# Poster: Understanding Human Mobility during COVID-19 using Cellular Network Traffic

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***Abstract*—In this paper, our goal is to analyze and compare cellular network usage data from Rio de Janeiro from pre-lockdown, during lockdown, and post-lockdown phases surrounding the COVID-19 pandemic to understand and model human mobility patterns during the pandemic, and to evaluate the effect of lockdowns on mobility. Our analysis reveals that human mobility increases significantly even before lockdown restrictions are eased, with the trend continuing in the post-lockdown period. We also observe that the day of week has a significant impact on mobility of individuals, with the overall mobility on Fridays increasing over time possibly due to people self-relaxing restrictions and engaging in social activities on Friday evenings. We also design an interactive tool that showcases mobility patterns in different granularities and can potentially help people and government officials understand the mobility of individuals and the number of COVID-19 cases in a particular neighborhood.**

## I. Introduction

To reduce the spread of COVID-19, strict lockdowns along with physical distancing, quarantining, mask-wearing, and contact tracing have been used in countries around the world. Despite these efforts, COVID-19 infections continue to soar in countries around the world. Therefore, our goal is to analyze and compare cellular network usage data (comprising of phone calls, 3G/4G data connections, and text messages) from pre-lockdown, during lockdown, and post-lockdown phases of the COVID-19 pandemic to understand and model human mobility patterns, and to evaluate the effect of lockdown on mobility.

To this end, we collaborate with one of the main cellular network providers in Brazil, TIM Brazil, and conduct a large scale study by collecting and analyzing anonymized cellular network connections from all users in the city of Rio de Janeiro. The data consists of aggregate and individual connection information made by users to approximately 1400 cellular antennas in and around the city of Rio de Janeiro and its suburbs during each 5-minute interval from March 1, 2020 to July 1, 2020. The dataset consists of approximately 10 billion connection logs. Our analysis provides valuable insight into human behavior and mobility in the pre-lockdown, during lockdown, and post-lockdown time periods, making it a comprehensive study of mobility that can offer valuable perspective for effective lockdown and pandemic management.

**Mobility Analysis:** To analyze and identify human mobility patterns, we first discern mobility events from the connection logs. A mobility event signifies the movement of an individual user from one antenna to another antenna on the same day. We construct a graph where the antennas correspond to the vertices and the movement of users between antennas corresponds to the weight of that particular edge. We observe that user mobility starts increasing around 3 weeks before the end of lockdown, with the trend continuing into the post-lockdown period. We also analyze the impact of the day of the week on mobility. We observe that weekdays and Saturday have similar levels of mobility during and after lockdown, while Sunday has least mobility. This difference in mobility between the other days of the week and Sunday is interesting because it suggests that many people do not have the opportunity to work from home even during the lockdown period. Additionally, as time increases, we observe Fridays having higher mobility than the Mon-Thu period, which is likely due to individuals engaging in social/leisure activities on Friday evenings.

**COVID-19 Borescope:** We design an interactive tool, COVID-19 Borescope, which helps people and government officials analyze the mobility of individuals as well as correlate it with the number of COVID-19 cases in the city. This tool provides users the ability to track the number of COVID-19 cases and associate the number of COVID-19 cases with the number of connections in a specific region during any desired time period.

**Related Work:** Due to the recent nature of the pandemic, there is limited work examining the impact of the pandemic on different network parameters. Lutu et al. [1] characterize the impact of COVID-19 on mobile network operator traffic and analyze the changes brought upon by the pandemic. Feldman et al. [2] analyze Internet traffic during COVID-19 and find that the overall traffic volume increases by 15-20% within a week of the pandemic. Additionally, in recent years, human mobility modeling has received significant attention. Zhu et. al develop spherical hidden Markov models for understanding human mobility [3], while a real-time model for human mobility using multi-view learning is proposed in [4].

## II. Data and Methods

In this section, we describe the cellular network traffic dataset that we collect and use in our analysis. We collect cellular network connection logs consisting of phone calls, 3G/4G data connections, and text messages from 1400 cellular antennas located all over the city of Rio de Janeiro from

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one of the main cellular network providers in Brazil, TIM Brazil. We collect **aggregate-level data** from March 1, 2020 and then collect anonymized **individual user-level** data from April 5 to July 2 (i.e., from week 6 onward). Our individual dataset consists of approximately 120 million connection logs for each day and encompasses 2 million users per day. Table I provides a couple of examples from our individual dataset, where each data instance corresponds to a single anonymized user connecting to an antenna at a specific instance in time. As Brazil enforced strict lockdown measures from the third week of March to the end of May, the aggregate dataset spans pre-lockdown, during lockdown and post lockdown periods, while the individual dataset contains data from 2 weeks into the lockdown period and the post lockdown period.

TABLE I: Example instances from the individual dataset

| Timestamp | User ID | Latitude | Longitude |
|---|---|---|---|
| 26th April, 2020, 00:00:00 | hash-1 | -23.003431 | -43.342206 |
| 21st May, 2020, 00:00:00 | hash-2 | -22.8415 | -43.278389 |

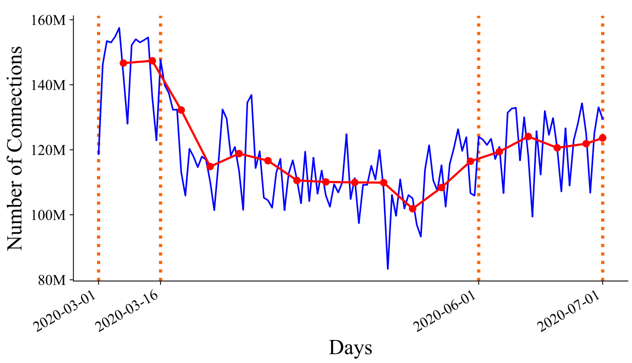


Fig. 1: Number of connections per day from March 1, 2020 to July 1, 2020

Figure 1 shows the total number of connections obtained from the aggregate dataset (from March 1, 2020 to July 2, 2020), with the red line representing the average number of connections per week. The vertical lines in the figure mark the pre-lockdown, during lockdown and post-lockdown periods. We notice that the total number of connections decrease when lockdown restrictions are enforced. We also see that the total number of connections start to increase even before lockdown restrictions are eased, with the increasing trend continuing into the post-lockdown period.

## III. Mobility Analysis

In this section, we analyze the individual user-level traces to understand the overall trends in user mobility in Rio and its suburbs. To perform this analysis, we construct a graph where the nodes/vertices correspond to the antennas (i.e., the graph has approximately 1400 vertices). We parse the individual user data and every time a user switches from one antenna to another antenna (referred to as a mobility event), we increase the weight of the edge between those two vertices by one. Figure 2 shows the distribution of the total number of mobility events over weeks. The vertical orange line represents the day when lockdown is eased. The figure shows that overall user mobility in the city of Rio de Janerio begins to increase about three weeks before the lockdown restrictions are eased. The rise in the overall mobility persists even after the lockdown restrictions are lifted.

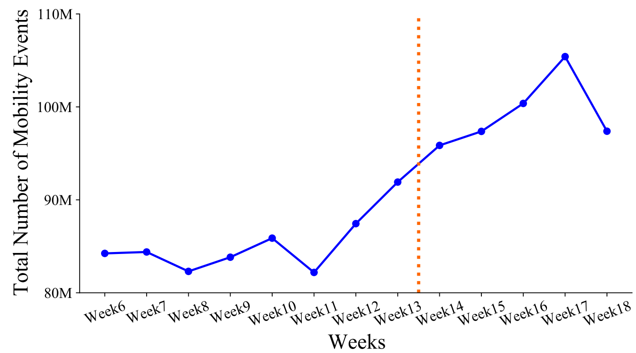


Fig. 2: Total number of mobility events over weeks

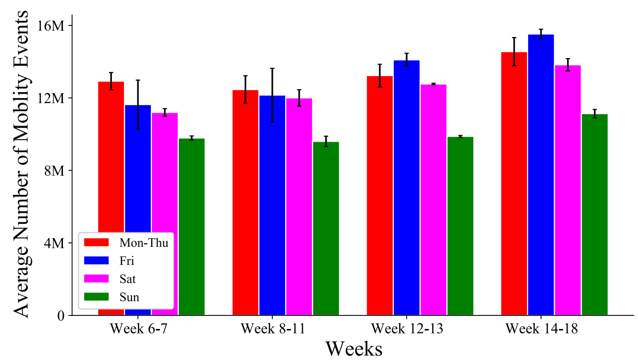


Fig. 3: Average number of mobility events over weeks on different days of the week

We next investigate the impact of the day of the week on the mobility of individuals (Figure 3). To perform this study, we first observe from Figure 2 that the overall mobility pattern remains similar for some weeks. Therefore, we group weeks together based on their mobility patterns (weeks 6–7, weeks 8–11, weeks 12–13, and weeks 14–18). We then group Monday through Thursday together because these are working days and consider Friday, Saturday, and Sunday separately. Friday is distinguished from the rest of the weekdays because it captures the versatility pattern of a workday in the early hours of the day and that of a weekend in the late evening. The error bars capture the variation in the number of mobility events. Figure 3 shows that overall mobility is lower on weekends, particularly on Sundays. Although this behavior would be expected in a pre-COVID society, we note that it continues even during lockdown. This also implies that a large portion of the population who goes outside during the week does so for work and does not have the choice of working remotely. Interestingly, during the initial part of the lockdown period, Friday mobility is lower than Mon–Thu, but then rises and surpasses Mon–Thu. One possible reason could be the gradual social self-relaxing of the lockdown restrictions, with people going to work during the day on Friday and then engaging

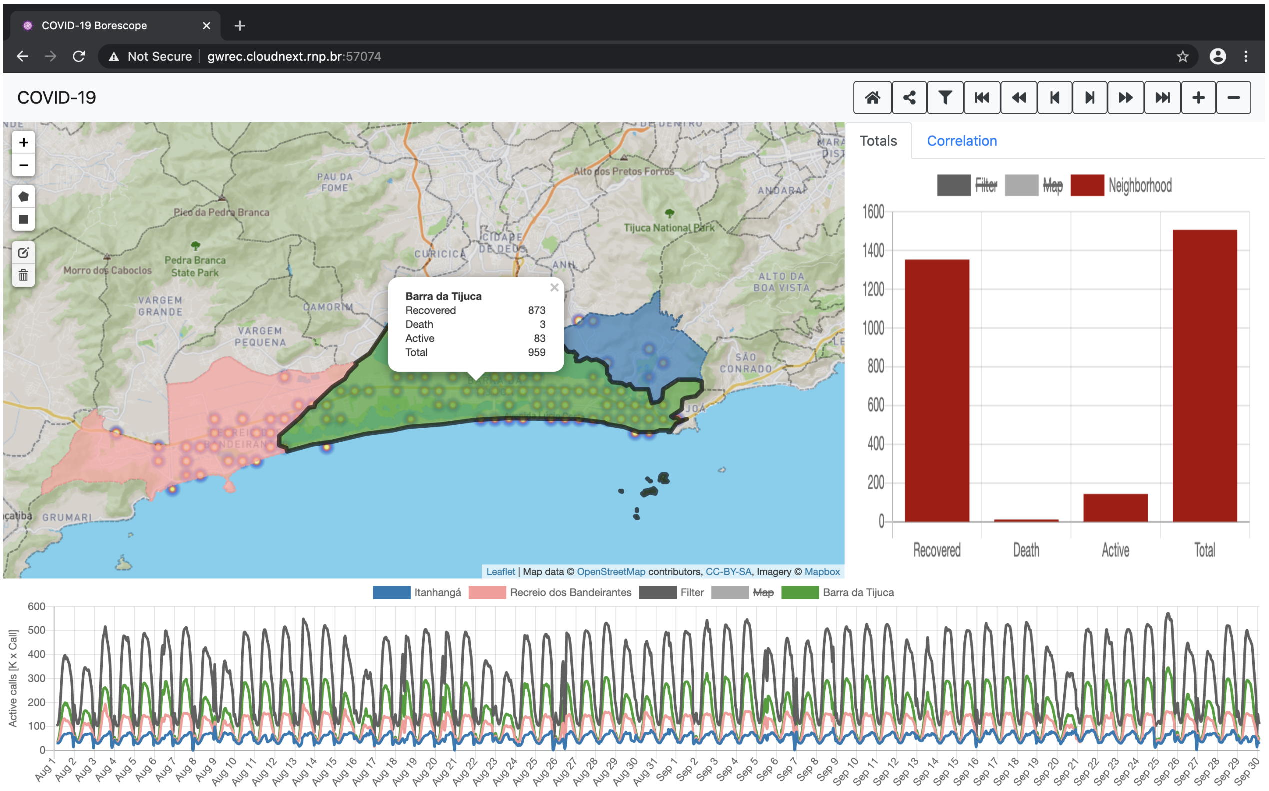


Fig. 4: COVID-19 Borescope Web Interface

in leisure and/or social activities in the evening, resulting in a higher number of mobility events on Friday than on Mon–Thu. Our initial analysis and conclusions lays the foundation for more fine-grained analysis in the future.

## IV. COVID-19 Borescope

In this section, we present another significant contribution of this study, a visual/interactive tool called COVID-19 Borescope that can aid government and municipal administrations to better understand COVID-19's evolution by examining the relationship between people's mobility and infection rate in different regions of Rio de Janeiro. This powerful tool is available to the public[1] and will be continuously updated as new strides are accomplished in the analysis. The interactive web interface provides users the ability to investigate the number of cases by region and correlate the number of infections to the number of connections in a region during any desired time period.

To ensure scalability as well as efficient data processing from multiple sources, COVID-19 Borescope is supported by a robust architecture. The architecture consists of three servers, two in the back-end and one in the front-end. At the front end, we have NginX[2] running as the application server. At the back end, we have two data servers, one to store the data received from the cellular network provider and another one to store the data that is obtained from the Open Data repository provided by the Brazilian ministry of health[3]. As shown in Figure 4, users are able to select the region(s) in the map they want to analyze. Users are also able to visualize the evolution of the number of connections with time for the selected area of the map and the histogram of COVID-19 reported cases, which includes the number of recovered, deaths, active, and total cases during the selected time period.

[1]Accessible at: http://gwrec.cloudnext.rnp.br:57074/
[2]NginX: http://nginx.org/
[3]Brazilian COVID-19 OpenData: https://opendatasus.saude.gov.br/dataset

## V. Conclusion

In this paper, we analyzed and identified human mobility patterns during the different phases of lockdown in the city of Rio de Janeiro and its suburbs by investigating cellular network connection logs. Since our analysis is based on large scale data from one of the most populous cities of the world, our approach and resulting conclusions can potentially have positive implications on understanding mobility and designing lockdowns in other cities to combat COVID-19. Our research and interactive website arms government officials with scientific information and tools so that they can design and enforce successful strategies to combat the current pandemic.

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