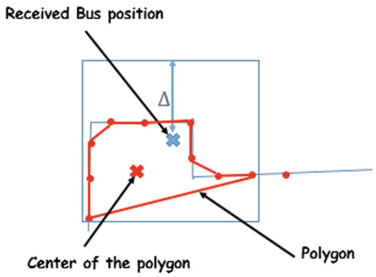


Fig. 7. Potential mismatch with the polygon-based geolocation approach.

For instance, a sampling distance of 65 m means that the distance between two landmarks is equal to 65 m and 239 landmarks are considered over the bus road. Each micro-segment has a unique ID which depends on its position along the bus road. All these information are stored in our MySQL data base. In order to localize a target host, the following steps are performed: *"i"* the DAQ module which is configured to send by SMS the geographic location of the targeted bus is embedded in the bus. The geographical position of the bus is sent only if a distance equals to fixed threshold $D_l = 100$ m is travelled by the bus; *"ii"* at each received SMS, the DDDT process is run in order to retrieve the bus position. Finally, based on well known geographical position of 130 target bus passengers, we evaluate the estimation provided by the DDDT tools with respect to the actual position of the target.

4.2 Results

Figures 8, 9 and 10 compare the CDF (Cumulative Distribution Function) of the location error estimation of Landmark-Based (LB) and Polygon-Based (PB) approach with respect to several sampling distances and Δ confidence region values. The purpose of these figures is to study how LB and PB approach estimate

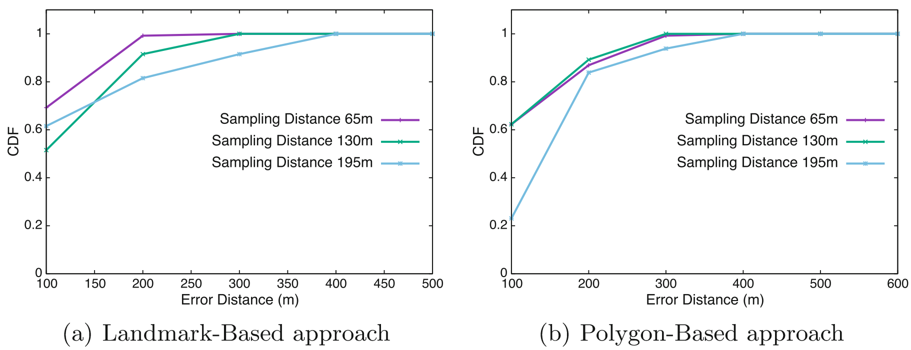
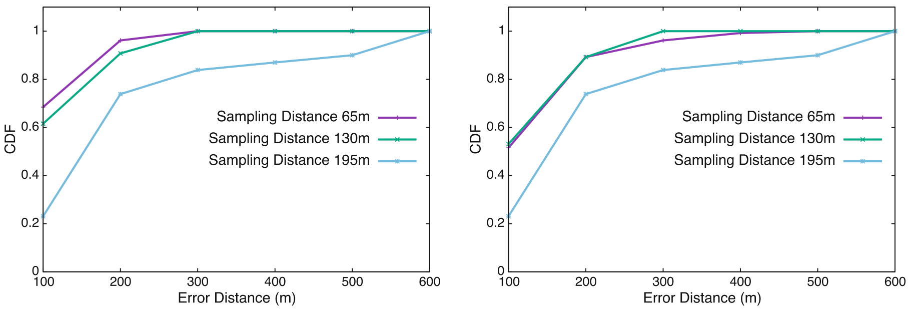
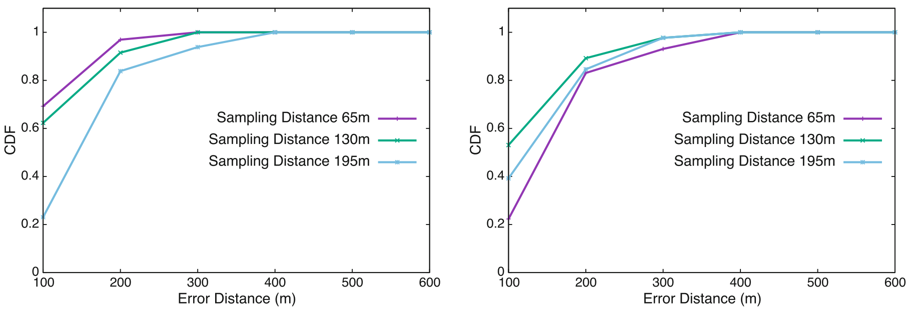


Fig. 8. Location estimation error according to a confidence region $\Delta = 100$ m.



(a) Landmark-Based approach (b) Polygon-Based approach

Fig. 9. Location estimation error according to a confidence region $\Delta = 150\,\text{m}$.



(a) Landmark-Based approach (b) Polygon-Based approach

Fig. 10. Location estimation error according to a confidence region $\Delta = 200\,\text{m}$.

the position of target bus passengers with respect to a fixed bus station stop. The location error estimation for a given bus passenger is the difference between its actual geographic location and its estimated location. On the x-axis, we have the error distance location for different target bus passengers with respect to their actual position. On the y-axis, we show the probability that the location estimation for the target bus passengers have an error less than x.

We note that the sampling distance has en effect on the accuracy of the location estimation. Concerning LB approach, the obtained results show that the confidence region Δ has less impact on the accuracy compared to the sampling distance. We observe in Figs. 8(a), 9(a) and 10(a) that the sampling distance equals to 65 m is a stricter upper bound on error location than other sampling distances. The reason is because to the fact that when the sampling distance increases, the potential landmark points that can be considered as location estimation for a targeted bus passenger is reduced. Consequently, the computation time is reduced but the error location can be increased. The LB approach estimates, 70% of the target bus passengers with a error distance less than 100 m. Furthermore, when the confidence region Δ ranges from 100 m to 200 m, with the a sampling distance equals to 65 m, LB approach localizes 97% of the target bus passengers with a error distance less than 200 m.

The performance gap between sampling distance is larger in the LB approach. With the PB approach (Figs. 8(b), 9(b) and 10(b)), the sampling distance which is equal to 130 m outperforms other sampling distances. Nevertheless, the obtained curves with respect to a sampling distance equal to 65 m illustrate the same trend for δ values equal to 100 m and 150 m (Figs. 8(b) and 9(b)). According to a sampling distance equals to 130 m (resp. 65 m), the LB approach estimates 90% (resp. 88%) of the target bus passengers with a error distance less than 200 m; whereas with both sampling distances 62% are localized with an error distance less than 100 m.

The obtained results exhibit that the LB approach outperforms the PB approach. The fact is due how LB heuristic maps the target bus passenger into the closest landmark; whereas for the PB heuristic it is the centroid of the polygon that is mapped into the closest landmark. Notwithstanding, the PB approach has the advantage of providing a conservative upper bound on the error distance. In fact, in situation where the target hosts tend to be far away from the landmark points, the centroid of the polygon will be able to shift the target towards the baseline which is formed by the set of landmarks.

5 Conclusion

Since economic activities and most urban infrastructures are located in Dakar-downtown, the DDD society should provide an efficient transportation system. Relying on private transportation in order to overcome the lack of punctuality of buses is not a good deal and then increase the air pollution in Dakar Region. Nevertheless, the provided DDDT architecture is able to provide either the remaining bus stops from a fixed bus stop, or the distance between the target and the bus. Two geolocation heuristics were designed and the *LB* approach localizes 70% of targets with an error distance less than 100 m. We are investigating to predict the waiting time at bus stop as well to develop applications which are based on the web-mapping for users with a 3G or Internet connection.

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