

Human Mobility during Religious Festivals and its Implications on Public Health in Senegal

A Mobile Dataset Analysis

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Abstract—Mobile phone call details records (CDR) are particularly useful to study human mobility and support decisions related to public health, transportation and resource management. We used the 2013 mobile dataset released by the Orange mobile operator to model human mobility before, during and after one of the most attended religious festivals in Senegal called the Magal of Touba. We observed interesting structures in the human mobility patterns showing that this festival involves massive movements of population from different parts of Senegal. Our analysis also presents the main routes used by the pilgrims and their travels' times. These findings are worthwhile for numerous structures, including the ministries of Health, Transport, and Hydraulic, as well as other stakeholders planning religious festivals. They have important health implications ranging from awareness campaigns to resource management and service allocation before, during and after religious festivals in Senegal.

1. Introduction

Availability of large datasets of mobile phone call details records (CDR) inspires researchers from different domains, including Physics, Computer Science, Economics, Public Health, Anthropology and Sociology, to study human dynamics, a branch of Complex Systems [1]. Mobile phone records are particularly useful to study human behavior by providing temporal and spatial information at scale and at different levels of granularity [2]. In particular, they can be used to model mobility and migration patterns [3]. Understanding these patterns is crucial for urban planning, transport infrastructure design, analysis of communities' networks, spreading and mitigation of diseases, disaster management, etc.

We used the 2013 mobile phone records released by the Orange mobile operator as part of the 2014 Data for

Development Challenge (D4D 2014, <http://www.d4d.orange.com>) to model human mobility before, during and after one of the most celebrated and attended religious festivals in Senegal called the Magal of Touba. This event brings millions of people from Senegal and throughout the world to the holy city of Muridism, Touba. This large gathering comes with consequences and carries potential issues including the ones linked with health, transportation, and resource management. In this research, our aim was to investigate mobility and transport patterns by studying the changes of communication volume between the city of Touba and other locations in Senegal before, during and after the Magal and discuss the implications of these changes on public health.

We found interesting structures in the human mobility patterns showing that the Magal of Touba implies massive movements of population from diverse parts of Senegal. These patterns permitted us to identify the interconnectedness of this religious community. We created maps depicting these movements of population that can be easily interpreted and conveyed to any audience, from data scientists to the Senegalese population. These visualizations are the first ones available for understanding the scope of this festival using mobile data. These findings will be worthwhile for numerous structures, including the ministries of Transport, Health, and Hydraulic, as well as other stakeholders planning religious festivals. They have important implications ranging from resource management to service allocation and awareness campaigns before, during and after religious festivals in Senegal. Understanding how and when people are leaving for and returning from festivals is important to plan awareness

campaigns (e.g., health and road safety) and target messages types and contents (e.g., TV, radio and print). Our visualizations can be used to raise awareness amongst the population and plan actions based on tangible evidence. Planning is currently not based on accurate data availability and analysis. With the ubiquity of mobile phones in Senegal (mobile penetration of 93% in 2013) and the use of mobile phone records, planning can be done in a more systematic manner.

This paper is organized as follows. Section 2 presents the Magal of Touba and provides the background necessary to understand the relevance of the choice of this study. Section 3 describes the methodology we used to analyze the data. Section 4 presents our findings. Section 5 concludes, discusses our results, and presents our future work.

2. Religious Festivals in Senegal

Senegal has a population of 14.13 million (2013). The total number of mobile subscribers is 12.661 million with a penetration rate of around 93% and a total volume of 2.3 billion minutes [4]. Three operators, Orange (58.34%), Tigo (20.92%) and Expresso (20.74%), share the mobile subscribers. Internet penetration is around 9% and Internet usage is dominated by mobile data with over 70% users via 3G since 2008 and 4G since 2014. In this study we are interested in the city of Touba (182 km from Dakar, the capital). The population of Touba is 620,500 in 2010, compared to 2,396,800 in Dakar [5]. Islam is the predominant religion, practiced by 95.4% of the population. Christians (4.2%) include Roman Catholics and diverse Protestant denominations. There is also a 0.4% population who maintain traditional African religions [6]. Tijaniyya (4 to 6 million people) and Mouridiyya (3 to 5 million people) are the two largest Muslim Sufi brotherhoods in Senegal. Sufism distinguished itself from other branches of Islam by the presence of spiritual guides called Marabouts. The Tijaniyya brotherhood is the largest in number and Mouridiyya is the most active. The Gamou of Tivaouane and the Magal of Touba are the main festivals of these brotherhoods respectively. Their dates depend on the Muslim calendar and, thus, change every year. Pilgrims, called Talibés, join from different places in Senegal and abroad, and travel by car, bus, motorbikes, trucks, carriages and foot. They are hosted in the holy cities by local inhabitants. The number of pilgrims attending the Magal of Touba is estimated between 2 and 5 million. The festivals revolve around prayers and meditations, but also official ceremony with government representatives. Mobile service operators have strategic roles during these festivals: they are present to advertise and sell their products and responsible in providing quality services. For example, in 2013, Orange deployed 40 temporary 3G stations and 187 voice and SMS stations in Touba and its neighbor cities and ADSL lines to transmit the festival live on TV and the Internet [7]. ARTP, the telecommunications regulator, is monitoring the quality of service. Festivals have an important economic impact at the micro and macro levels in Senegal. In Touba, a pilgrim usually spends around 92,000 FCFA (around \$200) for the Magal including transport, phone, religious items, clothes and hair, and contributions. Touba contributes 250 billion FCFA (around \$450 million) to

Senegal economy [8]. The informal sector benefits greatly from the religious festivals (e.g., tailors, hairdressers, mattress sellers, house renovations). The agro-alimentary industry is greatly involved as water and food need to be available for pilgrims [9, 10]. Banks and financial institutions benefit from the festivals; Money is sent to pilgrims by family in Senegal and abroad (e.g., through mobile money mechanisms).

In this paper, we will focus on the Magal of Touba festival that is followed by the Mouridiyya community. The Grand Magal, also called the Magal of Touba, is a highly regarded Muslim festival followed by Murids that takes place in the city of Touba. Magal means “to pay respect, celebrate and magnify” in Wolof, the main local language of Senegal. People attend the festival in the name of Cheikh Amadou Bamba (1853-1927), a powerful Islamic leader who founded the Mouridiyya brotherhood, preached non-violence, and returned to the city of Touba after being exiled due to colonial rules. The festival is celebrated on the day of the exile of Cheikh Amadou Bamba to Gabon (1895). Touba is in the department of Mbacke in the Region of Diourbel. Two Magals of Touba took place in 2013, in January and December. We only considered the Magal of December 22nd, 2013 in this study.

Movements of population during festivals can create important problems with crowded and insecure roads and numerous accidents and deaths [11]. They can also foster unsanitary conditions (poor sanitation, lack of storage for clean water and food, and lack of septic systems) leading to epidemics. For example, the last cholera outbreak happened during the Magal of Touba in 2008 with a total of 2,054 cases and 8 deaths [12]. In terms of transportation, while it normally takes around 4 hours to reach Touba from Dakar (192 km), it may take more than 12 hours close to the festival day. This is due to traffic congestion and accidents. Accidents and deaths occur, in general, due to traffic violations, lack of vehicle and road maintenance, two-way roads, etc. During festivals, firefighters, ambulances, police and security agents are mobilized to improve the situation. In terms of health, campaigns on TV and radio focus on hand washing, especially after numerous Salaam Aleykum greetings involving handshaking, a practice in Senegal, and avoidance of street food, food conservation for prolonged periods, and avoidance of water storage [9,10].

3. Methodology

Our analysis focused on the 2013 Call Detail Record (CDR) data released by Orange for the Data for Development Challenge for Senegal (D4D, <http://d4d.orange.com>). We subsetted the data based on the dates and cities of the festivals we considered.

- City: Touba
- Festival: Magal of Touba (12/22/2013)

We modeled human mobility before, during and after the festival in Senegal based on volumes and changes of volumes of communications between Touba and other locations in Senegal. We used plots to show the frequencies of calls and SMS during specific periods and map visualizations to show human mobility.

3.1. Orange Data

The Orange data we used show the calls between two sites (cell towers) and provide the number of calls and total call duration on an hourly basis. In the case of SMS, it provides the number of SMS on an hourly basis. One year of site-to-site traffic for 1666 sites on an hourly basis were provided. The descriptions of these data are provided below (Tables 1 and 2). We subsetted the data based on the date and city of the festival we focused on. We considered seven days before and after the festival. For Touba, the SITE_IDs are described on the maps below (Figure 1). We used 6 sites in the center of Touba (out of the 47 potential sites for the city due to lack of access to a more powerful server). We considered 708,476 records for voice communications and 216,343 records for SMS communications.

Time	Outgoing_site_id	Incoming_site_id	Number_of_calls	Total_call_duration
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Table 1. Header of the SET1 Orange Data (Voice)

Time	Outgoing_site_id	Incoming_site_id	Number_of_SMS
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Table 2. Header of the SET1 Orange Data (SMS)

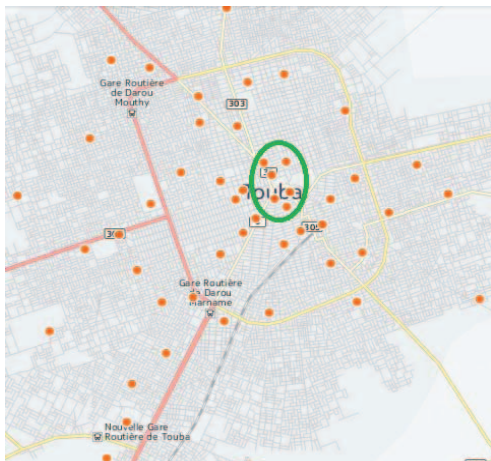


Figure 1 - Sites for Touba (SITE_ID: 1043, 1046, 1049, 1050, 1054, 1055)

3.2. Tools

We used Amazon Cloud (<http://aws.amazon.com/ec2>) for storage and processing of our data. Our language for data manipulation was R (version 3.1.2, <http://cran.r-project.org>) and we installed R Studio (<http://www.rstudio.com>) on Amazon Elastic Compute Cloud (EC2). R is a free language and environment for statistical computing and graphics. It was developed by Ross Ihaka and Robert Gentleman at the University of Auckland in 1993. R provides a wide variety of statistical techniques (e.g., linear and nonlinear modeling, time-series analysis, classification, and clustering) and graphical techniques (e.g., plots and scatterplots). It is highly extensible and numerous libraries are available. We used the following libraries: data.table, for fast aggregation and manipulation of data (e.g., 100GB in RAM); dplyr, for fast manipulation of data frames within and outside memory; sqldf, to manipulate R data with SQL; reshape, to restructure

and aggregate data with cast and melt; and ggplot2, a plotting system for R. We also used GitHub as a repository.

We were awarded a CartoDB grant (<http://cartodb.com>) for this project; the grant consisted of 1GB storage, unlimited tables and georeferencing. CartoDB is a cloud-based mapping, analysis and visualization tool that generates spatial and temporal mobile and web applications.

3.3. Methodology

We created plots of the Orange data using R to show the frequency of calls and SMS annually and during the month of the festival to observe changes. We distinguished incoming and outgoing calls and SMS in / to Touba. We also looked at the difference between the volume of calls and SMS.

Our goal was, in addition, to provide visualizations to present data in a stimulating way to captivate and reach people from different backgrounds. CartoDB permitted us to produce and publish animated map visualizations that showed the mobility of the population based on dates. We manipulated the data using SQL to get desired views in CartoDB.

We used torque map visualizations of the Orange data. Torque visualizations display temporal data on maps and permit to see the progression of points (numbers of calls per sites) based on dates. We provide screenshots in this paper.

4. Findings Related to the Orange Data

4.1. Calls from Touba

Figure 2 was obtained from the animated CartoDB torque visualization available at: <http://cdb.io/13q15Ha>. It shows the volume of phone calls to Touba seven days before, during and seven days after the Magal of Touba. Communications began to increase on December 18th, four days before the festival and decrease on December 23rd, the day just after the Magal. The highest number of communications took place on the day of the festival.

The roads used by pilgrims are visible: Dakar - Thies - Diourbel - Touba, Saint Louis - Louga - Thies - Diourbel - Touba, Kaolack - Dioubel - Touba, and Fatick - Bambey - Diourbel - Touba. Some smaller roads were also used by pilgrims. The phone calls permitted to observe human mobility during the festival of the Magal of Touba. Thies, Diourbel and Louga were hubs with heavy traffic volumes.

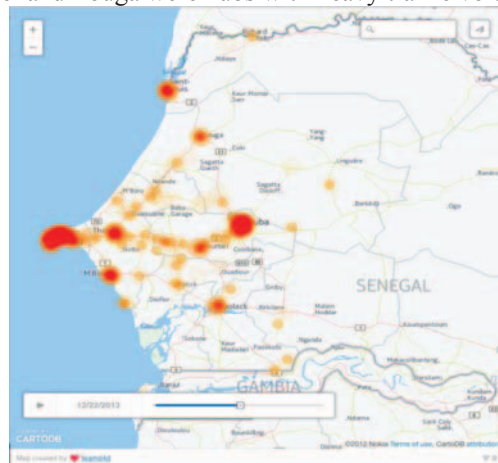


Figure 2 – Calls from Touba in CartoDB (Magal of Touba - 12/22/2013)

Figure 3 shows phone call communications from Touba. The highest frequency of calls took place on the day of the festival. Communications were about 12 times higher than during regular days. This shows that there was a massive number of pilgrims who attend the Magal of Touba.

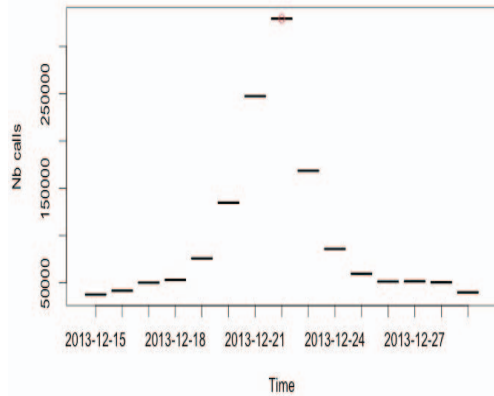


Figure 3. Frequency of calls from Touba (Magal of Touba on 12/22/2013)

4.2. Calls to Touba

The animated Torque visualization of the calls to Touba is available at: <http://cdb.io/1vcpYgV>. In Figure 4, we show the volume of phone call communications to Touba seven days before, during and seven days after the Magal of Touba. The patterns are similar to the calls from Touba. Figure 5 shows that the highest number of calls were made to Touba on December 22nd, 2013.



Figure 4 - Calls to Touba in CartoDB (Magal of Touba on 12/22/2013)

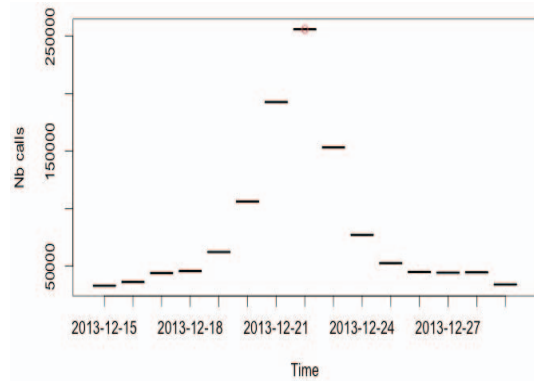


Figure 5. Frequency of calls to Touba (Magal of Touba on 12/22/2013)

4.3. Calls within Touba

Figure 6 shows phone call communications within Touba, with the highest number of calls on the day of the festival.

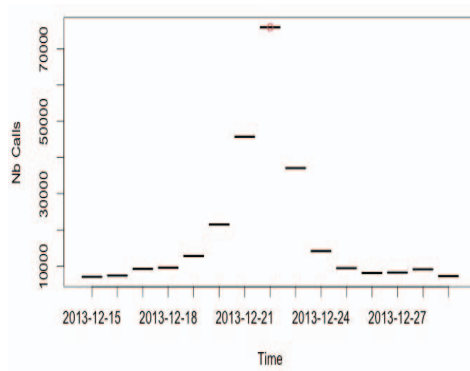


Figure 6. Frequency of calls within Touba (Magal of Touba on 12/22/2013)

4.4. SMS from, to and within Touba

We examined the SMS communications from, to and within Touba, and noticed that the highest number of messages was also sent on the day of the festival.

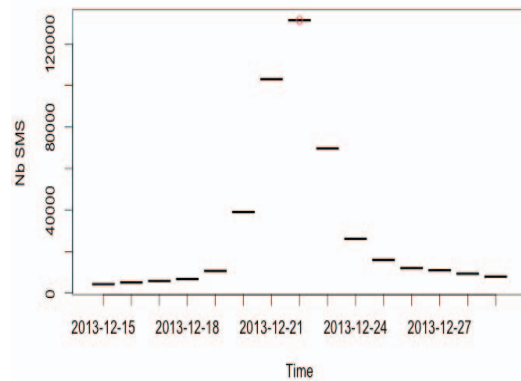


Figure 7. Frequency of SMS from Touba (Magal of Touba on 12/22/2013)

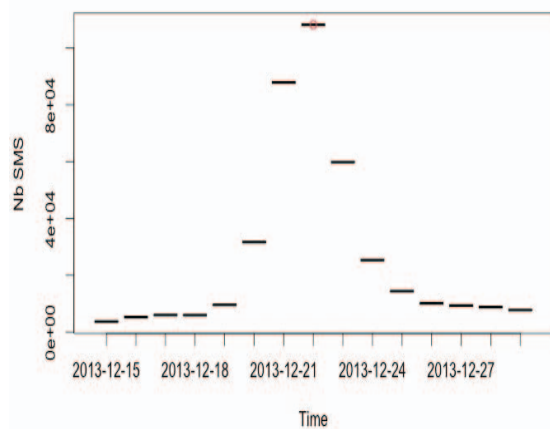


Figure 8. Frequency of SMS to Touba (Magal of Touba on 12/22/2013)

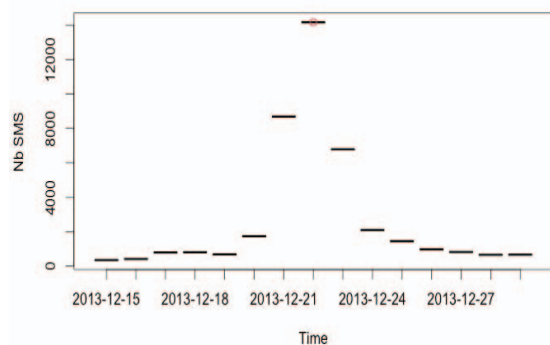


Figure 9. Frequency of SMS within Touba (Magal of Touba on 12/22/2013)

4.5. Analysis

The plots of the frequency of phone calls and SMS to, from and within Touba show that the number of phone calls and SMS increased dramatically during the festivals (more than 10 times for phone calls and more than 15 times for SMS). The range of the numbers indicate that the number of people increased in the city itself (not that people were making more calls on that day).

It is also noticeable that there were more calls than SMS to, from and within Touba. This may be due to the fact that communications were discounted during the festivals and, also, that literacy rate is low in Senegal (39.30% in 2013).

Pilgrims were contacting people from their cities and villages of origin and people who were on their way to the festivals. Their journeys were clearly visible on the torque map visualizations. These animated visualizations permitted to observe when pilgrims were initiating their travel and returning, the routes they used to reach Touba, and what regions they came from. Thies, and Louga were traffic hubs of the Magal of Touba.

Communications during the Magal of Touba were from the West of Touba and from regions above Gambia.

5. Conclusions and Discussions

5.1. Mobility and Communications

The literature on analysis of call details records (CDR) shows that we can estimate the flow of traffic between areas

from the flow of communications [1,2,3]. In this study we used CDR to show human mobility during the Magal of Touba, a festival of the Mouridiyya brotherhood. The data revealed important patterns of mobility through the analysis of calls and SMS. It showed considerable amount of communications occurring during the festival due to human mobility. The analysis also showed the main routes used by the pilgrims and their travels' times, and provided insights into the areas most pilgrims were coming from.

5.2. Importance of Data for Development

Advances in technology provide opportunities to collect, store and analyze extraordinary amounts of data. Exploring this data is useful not only to advance research but also to understand a range of human experiences. In this study, we focused on an interdisciplinary project led by a team of researchers in computer science, public health and geography of health. Planning of festivals is currently based on estimations, not on data analysis and tangible evidence. Getting accurate data is very difficult. With the ubiquity of mobile phones in Senegal (mobile penetration of 93% in 2013) using CDR can play an important role for planning festivals in a more systematic way.

5.3. Structural and Health Implications

The findings on mobility have a wide range of implications and opportunities. Understanding the patterns of mobility, the timeline for pilgrims and technological needs can help for better planning of religious festivals and other gatherings. Government agencies, telecommunication organizations and other stakeholders can plan for the following years by looking at the current data. They can anticipate technological, transportation and health needs, and prepare to respond to these massive movements of population, including during public safety and emergency situations.

The considerable amount of use of mobile phone before, during and after the festivals provides great opportunities for mobile health initiatives. Understanding this mobility can be used in prevention well before the Magal to encourage adequate health awareness and preparedness. Prevention messages can be designed and implemented in areas where pilgrims are coming from, going back to and throughout the festival roads. Advertisements for resources such as the Numéro Vert (toll free number) are already set up in preparation for the festivals. However, such work could go further to include more SMS, voice and even video messages promoting healthy behaviors. Operators advertise their services in Touba during the festival, but are not really involved in preventive health campaigns. In addition, this mobility data can be used to provide instantaneous surveillance and response to potential health outbreaks. Health officials could use this information in controlling and stopping the spread of infectious diseases by providing information about health structures available during the festivals and sending SMS.

5.4. Sensitive Data Concerns

An understanding of the local context is important when reaching to conclusions. We realize that our study addresses sensitive cultural practices in Senegal and that religion is a

delicate topic. In its current state, our study has nothing that is subject to polemic.

5.5. Recommendations

Given these implications and opportunities afforded by this data analysis, we offer the following recommendations for situations of massive movements of population due to the Magal of Touba. We understand that some of these efforts are already in process but we believe it is important to cover the wide range of uses of Orange CDR data.

1. Integration of data from different sources to fully understand the scope and opportunities of Orange CDR data
2. Open data to all stakeholders so that informed planning can be fully coordinated
3. Setting up an emergency plan incorporating mobile components (e.g., SMS and voice messages on health and transportation)
4. Coordination of pilgrims' transportation plan using data on travel locations and times
5. Continuous review of data after large religious festivals to identify lessons learned and plan for following years.

5.6. Limitations

The Orange data we used for the Magal of Touba were collected from 6 sites (out of the 47 possible sites for Touba). We focused on the use of CartoDB through a paid account and a CartoDB grant that had only 1 GB of storage. With more storage we could have explored more sites and have a better vision of the scope of the Magal of Touba, especially if we want to compare it with other religious festivals such as the Gamou of Tivaouane.

5.7. Future Work

If granted further access to the data, we would be interested in mapping the complete data of the Magal of Touba from all 47 Orange sites of Touba. We would be interested in analyzing the data of the Magal of Touba of January 2013. To further explore human mobility during festivals and to draw stronger conclusions, we would use other sets of data provided by Orange. We also plan to cross-reference these data with health and transportation data.

Acknowledgment

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