# Call Detail Record (CDR) ANALYSIS: SIERRA LEONE

## Final Report

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# Call detail record (CDR) analysis: Sierra Leone

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# 1 Summary

The mobile phone is one of the most ubiquitous technologies of the modern era. Mobile phones are used as a tool not only for communication but also for information provision for many sectors such as government, finance, education, agriculture, and health, and it is especially important in the field of disaster and emergency management, providing crucial estimates of the number and movement of people prior to or during such events.

The situation in Sierra Leone is a prime example, being heavily impacted by the Ebola outbreak, along with neighbouring countries, Liberia and the Republic of Guinea, where understanding human mobility was critical to effective policy intervention to tackle the disease. Ebola is an epidemic disease, and by understanding human mobility, authorities can build models that are critical when it is necessary to make informed decisions, rapidly apply efficient policies, and make interventions to contain and tackle the disease effectively.

Call detail record (CDR) data provides information about activities not only on a mobile communication network but on aggregated human mobility that can enable swift action against the disease. This report demonstrates how analysed CDR data can contribute to addressing specific issues related to Ebola epidemics by estimating dynamic trajectories and spatio-temporal distribution of people.

For this report, a human movement analysis at two different scales has been conducted; city-to-city movement in Sierra Leone, and transboundary movement across three countries, Guinea, Liberia, and Sierra Leone. Results of the city-to-city scale analysis showed a strong correlation between the distribution of mobile phone users and actual populations at the district level and demonstrated the possibility of quantitatively estimating spatio-temporal distribution and movement of people. Although the scope of this report only includes the population covered by CDR data, the results of the analysis will give government and local authorities a better and quantitative understanding of population flow patterns over time (short- and long-term) and at specific events. This enables the extraction of people's city-to-city migration data for analysis from one city to another during an outbreak of disease that could be vital to understanding how and where the disease spreads and to manage its eventual control.

In addition, analysis of available data related to transboundary movement indicates that there are more frequent movements in neighbouring villages along the border than movement to and from central areas in neighbouring countries. This indicates that tracing movement to and from central areas is not sufficient to tackle an outbreak, however it should be noted that the data analysed was recorded during the containment stage of the Ebola outbreak.

This report explains how spatio-temporal user population movement and spatio-temporal distribution of mobile phone users can be used to analyse this and other societal issues. This report reviews the use of mobile technology and advanced methods of information gathering and dissemination. This report also demonstrates how data collected by mobile phone network operators can cost-effectively provide accurate and detailed maps of population distribution over a selected area. It also describes how mobile phone technology is generally used; it discusses GSM (the Global System for Mobile Communication) and future technologies; and it presents various applications for use in sectors such as agriculture, health, finance, governance, and disaster preparedness, response and recovery.

# 2 Background

Spatio-temporal data of the population can be considered as a key input for policy intervention to control the Ebola epidemic. This is because Ebola is a communicable disease and the way it spreads is significantly affected by human mobility. The globalization of economies has increased the volume and rapidity of human mobility, and it has lowered the cost of transportation and made large scale

human movement easier. Consequently, call detail record (CDR) data (mobile phone data), has been attracting the attention of policy makers and researchers in various fields because of the capacity of capturing population movement patterns and trajectories.

The CDR data generally consists of randomized identity tags, time stamps of mobile communications, and approximate locations of communications, which are represented by the geographic coordinates of cell phone antennas. Although the antenna locations do not allow us to pinpoint exact locations of mobile phone users, proxy location from cell phone devices can be a powerful source to describe the general pattern of population movement.

Traditionally, city monitoring and analysis rely on a fixed location and a considerable amount of statistical data and this does not permit the identification of multi-temporal events in wide areas. However, in addition to the quantitative aspect of human mobility (e.g. such as population volume and its speed), understanding qualitative aspects of the people in CDR data (e.g. gender, age, and occupation) is expected to expand the use of CDR data to various applications. In this case, the usage logs of mobile devices will be treated as a medium for data collection.

Call detail records represent mobile communication network activity data, all of which could be used as aggregate data to estimate the target area population density.

For large scale monitoring, CDR data from mobile network base stations provides excellent spatial patterns that reflect urban life, its temporal dynamics, and it could potentially become a new way to extract or identify less evident problems. Analysis of CDR data captures human movement. However, most analysis uses CDR data of a single country or part of a region of a country because mobile network operators cannot trace transboundary movements.

In the last outbreak of Ebola in West Africa over 11 000 people died. National-health authorities in West Africa have struggled to contain Ebola, especially how to estimate the affected population in the outbreak prone area and how to understand outbreak patterns spreading from one area to another. Currently, population movement simulations are based on statistical data that cannot provide reliable and dynamic population flows from an area where an outbreak has occurred, nor can they predict where outbreaks were likely to happen next. This type of simulation can be better served by using call-data-records (CDR) generated from mobile phone data. The CDR data contains time and location information for voice, messaging, and data communication of each handset - collected for billing purposes - and it can also be used to estimate time-based and up-to-date dynamics of population movements, leading to better support and preparation and more lives saved.

## 3 Mobile communications in Sierra Leone

### 3.1 Mobile phone technology

In real terms, the first mobile network came into existence nearly 35 years ago and has been steadily developing into the modern high-speed services that are taken for granted today:

- In 1982, the Conference of European Posts and Telecommunications (CEPT) established a *Group Special Mobile* (GSM), because existing analogue systems were unable, from a subscriber point of view, to offer an acceptable service. A GSM system is basically designed as a combination of three major subsystems: the Network Switching System (NSS), the Base Station System (BSS) and the Operation Support System (OSS).[1] In general, data is collected from the Base Station Controller (BSC), which is part of the radio subsystem. When a user makes a call, a mobile phone

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[1]    GSM: https://www.itu.int/osg/spu/ni/3G/casestudies/GSM-FINAL.doc

connects to the closest Base Transceiver Station (BTS). A coverage area of a single base station indicates the capacity of mobile usage in the area.[2]

Figure 3.1: Commutation basis of GSM system
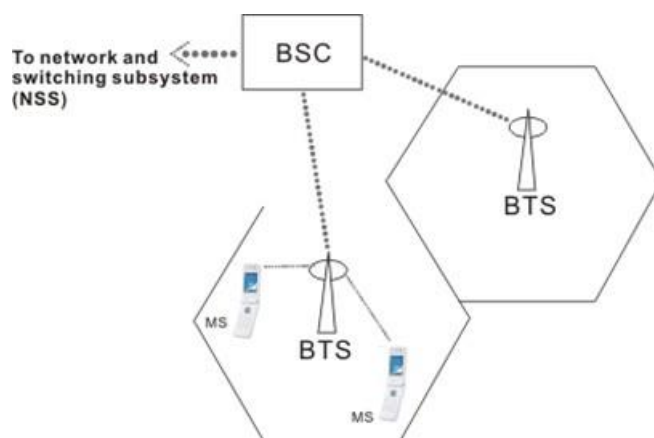


Source: ITU

Current and next generation of mobile phone technology

- 2G networks, first introduced in 1992, the second-generation of cellular telephone technology was the first to use digital encryption of conversations and the first to offer data services and SMS text messaging.

- 3G networks succeeded 2G, offering faster data transfer rates and were the first to enable video calls. This makes them especially suitable for use in modern smartphones, which require constant high-speed Internet connection for many of their applications.

- 4G is the fourth generation of mobile phone communications standards. It is a successor of the 3G and provides ultra-broadband Internet access for mobile devices. The high data transfer rates make 4G networks suitable for use with wireless modems for laptops and even home Internet access.

## 3.2    Situation of mobile subscribers in Sierra Leone

The Republic of Sierra Leone is composed of four regions: the Northern Province, Southern Province, the Eastern Province, and the Western Area. The first three provinces are further divided into 12 districts. The districts are divided into 149 chiefdoms, which have traditionally been led by hereditary paramount chiefs, recognized by the British administration in 1896 at the time of organizing the Protectorate of Sierra Leone.

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[2]    T. Horanont. CSIS Discussion Paper. 2012. A Study on Urban Mobility and Dynamic Population Estimation by Using Aggregate Mobile Phone Sources No. 115.

Figure 3.2: Administrative map of Sierra Leone



Source: ITU

As of 2013[3], Sierra Leone had a population of 6.2 million people. Approximately 80 per cent of the population are covered by mobile network operators. There are six major mobile phone operators in Sierra Leone: Africell, Comium, Airtel, GreenN, Sierratel and Smart Mobile. They offer GSM services, which work on both a prepaid and post-paid service. The National Telecommunications Commission (NATCOM) regulates the Sierra Leone telecommunication sector.

# 4    Call detail records (CDR)

Call detail record data contains basic information about mobile phone usage, such as, which cell towers the caller and recipient's phones were connected to at the time of the call, the identities of sources (points of origin), the identities of destinations (endpoints), the duration of each call, the amount billed for each call, the total usage time in the billing period, the total free time remaining in the billing period, and the running total charged during the billing period. In the case of pinpointing people, the operator knows cell tower locations and it is possible to use CDRs to approximate the location of both parties. The spacing of cell towers, and thus the accuracy in determining caller location, varies according to expected traffic and terrain. Cell towers are typically spaced 2 to 3 km apart in rural areas and 400 to 800 m apart in densely populated areas. This geo-spatial information is extremely useful for humanitarian and development applications.

## 4.1    Extracting human mobility and spatio-temporal distribution from CDR data

Sequential locations recorded in CDR data can provide a partial view of population trajectories because CDR data are specific, allowing individual movements to be traced. With the aggregation of individual movements in CDR data, patterns, trends, and spatio-temporal distribution of the whole population can be tracked. By overlaying such information with secondary data, relationships between human mobility and other societal factors can also be analysed.

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[3]    http://statistics.sl/sldhs_2013_report/demographic_and_health_survey_2013_final%20report.pdf

## 4.2    Public and private sector impact

### Social impact (country level)

This section describes how information extracted from CDR data can be utilized to address societal issues:

- **Disaster response**: Natural disasters give rise to emergency situations, when providing time-sensitive information is crucial for fast allocation of resources, which aids the response and recovery process. In 2010, a research team led by the Karolinska Institute[4] in Sweden showed that CDRs can be used to direct emergency aid by analysing mobile phone records covering the time period when people are fleeing natural disasters.

- **Health**: Researchers have also used CDRs together with a simple disease transmission model based on infection prevalence data, and in doing so were able to map routes of disease dispersal. By analysing the regional travel patterns of millions of mobile subscribers, researchers were able to map the specific locations where disease had a higher probability of spreading.

- **Socio-economics**: CDRs can provide a proxy indicator for assessing population census, regional poverty levels, and can valuably augment national surveys in estimating changes associated with a growing economy.

- **Transportation**: Rapid urbanization in developing countries has increased pressure on infrastructure such as road networks. Roads and public transportation systems become saturated, and people lose a great deal of time traveling from home to work, which in turn has a collective economic cost. By analysing CDR data, scientists can map new routes to decongest crowded roads, which would reduce travel time.

### Private sector impact (mobile phone operator)

- **Evaluating patterns of telephone use**: Many usage patterns can be extracted from CDR data. One example is the call behaviour of people in different demographic groups. This includes both spatial and temporal data such as number of calls at each time period, call average, call duration for identified user groups (such as male, female, student, worker, housewife), location (where people in the same or other groups tend to make voice or data calls), minutes of usage per user on average, local call percentage, long distance call percentage, roaming percentage, idle period local call percentage, idle period long distance call percentage, idle period roam call percentage. The requirement is that anonymized CDR data maintains links to information of the user group.

  Such information could help operators to adapt their service to specific groups of people as well as specific locations, maintain customer satisfaction with incentives, and also target customer support, for example for those who adopt specific services and features.

- **Build customer profiles**: Operators can build customer profiles from the patterns and then construct a pricing structure to maximize efficiency, whether it's based on mobile user data or customer service calls, the data available in call detail records can help to improve services and promote opportunities or ways to shorten time on call.

- **Sales forecasting**: Customers make calls or use services, and operators can improve services and network efficiency by predicting service usage. Usage analysis can determine a strategy of planned obsolescence or figure out complimentary services. Forecasting also looks at the number of customers, market-share, can predict usage and estimate revenue from groups of customers.

- **Identifying fraud or overuse on mobile phone**: Through the use of historical information of CDRs, operators can spot unusual calling behaviour and over-use behaviour, and can also help operators to limit or stop related services, and alert customers.

- **Plan for changes in resource needs**: The usage data derived from CDRs can help to plan for changes in resource needs such as to add a gateway or a media server in a certain location. It

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4    http://journals.plos.org/plosmedicine/article?id=10.1371/journal.pmed.1001083

can be used to measure quality of service by capturing information on packet loss, latency, or jitter. It can also be used for network planning for example events that may result in base station capacity issues.

# 5    CDR data sets and basic statistics

For the CDR Analysis project, two months of CDR data- from June to July 2015- were collected in Sierra Leone to demonstrate how dynamic population movements could be estimated. Data was prepared by the mobile network operators in Sierra Leone, Africell, Airtel and Smart. This meant that the data included the majority of the subscriber population, and subscriber privacy issues were reflected in the creation an anonymous set of information. The unique identification number was replaced using a cryptographic hash algorithm that generated new random numbers and there is no way to rebuild the original identities. Figure 5.1 depicts cell towers and their coverage area. Density map on the right side show a high concentration of cell towers in Freetown and to the west of the country.

Figure 5.1: Cell tower location at Sierra Leone
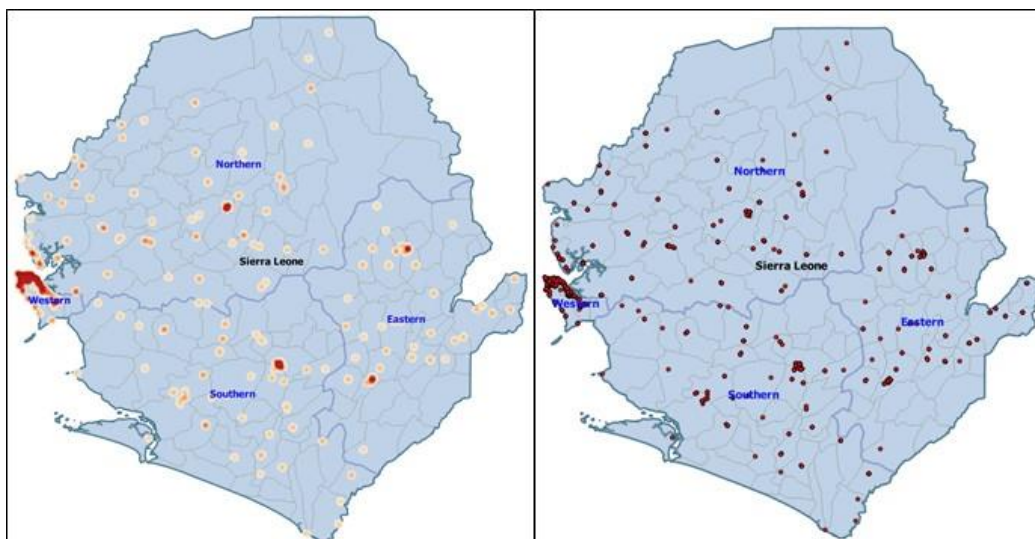


Source: ITU

Figure 5.2 illustrates the basic information obtained from CDR data. Even though data specifications were prepared for operators to provide data in a specific format, not all operators prepared the data in the correct format, and in this case, data pre-processing was necessary.

Figure 5.2: CDR data set

| Country | MNO | Voice SMS | | | | | | | | | |
|---------|-----|-----------|-------------|--------------|--------------|-------------|-------------|------------|-----------|------------|----------|
| | | Data Size | Data Period | Total record | IMEI (caller) | IMSI (caller) | Caller No | Time stamp | LAC/cell ID | Duration | Incoming Cal/ Outgoing Call |
| Sierra Leone | Africell | 70 GB | June,July 2015 | 696,386,153 | - | - | O (915,307) | O | O | O | - |
| | Airtel (1) | 87 GB | June,July 2015 (No June 2-3) | 560,145,533 | O (2,286,265) | O (1,504,092) | O (3,493,229) | O | O | O | - |
| | Airtel (2) | 50 GB | June,July 2015 | 590,408,085 | - | - | O (3,548,090) | O | O | O | - |
| | Smart | 272 MB | June,July 2015 | 2,179,595 | - | O (58,935) | - | O | O | - | In and Out |

Source: ITU

CDR basic statistics

CDR data was collected from the mobile network operators and the total activity generated averaged over 19 million items a day. Figure 5.3 illustrates the daily call activity, and Figure 5.4 shows an average of over 1.4 million users, and the CDR data per user averaged 10.81 per day.

Figure 5.3: Daily call activity
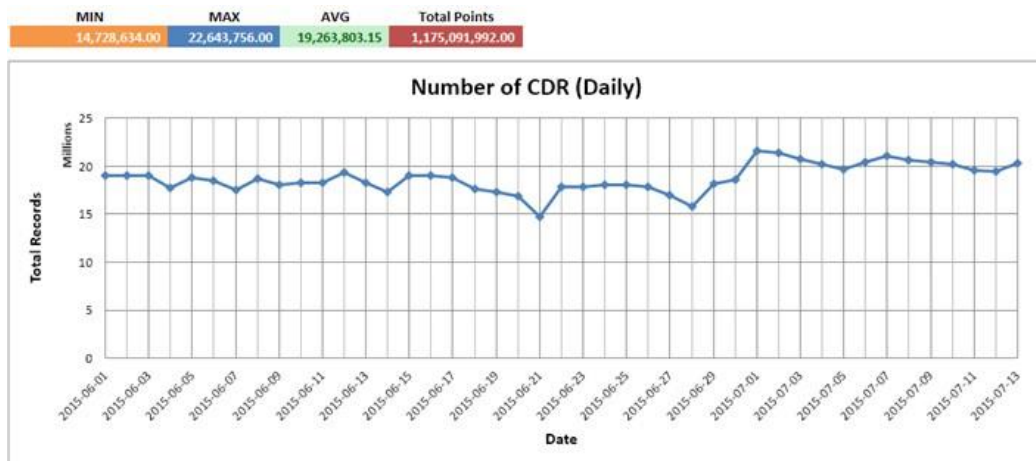


Source: ITU

Analysing user behaviour during events such as during the aftermath of a disaster could use CDR data. As seen in Figure 5.3, call activity is lower on some days and higher on other days, which may correspond to some important event.

Figure 5.4: Daily unique user
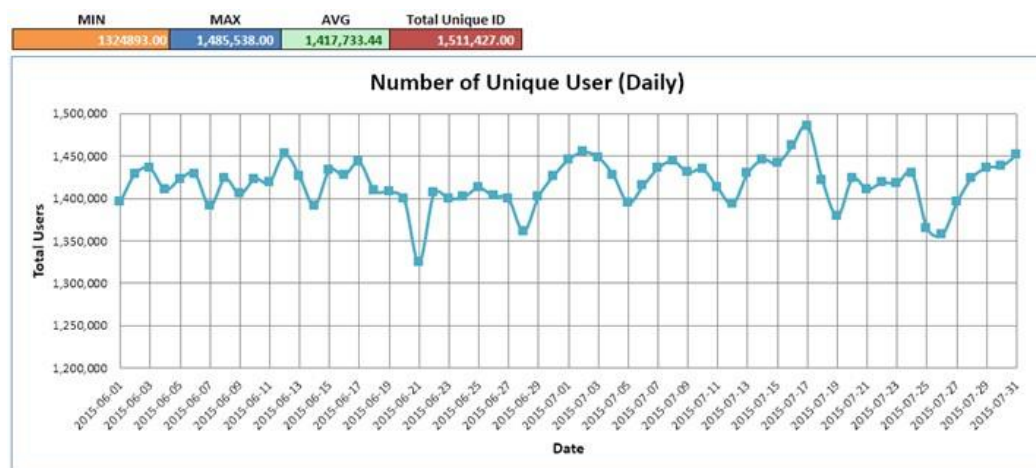


Source: ITU

Figure 5.5 shows the average total unique location of people reached 2.77, which means that people visited less than three locations a day.

Figure 5.5: Average total unique location (daily)
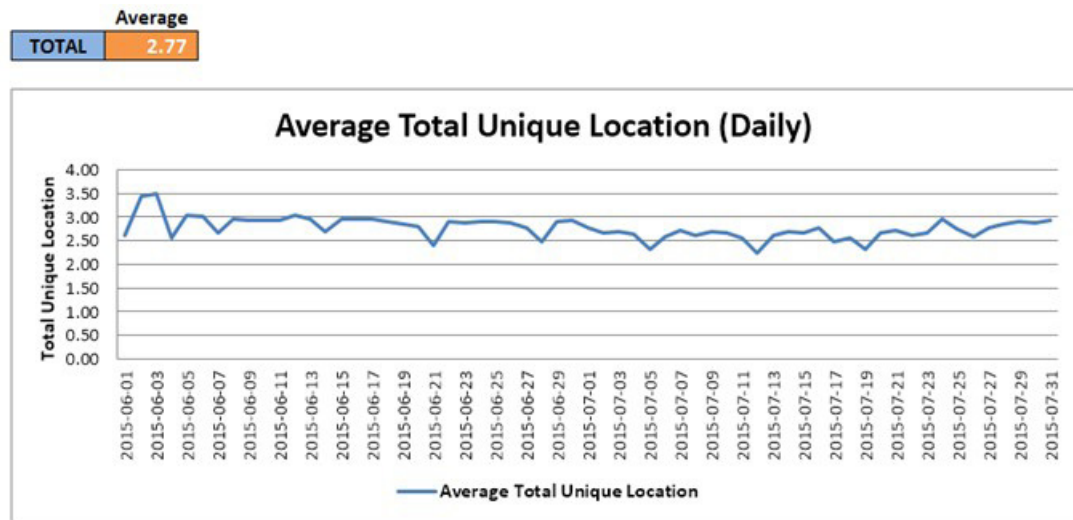


Source: ITU

# 6 CDR data: Limitations and difficulties

Even though applying CDR data can provide many benefits in various sectors and applications as previously described in section 4, there are some obstacles and difficulties that limit the use of CDR data.

- **Privacy concerns:** When mobile phones transmit voice they also collect and record other information, not only inherent to CDRs but also user specific and personal information, and this creates new challenges in terms of the conflict between technology innovation and rights to privacy.

- **Accuracy:** One major factor that could impact continued advancement of local analysis on these mobile devices is accuracy of their geolocation or estimated position. Almost all CDR data from telecommunication networks use the base tower location to infer the geographic location of the devices. In most cases, the accuracy from this method only varies from 50 to 300 metres in dense urban environments. To mitigate the accuracy issue, the report applies an estimation method of people stay locations and movement routes by using digital map data including POI (Point of Interest) and transportation network data.

- **Availability of data:** In most countries, the research and study of mobile phone data is limited to the availability of data from operators. Although datasets have become available in recent years and have opened the possibility for researchers to carry out large-scale urban and social impact analysis, both support from the mobile industry and data availability are still very limited.

- **Data discontinuity:** Call detail records are generated when people use their mobile phone, creating a lack of continuity in consecutive access points in CDRs, creating a core user location problem when analysing the data. The discontinuity issue is tackled by the estimation method of people stay locations and movement routes, described above. In addition, and despite industry-wide formatting standards, the variation of data format requires much data pre-processing and cleaning before analysis.

# 7 Methodology

## 7.1 Overview of CDR data analysis (including stakeholders)

Figure 7.1: CDR data analysis process
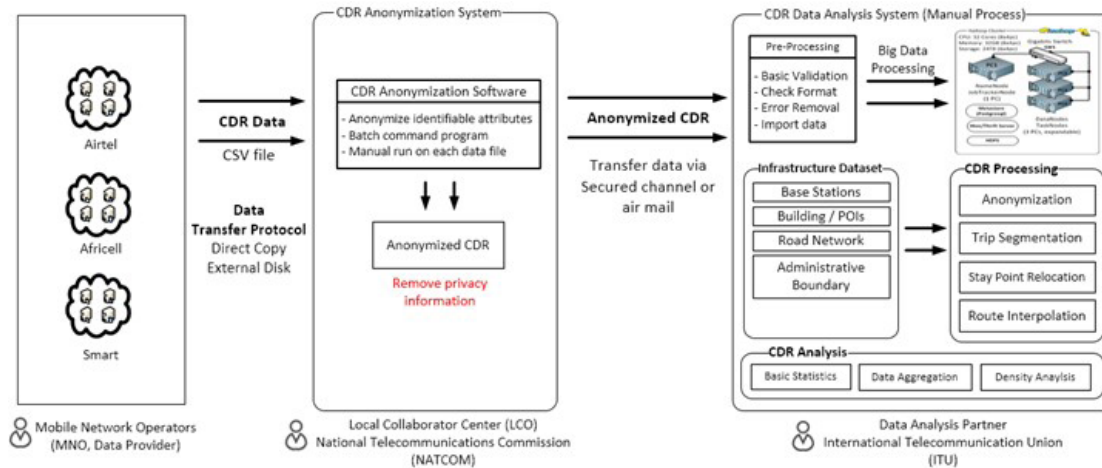


Source: ITU

The process of CDR analysis requires a certain number of steps that could eventually be automated, including the use of anonymization software, which has been developed and shared to data providers to remove personally identifiable information from their data sets, so that the people remain anonymous. Data transfer was also carried out manually online using secure channels or offline using an external disk. Details of each step and module is described below:

- **Mobile network operator (MNO):** Data is collected from operators. In this case, the mobile operator collects position data of the mobile device stored on its server. Data is then exported and transferred to local collaborator centres (LCOs) for further processing, generally provided in a compressed CSV file format. For the purposes of this project, data transferring was carried out via direct copy.

- **Local collaborator centre (LCO):** This country specific unit stores and sanitizes data (eliminates the risk of personal data disclosure). Usually, this role is carried out by the regulator or mobile operator licence provider, which is also in charge of transferring anonymized data to a designated data analysis partner.

- **Data analysis partner (DAP):** The role of the DAT is to keep and maintain all sanitized CDR data received from operators through the LCO, and is in charge of processing and analysing CDR data:

  - CDR anonymization: This function handles the anonymization process on CDR data. The LCO retrieves raw CDR data in csv format and manually processes it to remove all privacy related information. The CDR data can then be transferred to the data analysis partner. In this project, a macro-programme was run (a command line application) once certain parameters such as path of input, path of output, seed data and CDR format parser had been set.

  - CDR data analysis: This function collects all CDR data from the LCO, manually checks the data and imports it to a big data platform before it carries out deeper analysis. This analysis by DAP staff incorporates many modules including: pre-processing, big data processing and CDR processing. CDR data processing is explained in detail in the next section.

## 7.2 Overall work flow

Figure 7.2 describes the overall work flow of the process from anonymization of raw CDR data to analysis.

**Figure 7.2: Overall work flow: From raw CDR data to analysis**
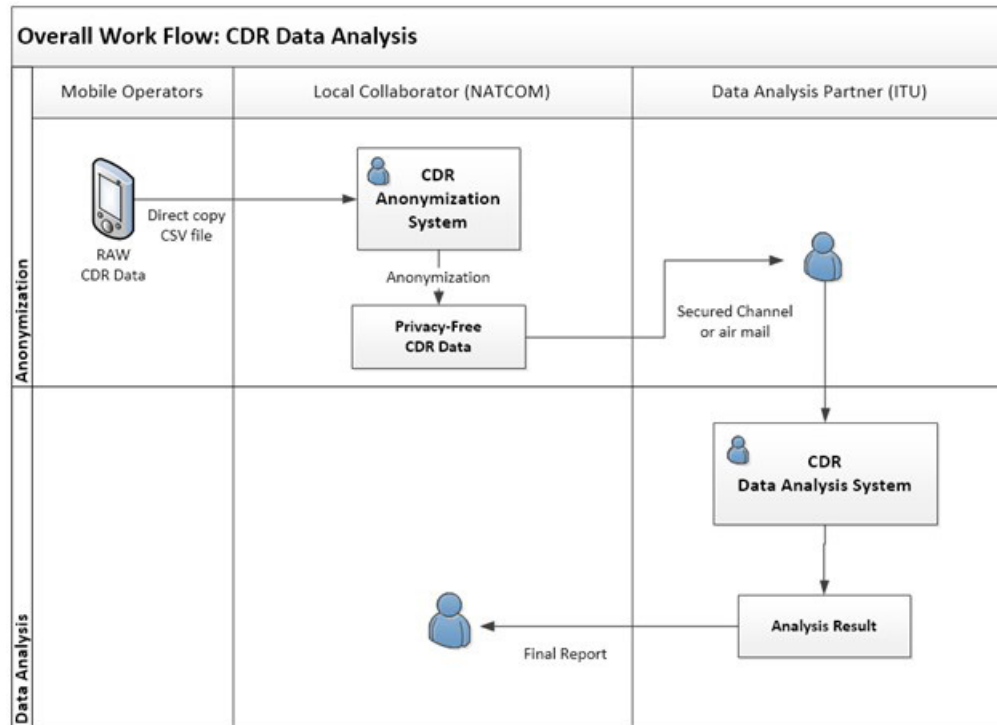


Source: ITU

## 7.3 CDR data specification

The operator is asked to provide the following standardized information:

- International Mobile Equipment Identity (IMEI) of both calling and called party is:
    - unique for each device;
    - will be irreversibly encrypted (using hash function);
- International Mobile Subscriber Identity (IMSI) of both calling and called party is:
    - unique for sim (subscriber identification module) card;
    - will be encrypted using Hash function, irreversible.
- time stamp of call-start and call-end format is YYYY-MM-DD HH24:mm:ss (e.g. 2016-07-16 12:05:22)
- base station calling party identity and coordinates:
    - LAC, cell identity;
    - Longitude, Latitude.
- base station called party identity and coordinates:
    - LAC, cell identity;
    - longitude, latitude.
- mobile phone number of calling party: irreversibly encrypted using hash function.

- activity type:
  - Voice, SMS, data;
  - 2G, 3G, LTE.

## 7.4    CDR processing procedure

Figure 7.3: CDR processing procedure
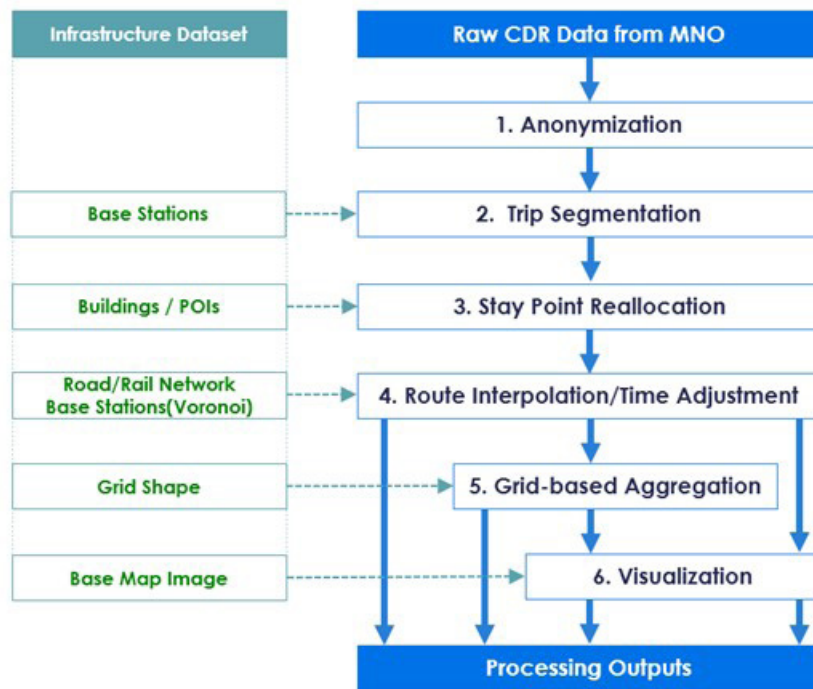


Source: ITU

1. **Anonymization (hash[5]):** Any identifiable attributes are anonymized with a cryptographic hash function (SHA-256) to protect user privacy. Original attributes will be removed and replaced with randomly generated hashing key.

2. **Trip segmentation:** Extract stay points from anonymized CDR data, and divide move/stay segments. Figure 7.4 explains how stay points are extracted by applying parameters and thresholds to CDR data.

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[5]    Hashing works by running a program that can take text input and turn it into another unique but random value.

Figure 7.4: CDR Process of stay point extraction
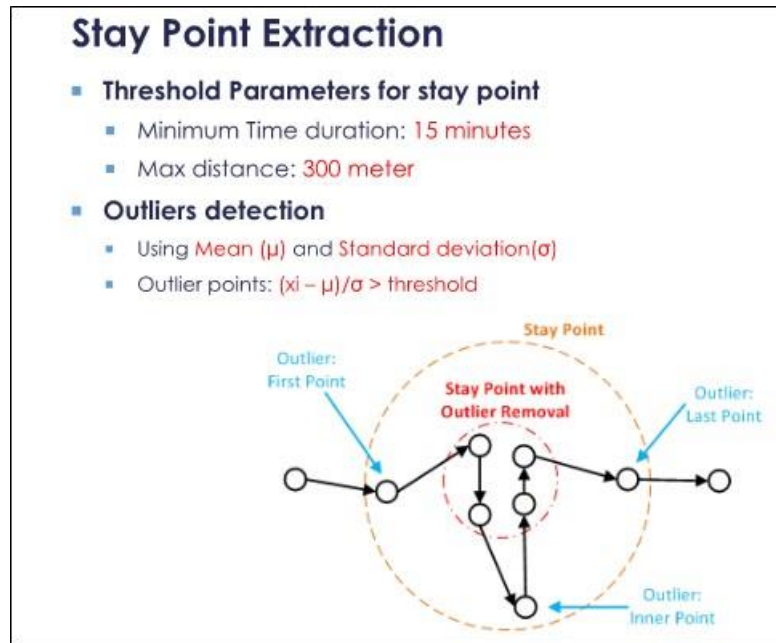


Source: ITU

3. **Stay point reallocation:** Reallocate stay points (Trip OD) to surrounding points of interest (POIs) with a certain probability and fill gap between stay/move segments. POIs are regarded as surrounding a certain cell tower if they are closer to the cell tower location than to the others (Voronoi tessellation). The reallocation is necessary because CDR location data is based on cell tower location, which means that all users in the same area have the same location. Reallocation can make the distribution of people more realistic or likely because POIs can be considered places where people likely stay, such as shopping areas, residential houses, villages, to which people are reassigned rather than concentrating on cell tower locations. A new dataset of POIs was constructed for this process by collecting data from the distribution of buildings from open access Internet data (see Appendix 2). Figure 7.5 shows how POIs are distributed in a city. Areas in blue indicate building POIs with extracted stay points, where location information originally based on antenna location, are reallocated.

Figure 7.5: Distribution of POIs in Freetown and process of stay point reallocation
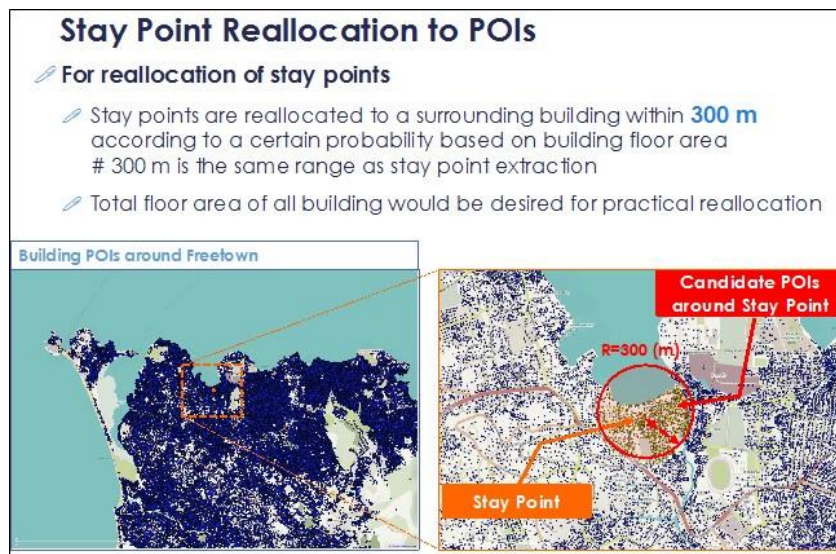


Source: ITU

4. **Route interpolation:** Routes between every pair of reallocated stay points (building POIs) are interpolated by searching the shortest path between the POIs (ODs). Because the time log of each record in CDR data does not coincide with the start and end time of a mobile phone user's trip, the time of trip occurrence is adjusted to match a certain probability distribution. Road network data was created for this process using Open Street Map (OSM) data (see Appendix 2), based on the travel time for the shortest path. Figure 7.6 shows how a shortest path connects a trip origin and destination. Red dots indicate the location of reallocated stay points and yellow nodes indicate a shortest path for the origin and destination. Some intermediate points, which are not stay points, are not on the shortest path because only the origin and destination of a trip is displayed. An algorithm selects the shortest path that connects not only the origin and destination but also intermediate points. A framework of the process of shortest path search is illustrated in Figure 7.7 and Figure 7.8 shows a route, which also goes through intermediate points.

Figure 7.6: An example of a shortest path search result
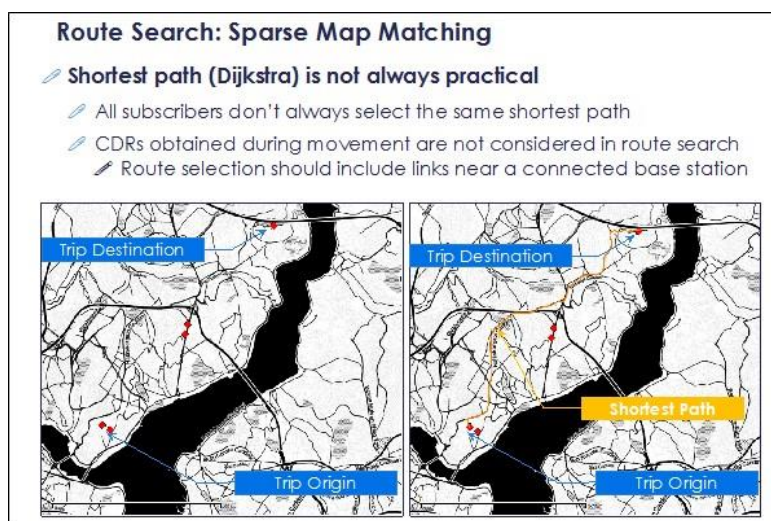


Source: ITU

Figure 7.7: Conceptual framework of the process of shortest path search
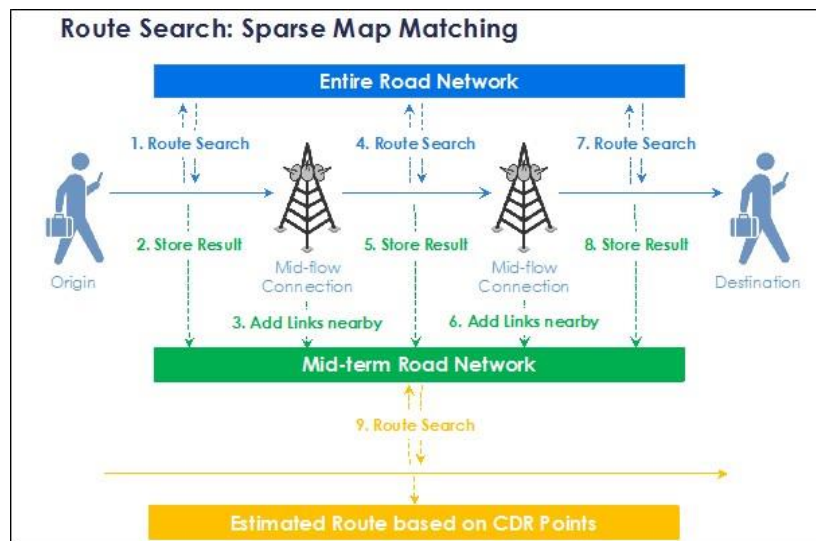


Source: ITU

Figure 7.8: Distribution of POIs in Freetown and process of stay point reallocation
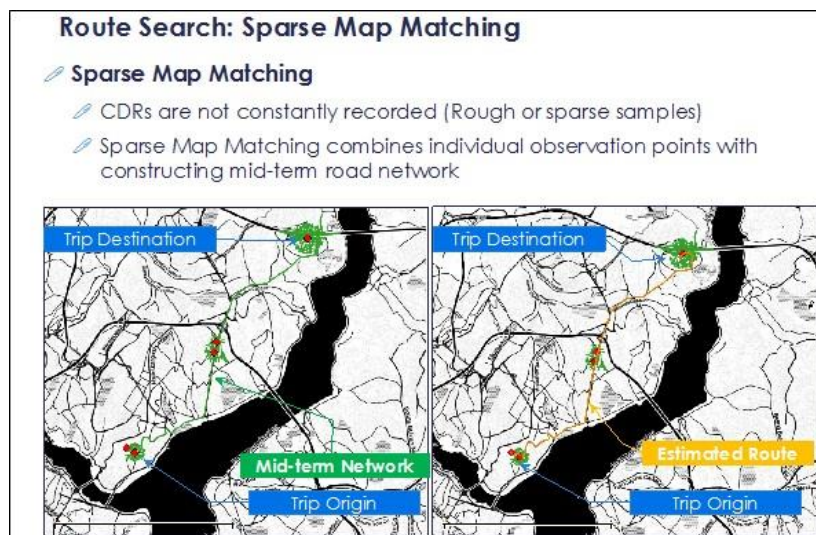


Source: ITU

5. **Grid-based aggregation:** This refers to the aggregate measurement of population density in a certain grid (1 km) and time duration (1 hour).

6. **Visualization:** This creates an animated projection (Mobmap generated film[6]) of disaggregate/aggregate movement of people (off-line).

## 7.5    Interpolation format specification

In this section, some basic definitions of trajectory data are explained. It also includes basic terminology for trajectory data mining.

• **Trajectory data:** This is a sequence of time-stamped points, P = ($p_1$, $p_{2,}$...$p_n$), where p = (ID, time, latitude, longitude) and n = a total number of points.

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6    http://shiba.iis.u-tokyo.ac.jp/member/ueyama/mm/

Figure 7.9: Trajectory data and stay point
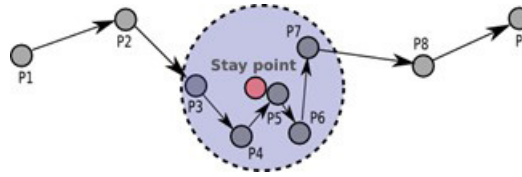


Source: ITU

- **Stay point:** This is a geographical reference to a place where a user stayed over a time threshold (tt) within a distance threshold (dt). In a trajectory, stay point is characterized by a set of consecutive points P = {$p_m$, $p_{m+1}$, ..., $p_n$}, where $\forall m < i \leq n$, Distance($p_m$, $p_i$) $\leq$ dt, Distance($p_m$, $p_{n+1}$) > dt and Time Interval($p_m$, $p_n$) $\geq$ tt. Therefore, s = (x, y, $t_a$, $t_l$), where x, y are a centroid location of those points in a stay point.

- **Location history**: This refers to an individual's location history (h) and is represented as a sequence of stay points they have visited with corresponding transition times:

$$h = \langle s_0 \xrightarrow{\Delta t_1} s_1 \xrightarrow{\Delta t_2} \cdots \xrightarrow{\Delta t_{n-1}} s_n \rangle$$

Where $s_i$ is a stay point and $\Delta t_i$ is the time interval between two stay points.

- **Significant places**: For each individual, significant places are the locations where they often visits in the life activity such as home, work place and supermarket.

- **Trip point**: Is a record attached with trip properties that represent a sequence of GPS points with same activity such as stay or move as shown in Figure 7.10. The properties include time duration, distance, type, transport mode and so on.

- **Sub trip**: This represents a group of sequential trip points from one stay point to the next stay point such as stay-> walk-> train-> walk-> stay. It also depicts an activity of a user such as going out from home to the office.

- **Trip**: This is a set of time sequential trip points or sub trips in a day. A trip must contain at least one sub-trip. It indicates overall sequential activity in a day of user. Normally, one trip contains multiple Trip Points of STAY and Move .The example is shown in Figure 7.10.

Figure 7.10: Time sequential trip points
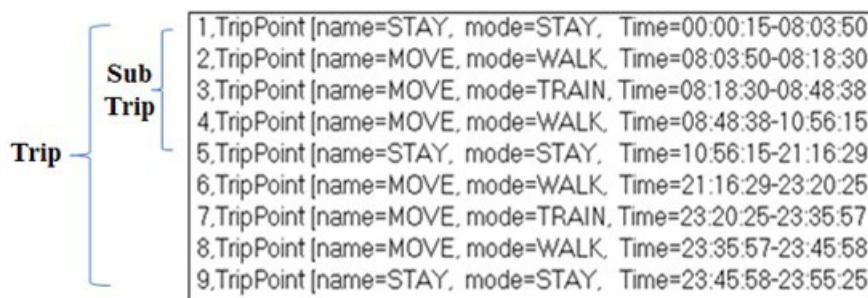


Source: ITU

Trip segment analysis for checking interpolation result

UID, DATE (yyyy-MM-dd), TRIP_SEQUENCE_ID, MOBILITY_TYPE, TRANSPORT_MODE, TOTAL_DISTANCE, TOTAL_TIME, START_TIME, END_TIME, TOTAL_POINTS, POINT_LIST

422a837717,2015-06-06,1,STAY,STAY,0.000,50003.000,00:00:00,13:53:23,1,1|2015-06-06 00:00:00|8.451033|-13.267844

422a837717,2015-06-06,2,MOVE,WALK,2775.678,2101.000,13:53:23,14:28:24,36,1|2015-06-06 13:53:23|8.450733|-13.268241;2|2015-06-06 13:54:23|8.451082|-13.268902;3|2015-06-06 13:55:23|8.451350|-13.269496;4|2015-06-06 13:56:23|8.451393|-13.270252;5|2015-06-06 13:57:23|8.451452|-13.271007;6|2015-06-06 13:58:23|8.451722|-13.271709;7|2015-06-06 13:59:23|8.451945|-13.272431;8|2015-06-06 14:00:23|8.452556|-13.272409;9|2015-06-06 14:01:23|8.453195|-13.272527;10|2015-06-06 14:02:23|8.453946|-13.272457;11|2015-06-06 14:03:23|8.454697|-13.272393;12|2015-06-06 14:04:23|8.455269|-13.272262;13|2015-06-06 14:05:23|8.454926|-13.271588;14|2015-06-06 14:06:23|8.454561|-13.270925;15|2015-06-06 14:07:23|8.454197|-13.270262;16|2015-06-06 14:08:23|8.453850|-13.269590;17|2015-06-06 14:09:23|8.453517|-13.268925;18|2015-06-06 14:10:23|8.453250|-13.268217;19|2015-06-06 14:11:23|8.453030|-13.267493;20|2015-06-06 14:12:23|8.452848|-13.266758;21|2015-06-06 14:13:23|8.452661|-13.266024;22|2015-06-06 14:14:23|8.452476|-13.265290;23|2015-06-06 14:15:23|8.452289|-13.264556;24|2015-06-06 14:16:23|8.452559|-13.264011;25|2015-06-06 14:17:23|8.453195|-13.263606;26|2015-06-06 14:18:23|8.453765|-13.263115;27|2015-06-06 14:19:23|8.454319|-13.262621;28|2015-06-06 14:20:23|8.454980|-13.262256;29|2015-06-06 14:21:23|8.455488|-13.261705;30|2015-06-06 14:22:23|8.456012|-13.261521;31|2015-06-06 14:23:23|8.456582|-13.261529;32|2015-06-06 14:24:23|8.457157|-13.261370;33|2015-06-06 14:25:23|8.457766|-13.261773;34|2015-06-06 14:26:23|8.458187|-13.262398;35|2015-06-06 14:27:23|8.458720|-13.261867;36|2015-06-06 14:28:24|8.459279|-13.261366

422a837717,2015-06-06,3,STAY,STAY,0.000,34295.000,14:28:24,23:59:59,1,1|2015-06-06 14:28:24|8.459106|-13.261265

Figure 7.11: Trajectory check (internal use)
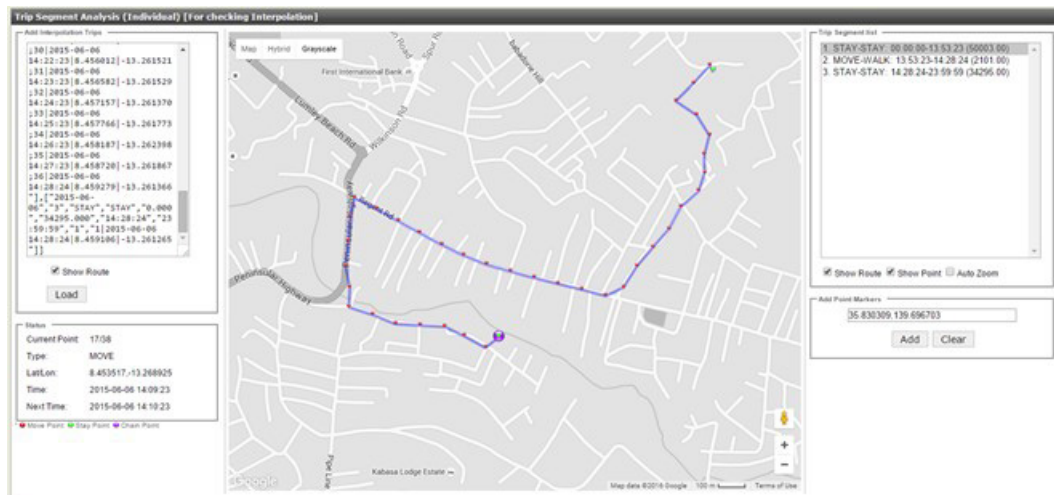


Source: ITU

Table 1 gives sample data of trajectory data that includes basic terminology and required information and format used in trajectory data mining.

**Data format**

Interpolation results are packed as trip data separated for each user and date. Output results contain 11 columns including user ID, date, trip sequence, mobility type, transportation mode, total distance, total time, start time, end time, total points and point lists. Output will be exported to a CSV file (comma-separated values), and values of each column is given.

## Table 1: Sample CSV file data

| Output results | CSV file column values |
|---|---|
| 1  User Id | • Column name: UID<br>• Unique for each device<br>• Encrypted using Hash function, irreversible |
| 2  Date | • Column name: DATE<br>• Date format: yyyy-MM-dd<br>• Example: 2015-12-31 |
| 3  Trip Sequence | • Column name: TRIP_SEQUENCE<br>• Order of sub trip in a day, start from 1 |
| 4  Mobility Type | • Column name: MOBILITY_TYPE<br>• Value: STAY or MOVE |
| 5  Transportation Mode | • Column name: TRANSPORT_MODE<br>• Indicate mode of transportation of corresponding sub trip<br>• Value: STAY, WALK, CAR |
| 6  Total Distance | • Column name: TOTAL_DISTANCE<br>• Total travel distance of sub trip in meter |
| 7  Total Time | • Column name: TOTAL_TIME<br>• Total travel time of sub trip in second |
| 8  Start Time | • Column name: START_TIME<br>• Indicate start time of sub trip<br>• Format: HH24:mm:ss<br>• Example: 23:20:00 |
| 9  End Time | • Column name: END_TIME<br>• Indicate end time of sub trip<br>• Format: HH24:mm:ss<br>• Example: 23:20:00 |
| 10  Total Points | • Column name: TOTAL_POINTS<br>• Indicate total number of point data in sub trip |
| 11  Point lists | • Column name: POINT_LISTS<br>• List of point data in sub trip<br>• Format: No.|time|latitude|longitude;<br>• No. is order number start from 1.<br>• Time: yyyy-MM-dd HH24:mm:ss<br>• Latitude and longitude in decimal format.<br>• Each point is separated by ";"<br>• Example: 1|2015-06-06 13:53:23|6.373743|-10.772951 |

Note: In the present project, the Move segment interpolation is set to 1 minute intervals.

## 7.6    Hadoop system for data processing

CDR data forms a very large dataset that ordinary computers or database systems are unable to process within an acceptable time frame, which is why the Hadoop system was introduced as main system for data processing for this project. Hadoop is an open source cloud computing software framework for data intensive and distributed application. There are many services and framework under Hadoop umbrella; however, in this project, Hadoop Distributed File System (HDFS) and Hive were used. To setup and use Hadoop for full operation mode, it required to run five components: NameNode, DataNodes, Secondary NameNode (SNN), JobTracker, and TaskTrackers. NameNode is the bookkeeper of HDFS; it keeps track of how your files are broken down into file blocks, which nodes store those blocks, and the overall health of the distributed filesystem. DataNodes are the workhorses of the filesystem. They store and retrieve blocks when they are told to (by clients or the namenode), and they report back to the namenode periodically with lists of blocks that they are storing. Secondary NameNode (SNN) is an assistant daemon for monitoring the state of the cluster HDFS and the SNN help snapshots NameNode to help minimize the downtime and loss of data. JobTracker is the liaison between your application and Hadoop. Once you submit your code to your cluster, the JobTracker determines the execution plan by determining which files to process, assigns nodes to different tasks, and monitors all tasks as they are running. TaskTrackers are responsible for executing the individual tasks that the JobTracker assigns and manages the execution of individual tasks on each node.

The experiment consisted of five computers with the same specification: Xeon 2.6 GHz, 8 GB memory, and 2x2 TB disk with CentOS 6.0 64-bit for database system, and library-based application. PostgreSQL 9.0.6 with PostGIS 1.5.3 was installed in the system. One computer runs as NameNode and the others as DataNodes and TaskNodes. Figure 7.12 illustrates the system used for this project: the Hadoop had 32 cores, 32 GB memory and 16 TB storages and could run up to 28 tasks at the same time. The version of Hadoop was 0.20.2, the version of Hive was 0.8.0, and the version of JTS was 1.12.

Figure 7.12: Sample Hadoop Cluster
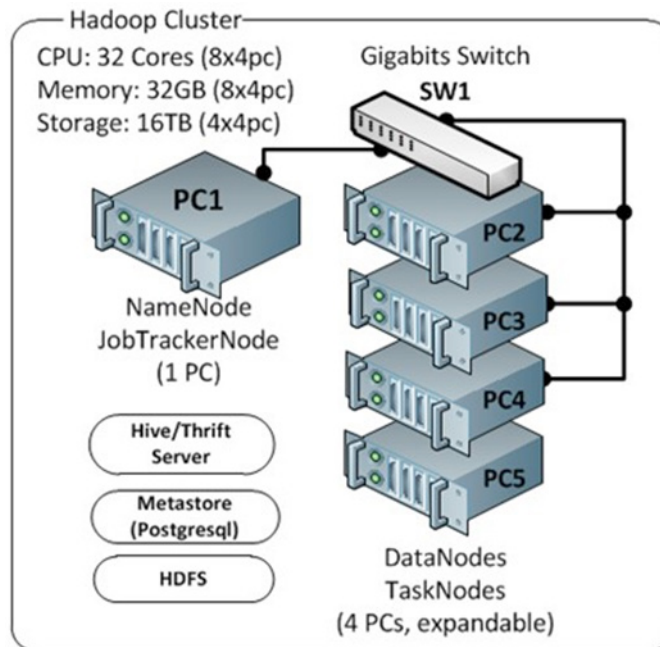


Source: ITU

Hive is a data warehousing package built on top of Hadoop, and users should be familiar and comfortable with using SQL to carry out ad-hoc queries, summarizations, and data analysis. Web GUI (interface) and Java Database Connectivity (JDBC) are provided for interacting with Hive by issuing queries in a SQL-like language called HiveQL.

## 7.7    Dynamic population estimation

Knowing the population distribution rather than the distribution of mobile phone subscribers in any given area during the daytime hours or at any time slice is crucial to calculating movement trajectories and patterns, and the challenge is how to:

1.    magnify CDR data or the number of subscribers to the real population with population census; and

2.    represent trajectory of people or where and when people are located. The magnification process is described in Figure 7.13.

In this process, the CDR data is first used to extract home locations of mobile phone users in terms of cell tower locations. Extracted home locations of mobile phone users are reallocated using POIs and complementary land-use and house distribution data around each cell tower. Then the reallocated mobile phone users are aggregated by each census zone (tracts) of population census. The magnification factor, describing how many people a single mobile phone user represents, can be computed by comparing real population of a census zone with the aggregated number of mobile phone users. For example, at a certain census zone, one mobile phone user may represent ten people. The magnification factor is also used to calculate dynamic population at each time period.

Figure 7.13: Home location identification with population magnification
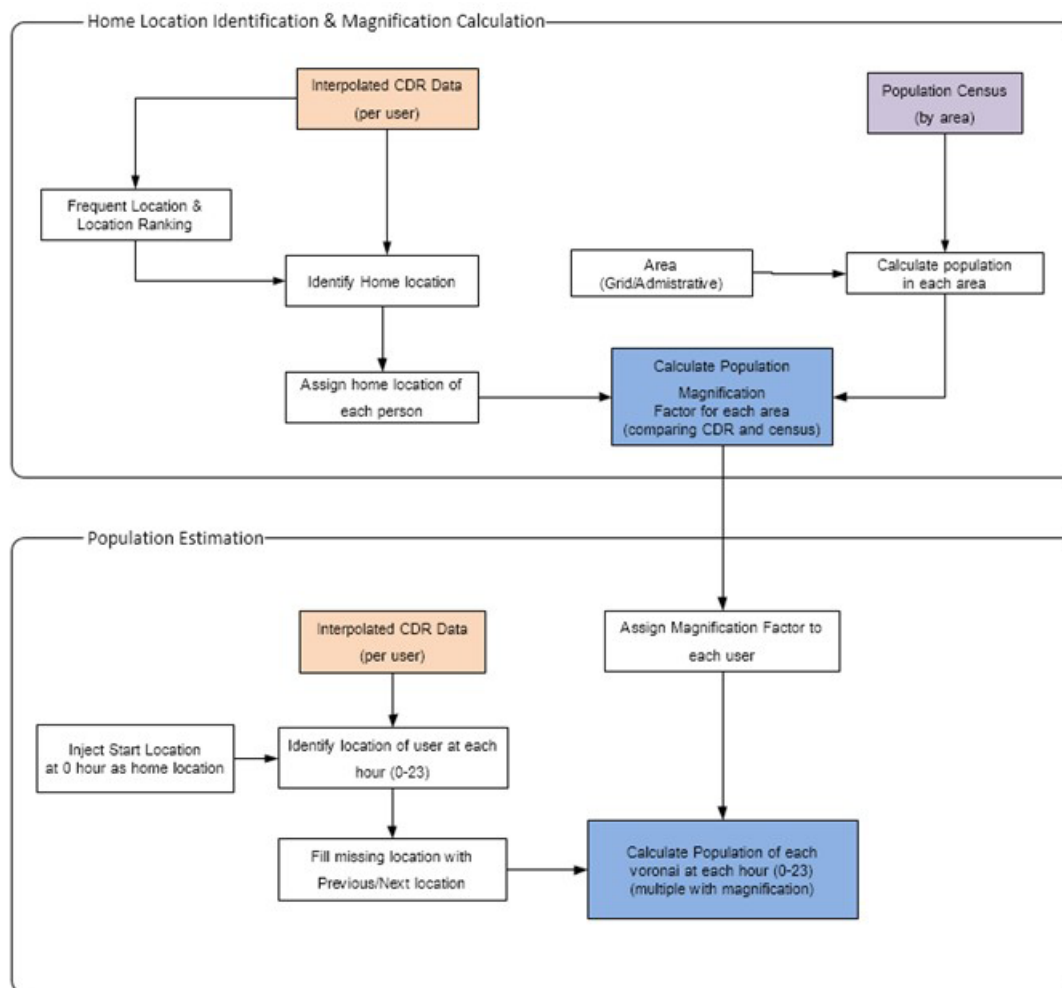


Source: ITU

Dynamic day time population (ambient population), unlike residential population, takes into account the movements of individuals through a given area (Figure 7.15). For instance, no individuals live on a main road, but they do travel on it from time to time. A resident population would show no one living on the road, whereas the ambient population would indicate the presence of individuals based on factors specific to the road.

Through CDR analysis, home locations and the other stay points, movement routes, and timing of mobile phone users are estimated to fully represent the trajectory, together with the magnification factors. Dynamic population at any time slice at any location (grid-cell) can be computed.

Figure 7.14: On a daily based data aggregation for dynamic population estimation
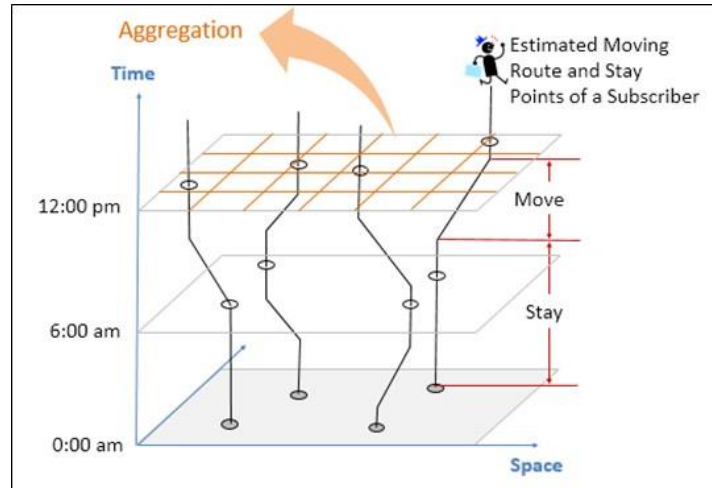


Source: ITU

## 7.8    Mobile phone and SIM card cloning

Mobile phone cloning[7] is a technique used to copy private data (identity theft) from one mobile phone onto another phone, which then becomes the exact replica of the original phone. Consequently, while calls can be made from and received by both phones, only the legal subscriber is charged for the bill as the mobile network operator does not have a way to differentiate between the legitimate phone and the 'cloned' phone. So when a subscriber is surprised by an enormous bill, there is a chance that the phone has been cloned. Many mobile phones, be it GSM or CDMA, run the risk of being cloned.

There are several kinds of user specific identity information depending on mobile network system. For GSM network, every handset has a unique IMEI number (International Mobile Equipment Identifier) and it needs a SIM card (subscriber identification module) inserted to be able to operate. SIM cards can be cloned and put in other handsets, and because inexpensive handsets can often have the same IMEI (to reduce production costs), cloning of SIM cards is generating a serious fraud problem. For CDMA networks, every handset has its unique ESN number (electronic serial number) and MIN (mobile identification number) that are burned into the chip in the handset, and cloning of this type of handset involves replacing these identity numbers.

Cloning can be detected from the duplication of identity, where the mobile phone use is transferred from one place to another place at impossible, or most doubtfully speeds (velocity trap). For example, if a call is first made in Monrovia, and five minutes later, another call is made but this time in Greenville, about 300 km away, there must be two phones with the same identity on the network. Mobile network operator reactions to mobile cloning once it is detected is often to shut them all off so that the real customer contacts operator customer services to complain. In order to detect mobile cloning,

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[7]    https://www.movzio.com/howto/cell-phone-cloning/

mobile network operators can analyse call detail records. Identity number, start call-time and cell tower location are significant keys to identify cloning behaviour. However, such analysis requires the processing of a lot of data, which requires high performance systems.

In this project, attempts were made to detect mobile cloning in GSM networks from CDRs using *big data* technology and spatial processing, and the results are expressed in the section 8.5 of this report.

# 8 Analysis results

## 8.1 Mobile phone user population by district

This section discusses the population distribution extracted from call detail record data. Figure 8.1 shows the number of mobile phone users computed from CDR data and population data by district level, which confirmed that the population of mobile phone users across districts correlates strongly with that of real populations obtained from census data. Figure 8.2 presents the most visited locations by the people living in Freetown. It revealed that Western Rural, Port Loko, and Bo are the most visited locations. Figure 8.3 shows the second most visited locations by the same people, which is Port Loko.

Figure 8.1: Mobile phone user population by district
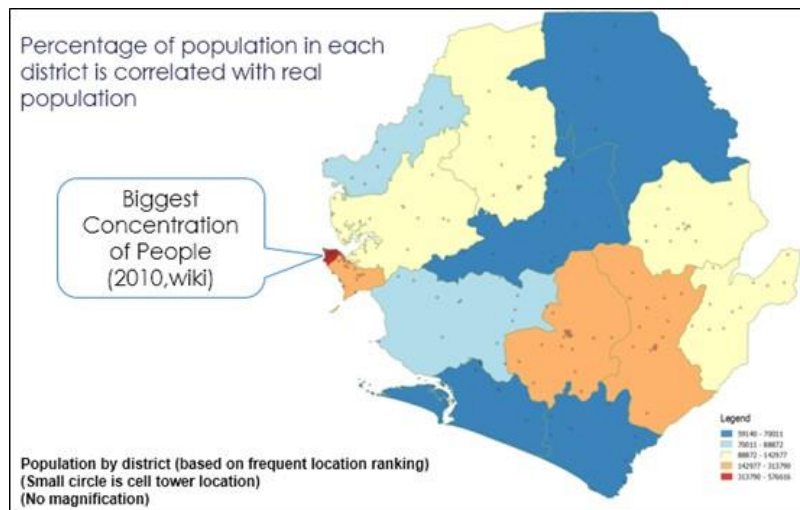


Source: ITU

Figure 8.2: Freetown, the most visited locations
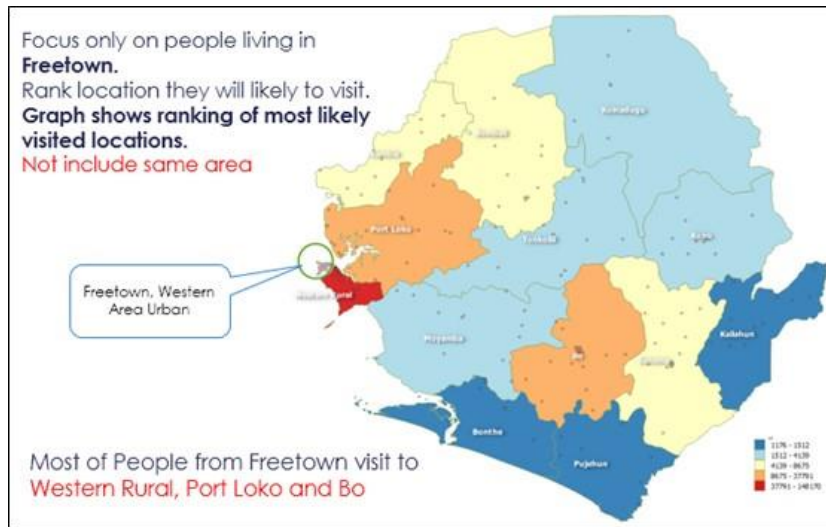


Source: ITU

Figure 8.3: Freetown, the second most visited location
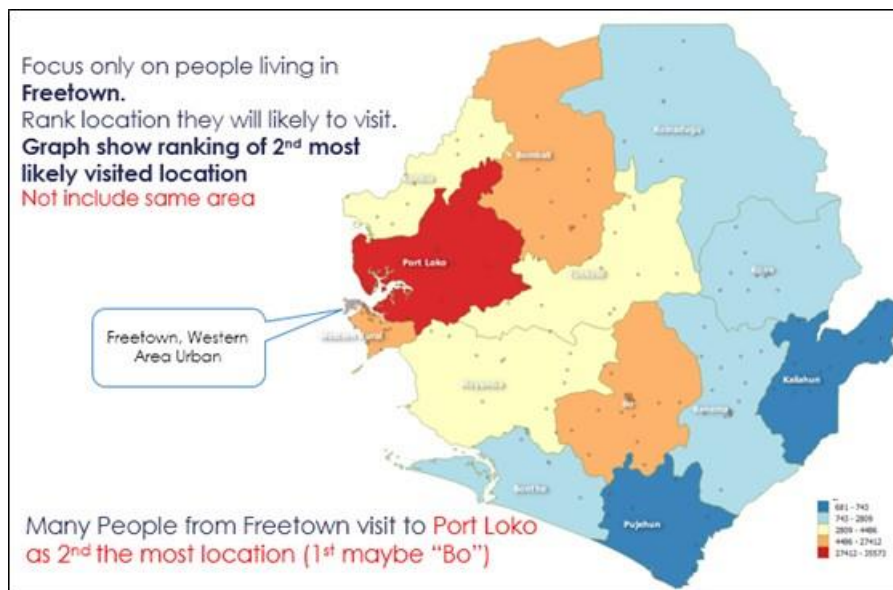


Source: ITU

## 8.2 People flow from interpolation result

This section provides the visualization of interpolated CDR data through the process described in Section 7. Figure 8.4 shows the people flow reconstructed from interpolation results at 6:00 a.m., 9 a.m., 12 p.m., and 3 p.m. that shows less people in Freetown in the early morning hours, while more people are observed in the afternoon. Interpolation results contain 11 columns including user id, date, trip sequence, mobility type, transportation mode, total distance, total time, start time, end time, total points and point lists. CDR data was interpolated at one-minute intervals.

Figure 8.4: People flow from interpolation result by time
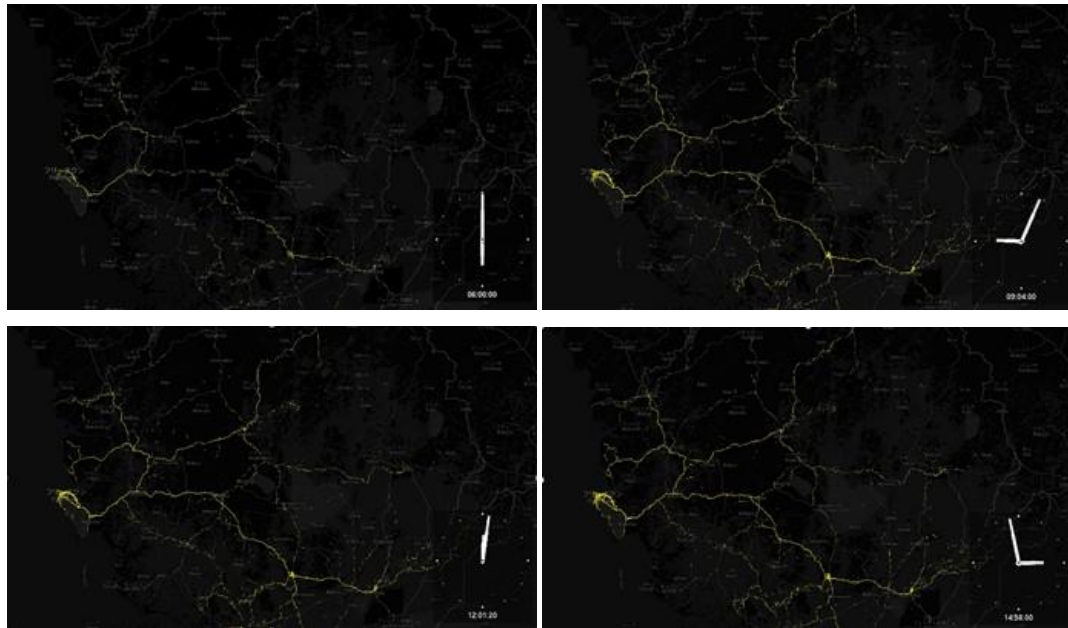


Source: ITU

## 8.3    Spread of people originated from a town (in 48 hours)

Figure 8.5 shows how people in a town spread at three-hourly interval over a 48 hour period. In a situation, where incidents are observed in the town, it is clear how quickly the communicable disease could spread due to the mobility of people.

Figure 8.5: Flow from a specific town (over 48 hours)
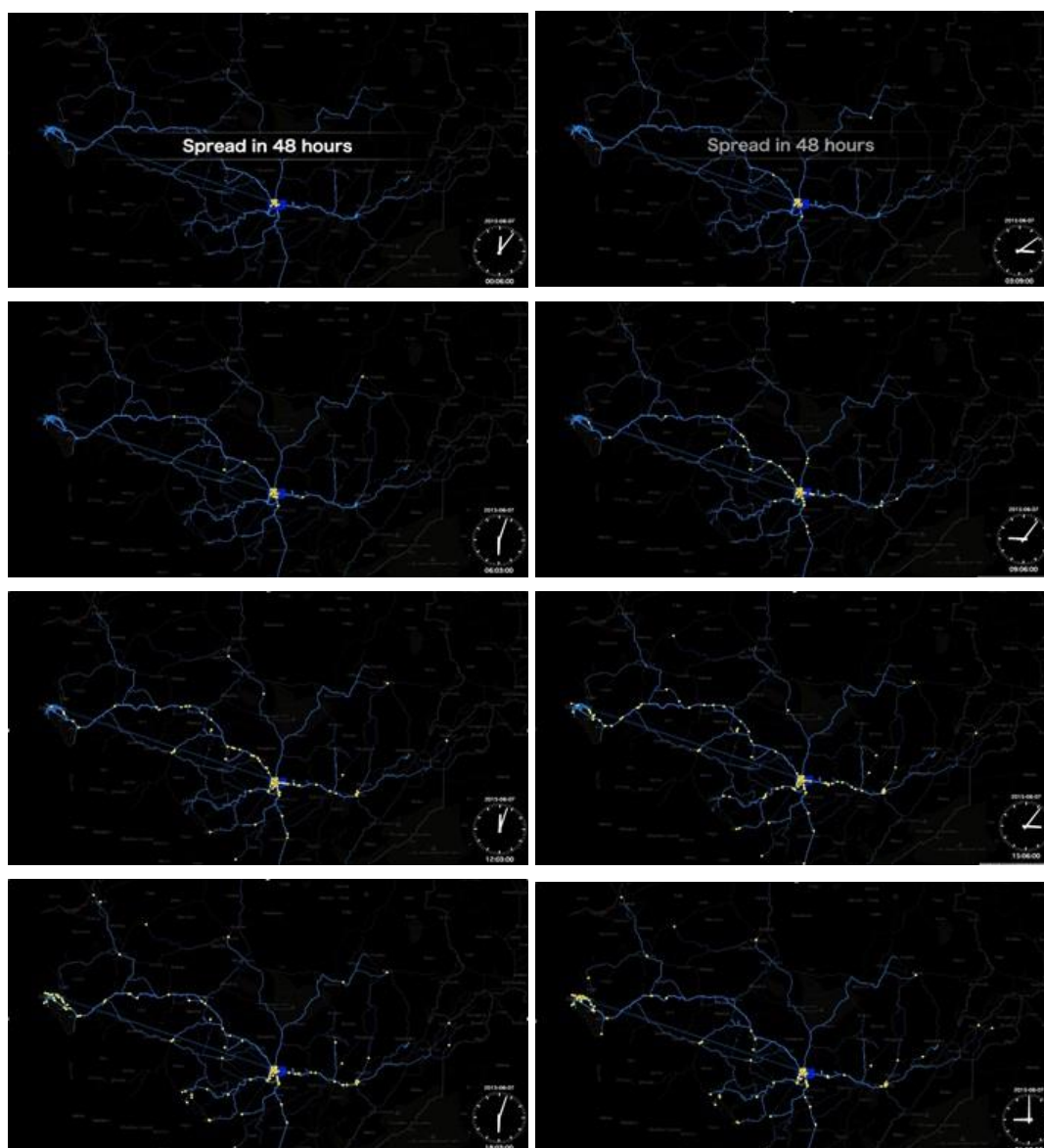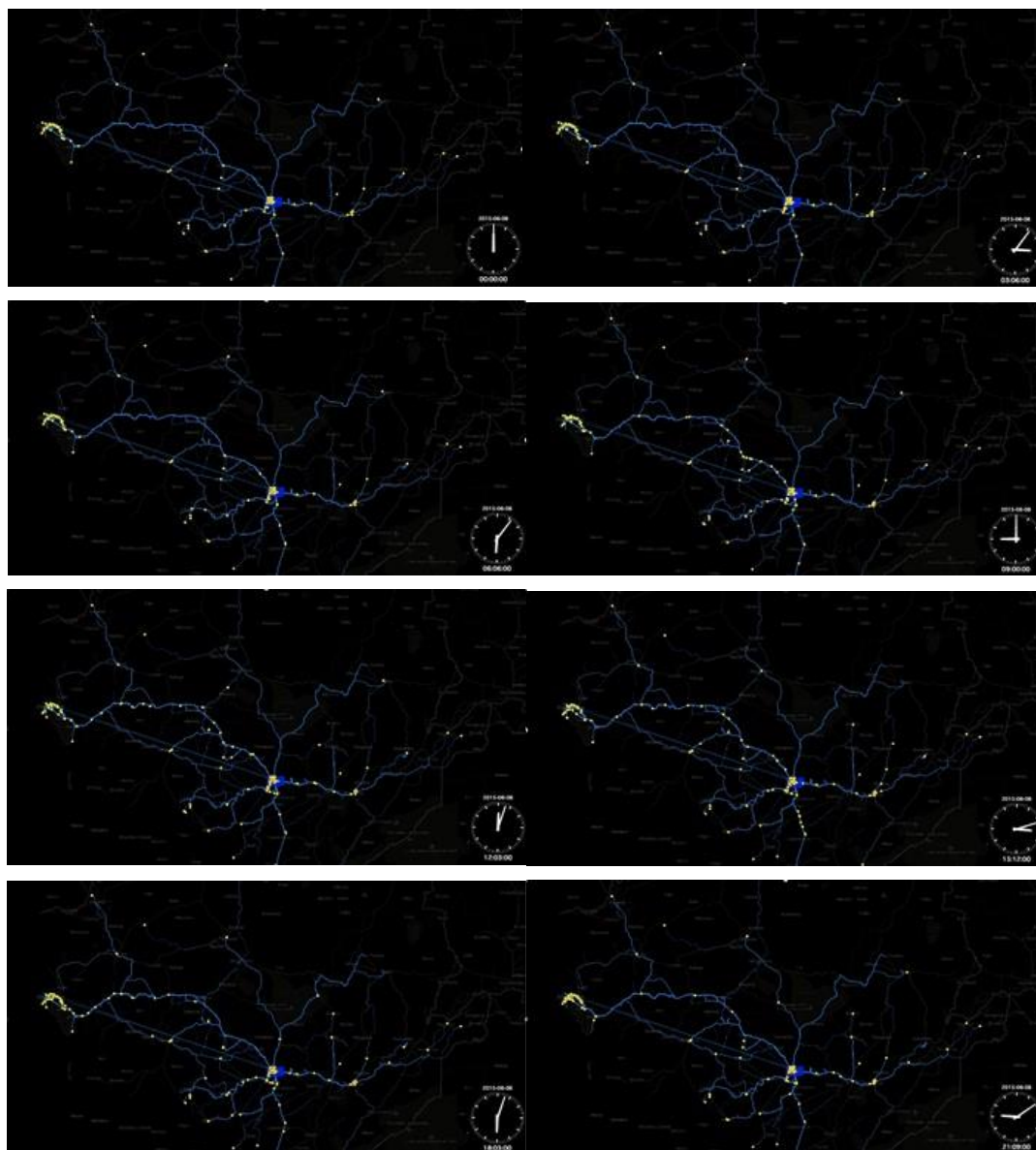
Source: ITU

## 8.4     Tracing people who passed through a hazard area

Figures 8.6 and 8.7 show the distribution of people who passed/did not pass through a hazard area. By overlaying the hazard area with the mobility estimates from CDR data, the larger-yellow dots inside blue polygons indicate those who passed through, and smaller dots outside the polygons indicate those who did not pass through the hazard area. As observed in 8.5, if mobility is high even for 48 hours, this poses a potential threat to a very large area in an Ebola epidemic.

Figure 8.6: Trace of people who passed through a hazard area
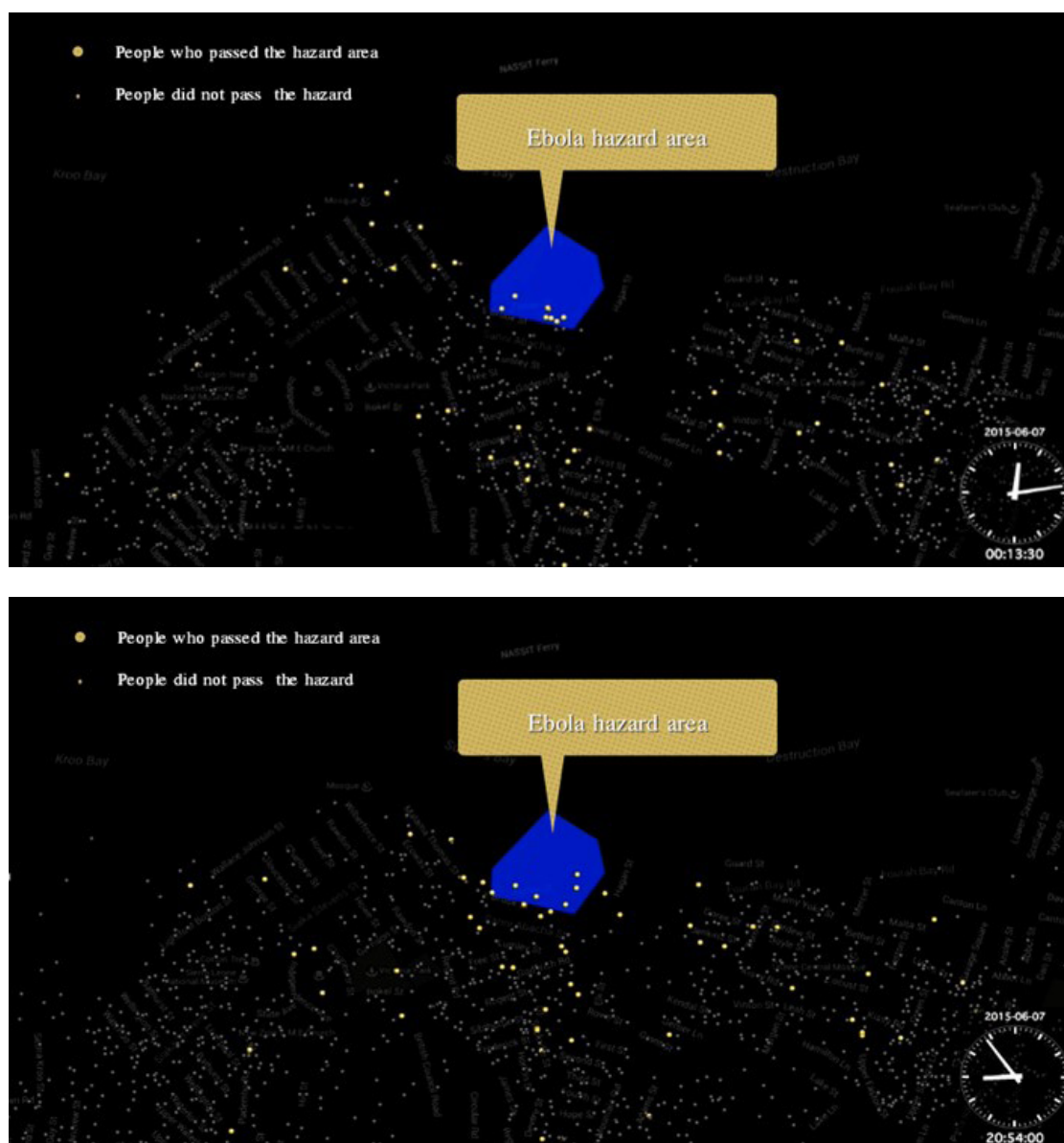


Source: ITU

Figure 8.7: Where did they go in the next 48 hours?
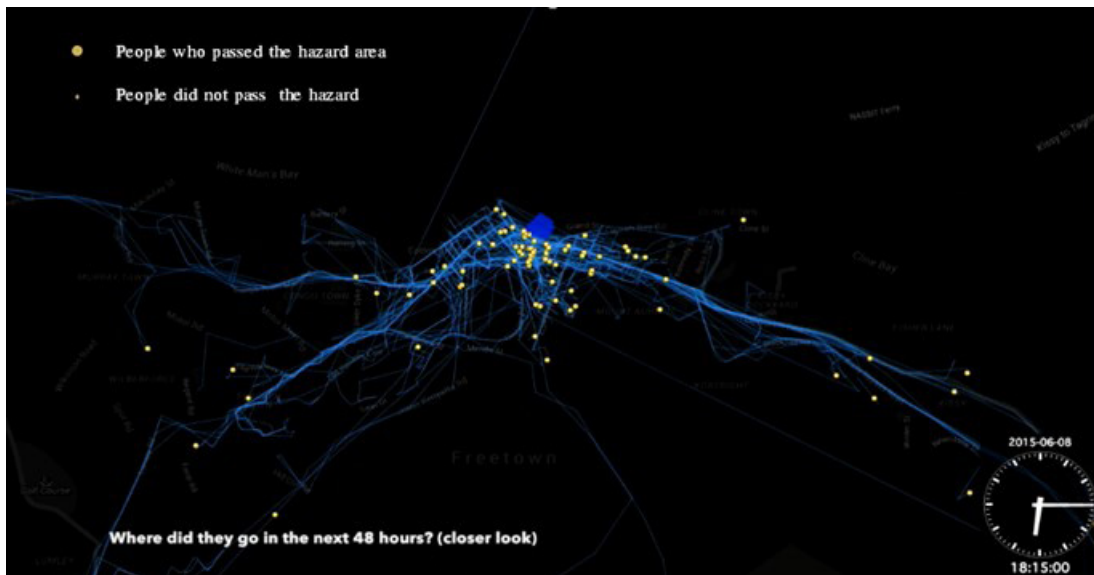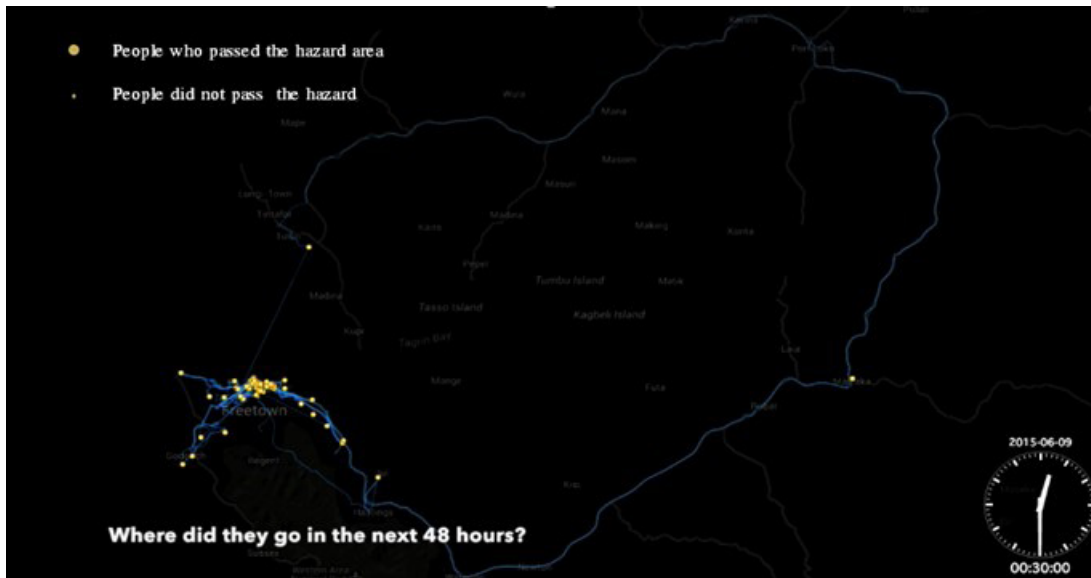




## 8.5    Attempt to detect cloning phones and SIM cards

As mentioned in section 7.8 above, CDR data can be used to detect cloning. Figure 8.8 shows the proportion of IMEIs (a single mobile phone record in CDR data) that are originating call records from multiple IMSI or SIMs. As described in Figure 8.8 (upper), in the CDR data used for this project, the number of unique IDs according to IMSI is almost 1.5 times the number of unique IDs according to IMEI, and about 8 000 unique mobile handset numbers were used with more than seven sim cards (IMSI) indicating probable cases of mobile cloning. For this project, IMEI used with more than seven IMSI were filtered out.

Figure 8.8: Cloning detection (Cloning IMEI)



**Attempt to detect cloning Mobile Handset (GSM) using Big Data technology and Spatial processing**

- Clone IMEI (same IMEI, multiple IMSI)
  - % of IMEI found use with 2 or more IMSI (SIM)

FOUND DUPLICATE IMEI

| Call Detail Records | |
|---|---|
| Total records | 560,145,533 |
| File size | 162 GB |
| Total Days | 59 |
| Unique Id (IMSI) | 1,504,092 |
| Unique Id (IMEI) | 2,286,265 |
| Unique Location | 971 |

- Focus only on "found IMSI > 7", order call by call time
- Check different IMSI, spatial distance, time different
- Fast process on Hadoop Cloud Platform with spatial support. (<1hr)



- Clone IMEI (same IMEI, multiple IMSI)
  - Focus only on "found IMSI > 7", order call by call time
  - Check different IMSI, spatial distance, time different
- Highlight
  - Location different with far distance
  - 1,278 IMEI were identified as possible clone IMEI

| IMEI | TIME | PREV_TIME | CALL DURATION | SITE | PREV_SITE | IMSI | PREV_IMSI | DISTANCE (km) | TIME_DIFF (min) |
|---|---|---|---|---|---|---|---|---|---|
| c0a7 | 2015-06-01 10:15:22 | 2015-06-01 10:10:08 | 0 | CT0030 | CT0025 | 27cc2679 | 4e3f01c1 | 78.04 | 5.23 |
| c0a7 | 2015-06-01 16:37:37 | 2015-06-01 16:32:44 | 122 | CT0118 | CT0030 | 4e3f01c1 | 27cc2679 | 79.42 | 4.88 |
| c0a7 | 2015-06-04 17:20:43 | 2015-06-04 17:18:32 | 14 | CT0030 | CT0103 | 27cc2679 | 4e3f01c1 | 78.85 | 2.18 |
| c0a7 | 2015-06-04 19:53:19 | 2015-06-04 19:46:43 | 73 | CT0030 | CT0025 | 27cc2679 | 4e3f01c1 | 78.04 | 6.6 |
| c0a7 | 2015-06-04 19:55:43 | 2015-06-04 19:53:19 | 13 | CT0025 | CT0030 | 4e3f01c1 | 27cc2679 | 78.04 | 2.4 |
| c0a7 | 2015-06-07 13:21:36 | 2015-06-07 13:21:14 | 85 | CT0234 | CT0079 | 27cc2679 | f228e374 | 10.69 | 0.37 |
| c0a7 | 2015-06-08 13:07:33 | 2015-06-08 13:05:36 | 17 | CT0030 | CT0257 | 27cc2679 | 4e3f01c1 | 78.31 | 1.95 |
| c0a7 | 2015-06-08 13:13:40 | 2015-06-08 13:07:33 | 0 | CT0140 | CT0030 | 4e3f01c1 | 27cc2679 | 78.47 | 6.12 |
| c0a7 | 2015-06-08 22:16:47 | 2015-06-08 22:14:16 | 0 | CT0030 | CT0025 | 27cc2679 | 4e3f01c1 | 78.04 | 2.52 |
| c0a7 | 2015-06-11 16:53:54 | 2015-06-11 16:48:19 | 52 | CT0030 | CT0201 | 27cc2679 | 4e3f01c1 | 80.15 | 5.58 |
| c0a7 | 2015-06-13 09:18:54 | 2015-06-13 09:16:45 | 0 | CT0079 | CT0030 | f228e374 | 27cc2679 | 83.30 | 2.15 |
| c0a7 | 2015-06-17 11:09:36 | 2015-06-17 11:09:03 | 40 | CT0030 | CT0005 | 27cc2679 | 01aaf098 | 79.98 | 0.55 |
| c0a7 | 2015-06-17 17:57:20 | 2015-06-17 17:47:21 | 51 | CT0180 | CT0030 | f228e374 | 27cc2679 | 82.22 | 9.98 |

Source: ITU

Figure 8.8 (lower) shows two call records from identical IMEI with different IMSIs. Their locations are too distant to have made one call within a minute of making a second call. Processing CDR data with IMSI and IMEI can detect cloning and this method was used for the purposes of this project.

Figure 8.9 (upper) shows an attempt to detect sim card cloning: there are more than 1.2 million unique sim cards that are being used in at least two handsets over the same period, and more than 65 000 sim cards were being used in seven handsets, which can probably be attributed to sim card cloning. For this project, the focus and filters were on IMSI found on more than seven IMEI.

Figure 8.9: Cloning detection (Cloning IMSI)



**Clone IMSI (SIM)**
- Bills go to legitimate mobile subscriber (Fraud)
- % of IMSI found use with 2 or more IMEI (Handset)

FOUND DUPLICATE IMSI

**Clone IMSI (SIM)**
- Focus only on "found IMEI > 7", order call by call time
- Check different IMSI, spatial distance, time different
- Highlight
  - location different with far distance
  - 612 IMSI were identified as possible clone IMSI (clone sim)

| IMSI | TIME | PREV_TIME | CALL DURATION | SITE | PREV_SITE | IMEI | PREV_IMEI | DISTANCE (km) | TIME_DIFF (min) |
|------|------|-----------|---------------|------|-----------|------|-----------|---------------|-----------------|
| 7a5179eb | 2015-07-31 11:39:25 | 2015-07-31 11:35:18 | 124 | CT0126 | CT0002 | f89d17a8 | 37ec8bc4 | 80.06 | 4.12 |
| b77b32e6 | 2015-06-16 12:57:26 | 2015-06-16 12:53:29 | 0 | CT0096 | CT0159 | 8add33b9 | 7f87a01a | 48.73 | 3.95 |
| 4bdb9750 | 2015-06-27 21:41:56 | 2015-06-27 21:37:44 | 0 | CT0165 | CT0104 | f8a649c9 | cf07a6fc | 48.43 | 4.2 |
| d2b36a24 | 2015-06-05 13:41:40 | 2015-06-05 13:38:45 | 0 | CT0242 | CT0027 | e90a49e8 | db5ee823 | 45.58 | 2.92 |
| d2b36a24 | 2015-06-05 13:46:43 | 2015-06-05 13:41:59 | 14 | CT0027 | CT0242 | db5ee823 | e90a49e8 | 45.58 | 4.73 |
| 4d60bc53 | 2015-07-12 17:30:38 | 2015-07-12 17:27:54 | 0 | CT0087 | CT0027 | 86f82e75 | 2500278d | 45.47 | 2.73 |
| 8dc9a851 | 2015-06-01 08:57:01 | 2015-06-01 08:54:07 | 0 | CT0027 | CT0087 | 521ad568 | e716f39f | 45.47 | 2.9 |
| b70554c6 | 2015-07-31 09:01:11 | 2015-07-31 08:58:12 | 9 | CT0027 | CT0087 | d3c57f7a | 6fe9c15a | 45.47 | 2.98 |
| b70554c6 | 2015-07-31 09:03:20 | 2015-07-31 09:01:11 | 0 | CT0087 | CT0027 | 6fe9c15a | d3c57f7a | 45.47 | 2.15 |
| ebb11fc5 | 2015-06-18 08:51:19 | 2015-06-18 08:47:35 | 1 | CT0109 | CT0122 | 1183da49 | b658768e | 44.98 | 3.73 |
| ca8a5934 | 2015-06-18 16:42:32 | 2015-06-18 16:38:41 | 7 | CT0165 | CT0046 | 46a83d0c | de1c4280 | 40.99 | 3.85 |

Source: ITU

Figure 8.9 (lower) shows the record (highlight) from identical IMSI with different IMEIs. Their locations are too distant for two calls to have been made with the same sim card. From this series of data, 612 IMSIs were identified as possible clones (sim card cloning).

## 8.6    Transboundary analysis

This section discusses the result of transboundary movement analysis. It demonstrates how CDR data can be used to understanding population movement in neighbouring countries. There are two types of transboundary population movement:

- **inbound** transboundary movement is when a person returns to the home country from a neighbouring country; and

- **outbound** transboundary movement is when a person leaves the home country to visit a neighbouring country.

Transboundary analysis uses the IMEI as a key, and CDR data of Guinea and Liberia were merged with Sierra Leone to trace transboundary movements. After the merge, each user's home country is identified based on the frequency of called locations.

### 8.6.1    CDR Data set with transboundary IMEI

Figure 8.10 illustrates the transboundary information obtained from CDR data including IMEI, which indicated the source of mobile phones being used in neighbouring countries. Only Airtel provided CDR data with the hashed IMEI code. So, there is a possibility that different movement trends were missed, including Africell and Smart subscribers.

Figure 8.10: CDR Data set with Transboundary IMEI of Sierra Leone

| NO | Country | Operator | CDR Data Info | | | | Transboundary (IMEI) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Data Size | Data Period | Total record | IMEI | Liberia | Guinea | Liberia & Guinea |
| 1 | Sierra Leone | Africell | 70 GB | June,July 2015 | 696,386,153 | - | - | - | |
| 2 | | Airtel | 87 GB | June,July 2015 (No June 2-3) | 560,145,533 | 2,286,265 | 30,542 | 51,871 | 2,845 |
| 3 | | Smart | 272 MB | June,July 2015 | 2,179,595 | - | - | - | |

Source: ITU

### 8.6.2    Daily activity statistics

Figure 8.11 and 8.12 illustrate the daily call activity of Sierra Leone based mobile phone users in neighbouring countries (Guinea and Liberia). Daily call activity averaged just under 95 000 in Guinea and 122 000 in Liberia indicating that Sierra Leone subscribers are more likely go to Liberia than to Guinea.

## Figure 8.11: Daily call activity of Sierra Leone mobile users visiting Guinea

| MIN | MAX | AVG | Total Points |
|---|---|---|---|
| 40,086.00 | 137,579.00 | 94,441.25 | 5,760,916.00 |
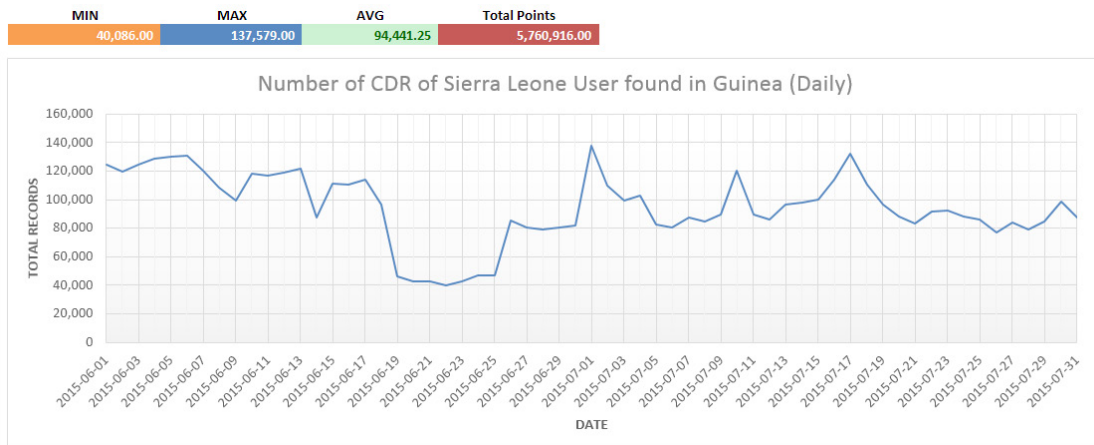


Source: ITU

## Figure 8.12: Daily call activity of Sierra Leone mobile users visiting Liberia

| MIN | MAX | AVG | Total Points |
|---|---|---|---|
| 1,030.00 | 145,926.00 | 121,514.77 | 7,412,401.00 |
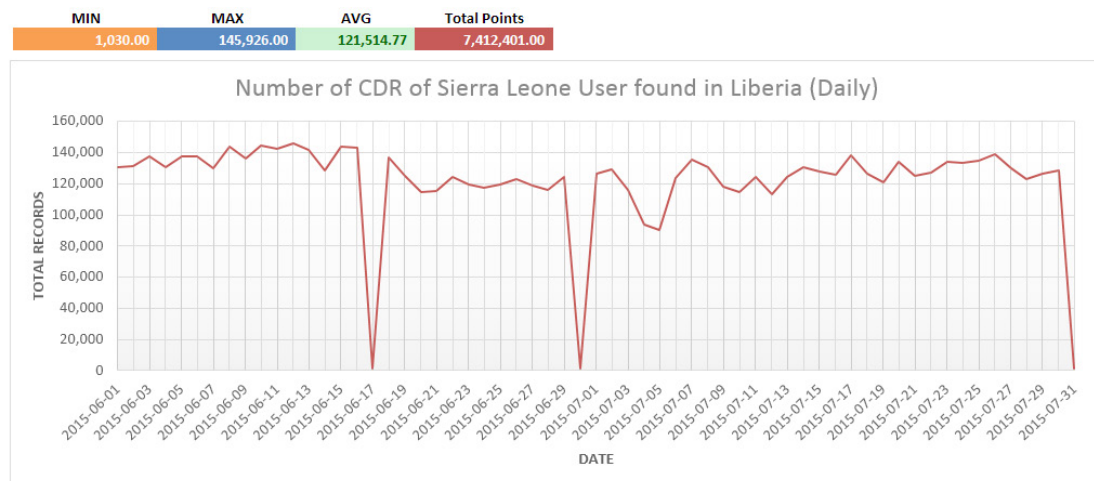


Source: ITU

## Figure 8.13: Daily unique users of Sierra Leone mobile users visiting Guinea

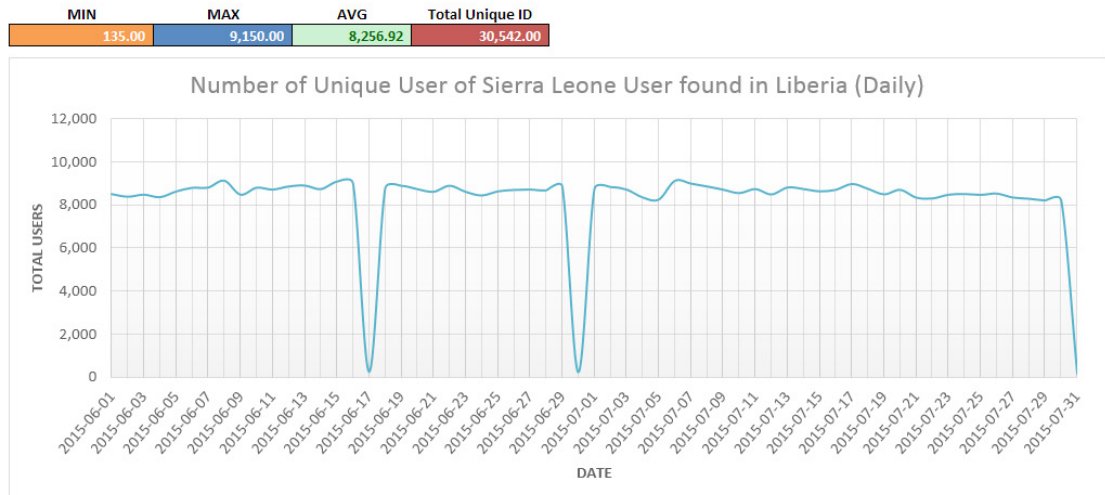| MIN | MAX | AVG | Total Unique ID |
|---|---|---|---|
| 3,996.00 | 9,835.00 | 7,801.56 | 44,037.00 |
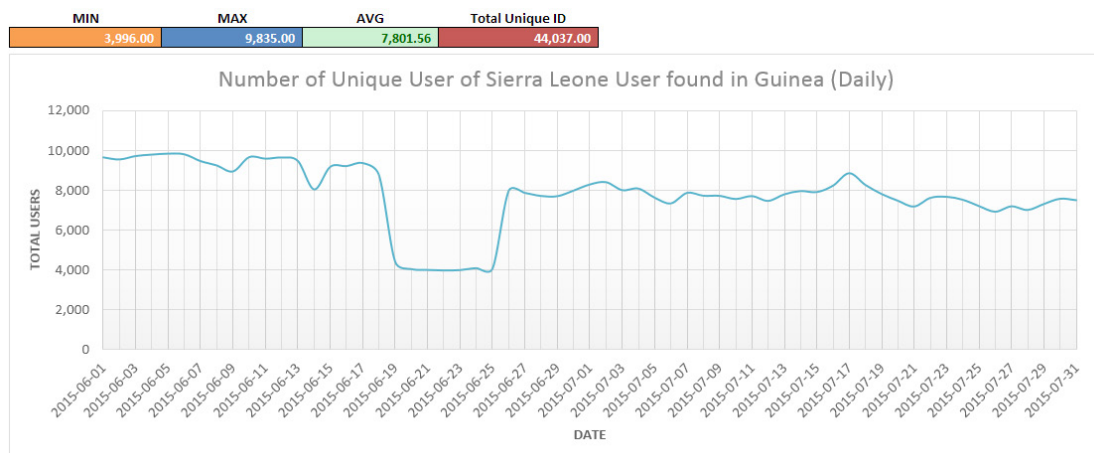


Source: ITU

Figures 8.13 and 8.14 illustrate the number of daily unique Sierra Leone mobile users in neighbouring countries including Guinea and Liberia. Daily activity reached nearly 8 000 users for in Guinea and 8 300 users for in Liberia.

Figure 8.14: Daily unique users of Sierra Leone mobile users in Liberia

| MIN | MAX | AVG | Total Unique ID |
|---|---|---|---|
| 135.00 | 9,150.00 | 8,256.92 | 30,542.00 |

Number of Unique User of Sierra Leone User found in Liberia (Daily)

Source: ITU

## 8.6.3   Inbound transboundary footprint

Figure 8.15 illustrates footprints of inbound transboundary movements from Guinea and Liberia to Sierra Leone. Footprints were calculated from mobile usage activity of mobile users, which indicated locations where users passed through and where they have high mobile usage activities. Figure 8.15 clearly shows that the most visited district is Western Urban, which includes the capital city of Sierra Leone. Second and third rank for most frequently visited locations are Bo and Western Rural district.

Figure 8.15: Footprint of mobile users from Guinea and Liberia visiting Sierra Leone
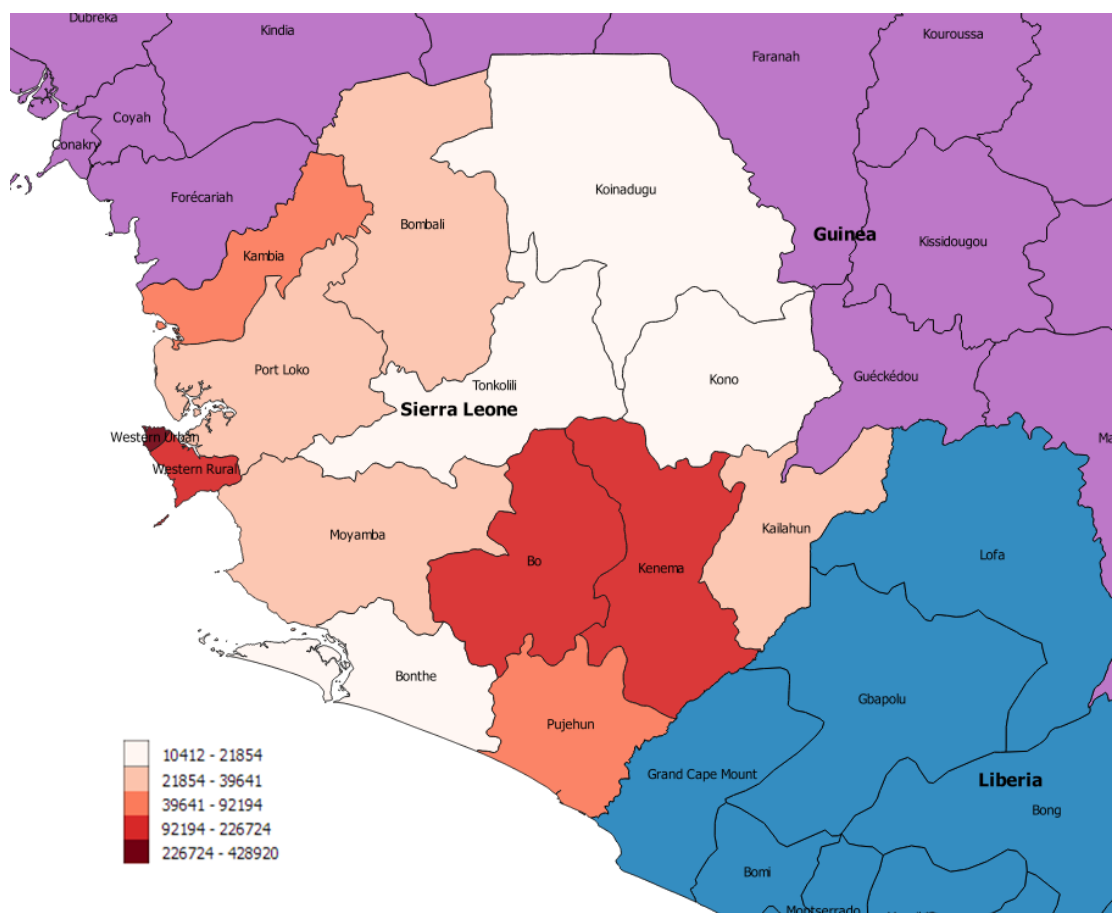


Source: ITU

Figure 8.16 illustrates the transboundary population of mobile users from Guinea and Liberia who visited Sierra Leone. Population was calculated from the total number of unique mobile users who visited Sierra Leone. It shows that the most visited district by inbound transboundary population to Sierra Leone are Pujehun, Kambia and Kailahun. Additionally, Kambia seems to be main boundary district for crossing from Guinea to Sierra Leone. For Liberia, Pujehun seems to be main boundary district.

Figure 8.16: Population of mobile users from Guinea and Liberia visiting Sierra Leone
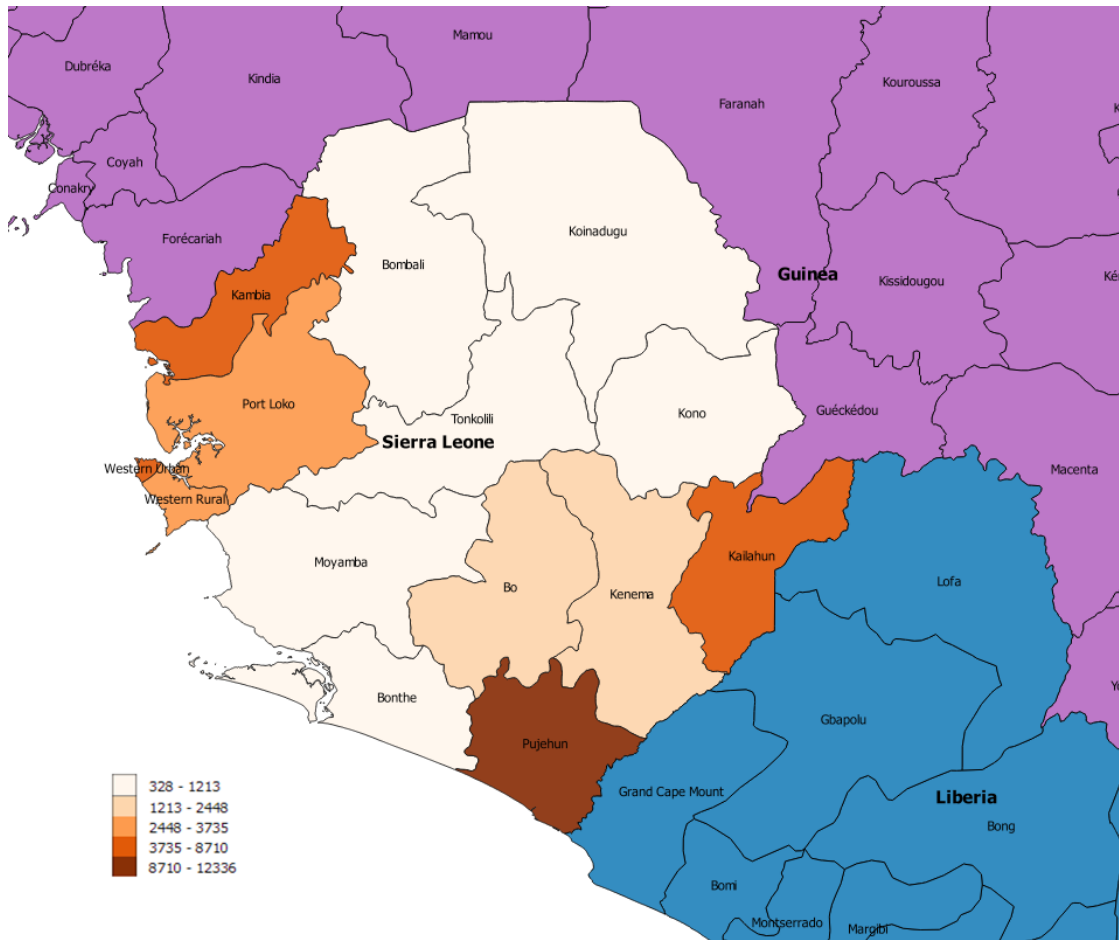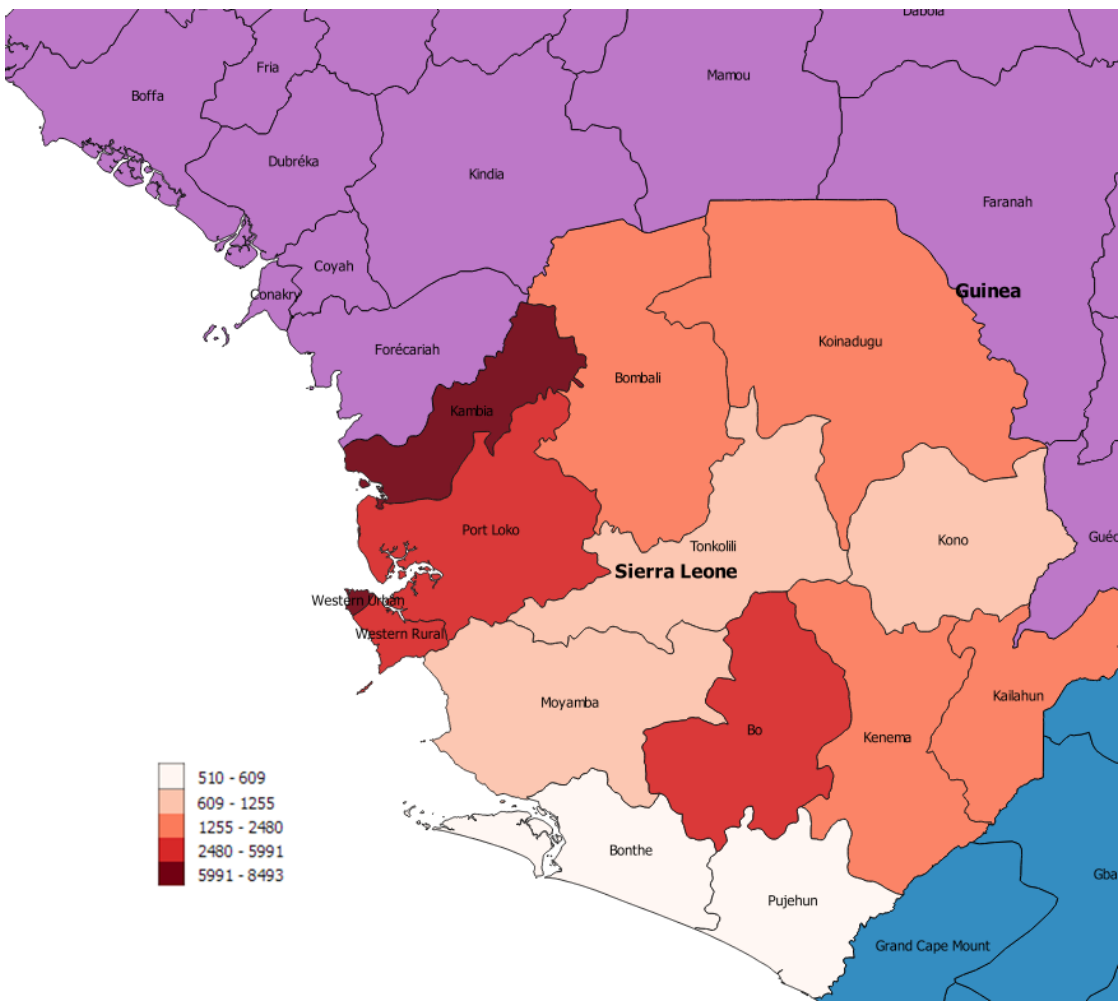


Source: ITU

### 8.6.4    Outbound transboundary population movement

Figure 8.17 illustrates the transboundary movement of mobile users who visited Guinea from Sierra Leone. It shows that the three most visited prefectures are Kambia, Western Urban and Western Rural.
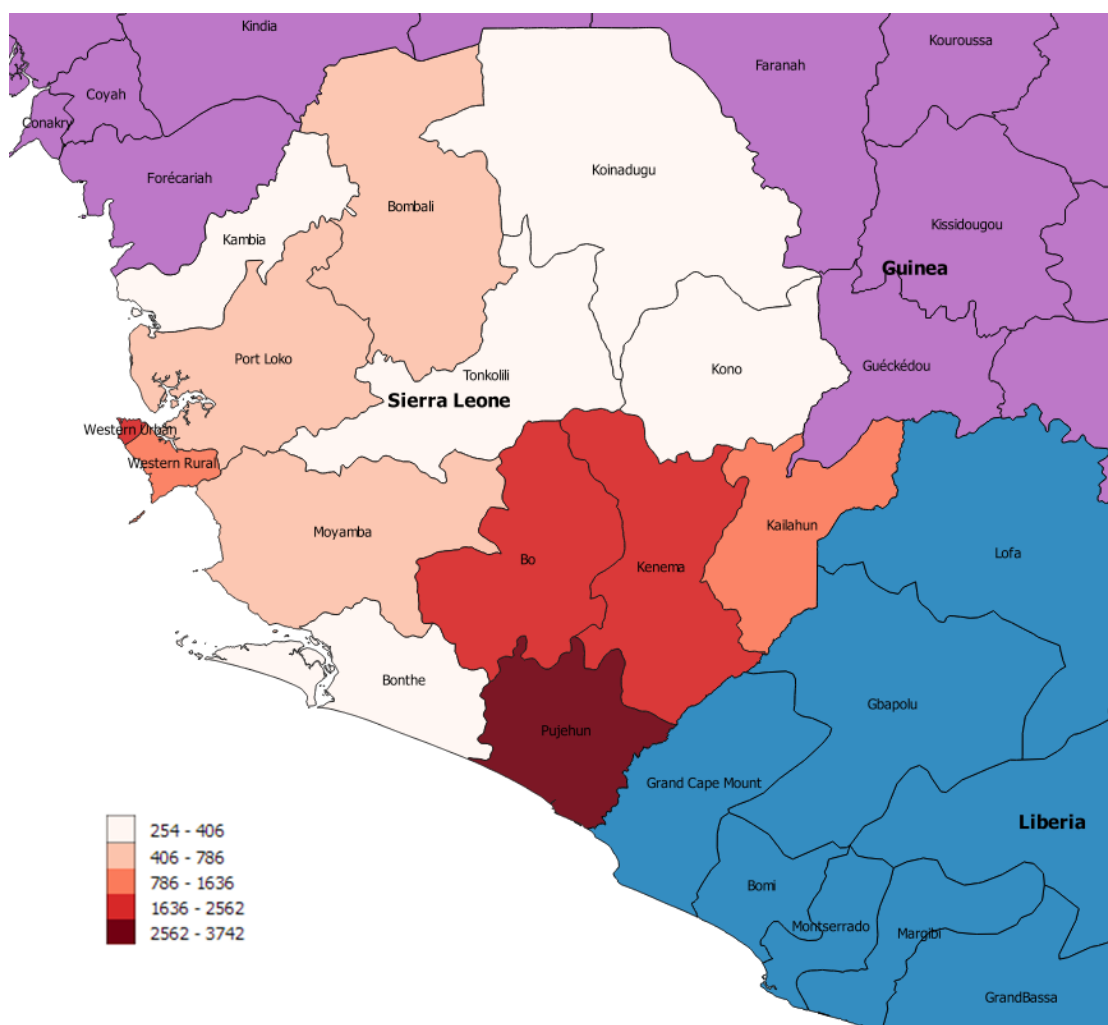
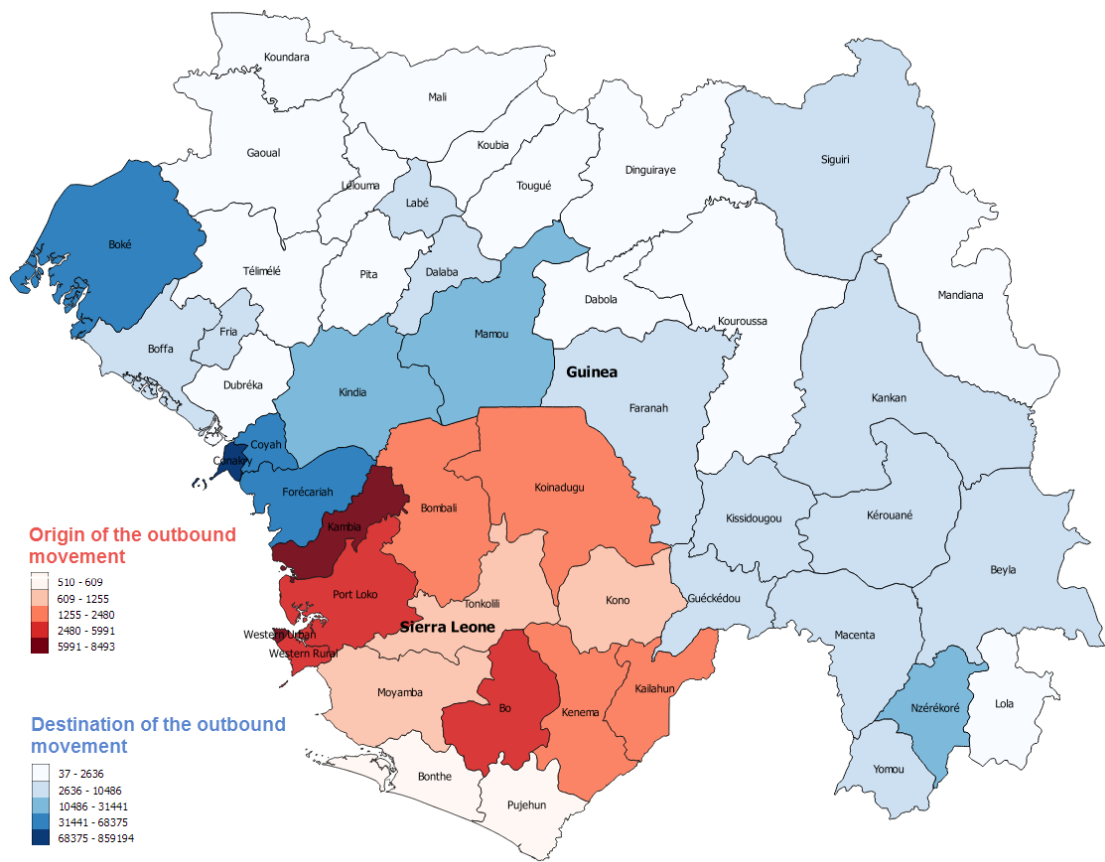Figure 8.17: Footprint of visitors to Guinea



Source: ITU

Figure 8.18: Footprint of visitors to Liberia
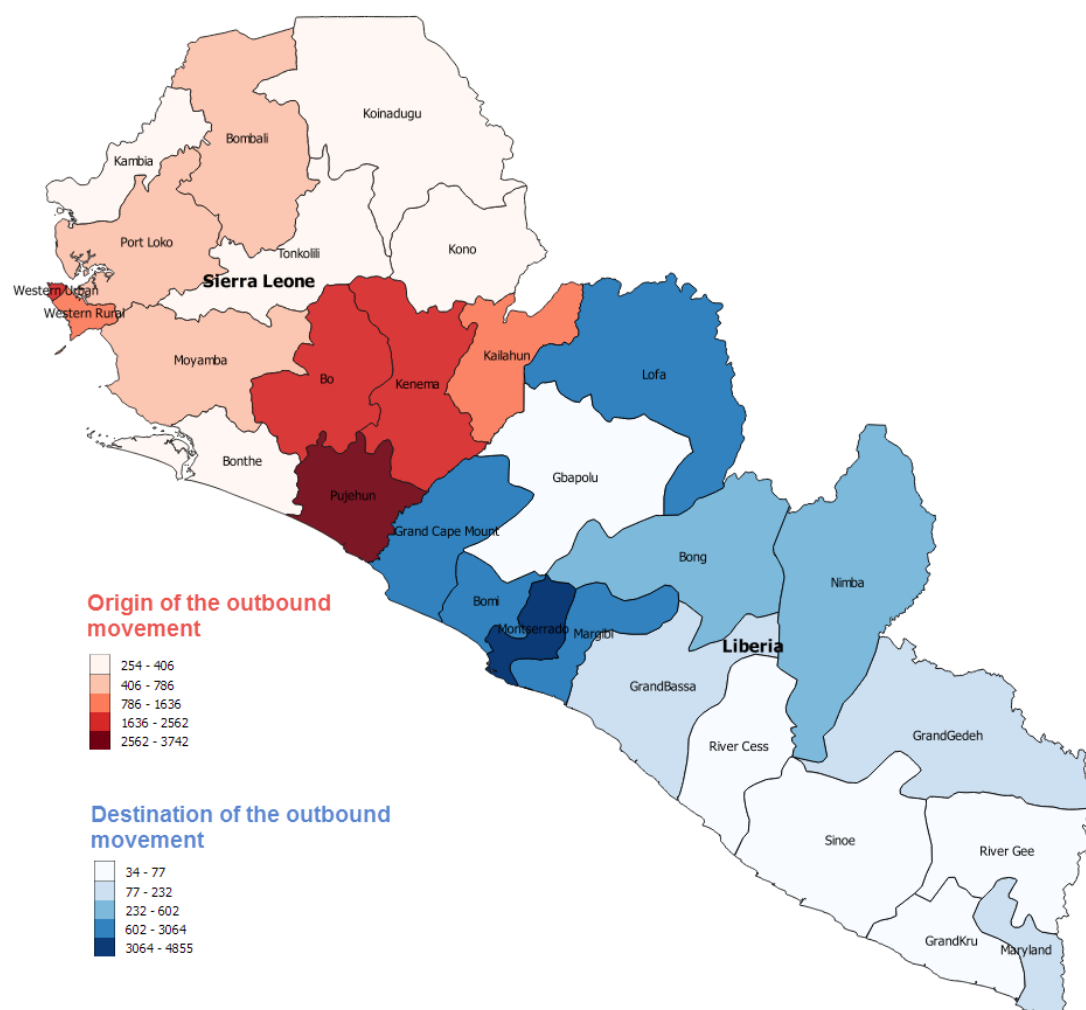


Source: ITU

Figure 8.18 illustrates transboundary population of mobile users who visited Liberia from Sierra Leone. It shows the three most visited districts with high transboundary population: Pujehun, Western Urban, and Bo.

Figure 8.19: Origin and destination of inbound transboundary population to Guinea



**Origin of the outbound movement**
- 510 - 609
- 609 - 1255
- 1255 - 2480
- 2480 - 5991
- 5991 - 8493

**Destination of the outbound movement**
- 37 - 2636
- 2636 - 10486
- 10486 - 31441
- 31441 - 68375
- 68375 - 859194

Source: ITU

Figure 8.20: Origin and destination of inbound transboundary population to Liberia



**Origin of the outbound movement**

| | |
|---|---|
| | 254 - 406 |
| | 406 - 786 |
| | 786 - 1636 |
| | 1636 - 2562 |
| | 2562 - 3742 |

**Destination of the outbound movement**

| | |
|---|---|
| | 34 - 77 |
| | 77 - 232 |
| | 232 - 602 |
| | 602 - 3064 |
| | 3064 - 4855 |

Source: ITU

Figure 8.19 and 8.20 illustrate target city where transboundary population visit to Guinea and Liberia.

# 9    Discussions

The lack of timely and accurate information about movements of people during a natural disaster, emergency or outbreak of disease, can seriously limit or damage the effectiveness of humanitarian preparedness, response and recovery. However, the ubiquitous nature of mobile phones has revealed new opportunities for accessing such information, and CDRs provide valuable insights into the behaviour of people during disaster or emergency situations. For example, variations in the number of active phones connected to each cell tower reveal activity patterns in specific locations during and after an event, and can be used to determine population displacement and social connectivity between and among cities. CDR analysis suggests a strong potential to improve early warning and emergency management mechanisms, and even to reveal potential disease outbreak patterns.

This report describes how CDR data could contribute specifically to monitor and control epidemics, such as Ebola, by estimating the human trajectories and spatio-temporal distribution of populations from CDR data at the local (rural and urban) level as well as border areas.

Results of the analysis have shown that there exists a strong correlation between the distribution of mobile phone users extracted from CDR data and actual populations extracted from national census data, and high transboundary mobility from rural and urban areas in countries neighbouring Sierra Leone was also observed.

The use of CDR data has shown enormous potential as a tool to help authorities during emergencies, disasters, and epidemic outbreaks. Ebola is an epidemic disease, and understanding the movement of potential disease carriers not just at the city-to-city level but on a national scale is critical for effective policy intervention.

In this project, CDR data was analysed and then aggregated to generate statistical information across a given area. The geographic locations of mobile phone devices are determined by the location of the mobile network base transceiver stations to which people connect when making or receiving a call. This is very important in terms of actual population calculations and estimates.

The analysis of the daily positions of millions of mobile devices collected over two months was used to estimate the home location of the mobile user population in Sierra Leone, which also explained the phenomenon of increasing and decreasing population numbers during the day at specific locations due to a unique method of correlating mobile phone activity with the population.

However, this raises the question of how to preserve user privacy. Ensuring privacy is a significant limitation to using mobile phone data, and is important not only to maintain public acceptance of data usage, but also because there is a potential for data to be used to compromise human rights, especially those of the vulnerable. In most cases, access to the data imposes data anonymization to preserve user privacy. For this reason, software has been developed that can be provided to operators or local authorities who, with minimal training, can perform the data anonymization task. Despite this, the use of anonymized data shows very promising evidence of its effectiveness in emergency situations.

In this pilot project, populations under study have been restricted to mobile phone users. To present the population distributions of real populations, including those who are not present in CDR data, further examination to set scaling factors, for instance, is needed. In addition, this project focused on quantitative aspects of mobile phone users, such as the number of people or groups of people and their trajectories. However, without qualitative aspects, such as gender and age of users, it is difficult to analyse how extracted movements of the population can relate to other socio-economic factors. The inclusion of personal attributes could greatly expand the potential of CDR data to address societal issues including control of epidemic diseases.

While anonymized CDR data does not include any personal information, it is possible to estimate basic demographic attributes. A key to estimating demographic attributes of CDR data is the use of supplementary data that relates calling behaviour and demographic attributes. The data can be collected from mobile phone users through a field survey, for instance, and can be used as training data and validation data for the estimation. Given the significance of having attribute information for utilizing CDR data for societal issues, it is vital to collect supplementary data from mobile phone users.

Human trajectories and spatio-temporal population distribution extracted from CDR data can be used to analyse the impact of human mobility on the spread of communicable diseases, and to estimate the number of evacuees under disaster or emergency conditions at a given time and location.

Hourly population distribution maps are useful when extracting statistical information, such as numbers of people at the disaggregated level rather than at the administrative unit. In addition, it can cover difficult to reach populations, without using an advanced national registration system, because mobile phone penetration is so wide-spread.

From the operator perspective, any data release involves both effort and risk, including contractual constraints over release of customer data, or at least a perceived loss of consumer trust if records are transferred outside company control. Nevertheless, operators may well release data either before or during an emergency driven by corporate social responsibility considerations. In addition, because

global issues are borderless, well organized coordination of local governments and operators in multiple countries is important for effective data utilization.

To drive the use of CDR data for disaster/outbreak risk management, the increasing role of mobile technology in communicating information during emergencies and disasters (data collection and data dissemination) needs to be recognised.

Finally, it is recommended that new policies be drawn up that permit the use of CDR data for security and emergency response so that the CDR data can be recorded, retrieved, analysed and used to plan for and mitigate the effects of future outbreaks.

## Appendix 1: Overall concept of automated CDR data analysis

Figure A1.1: Overall concept of CDR data analysis
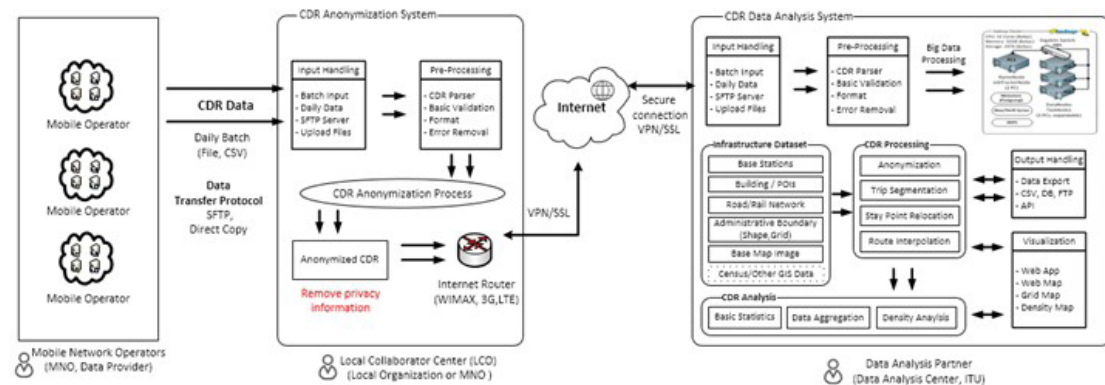


Source: ITU

For this project, the entire process still required manual operation such as input handling, pre-processing and data analysis. The automated CDR data analysis system allows the whole system to work automatically with less operator involvement. This system is recommended in case of expansion to large-scale deployment.

- **Data provider (mobile operator):** The data is collected from the mobile network operator (data provider). In this case, the operator collects mobile device location data and stores it, before exporting or transferring it to a local collaborator centre (LCO) for further processing. The data mainly comes in a CSV file format with compression (zip). Any data transfers between the data provider and LCO must be done via secure channel (SFTP, VPN) or by direct copy.

- **Local collaborator centre (LCO):** The LCO stores the anonymized CDR data (usually carried out by the regulator or mobile operator licence provider) however, the data provider can also act as LCO. In such cases, the data will be anonymized by the LCO (e.g. operator) in addition to transferring data to a cloud storage system (data storage partner).

- **Data analysis partner (DAP):** The DAP maintains all sanitized CDR data (possibly multiple operators). It has to ensure that all data and information are secure. This unit will provide cloud storage system to allow other data providers to upload their data to the cloud storage system for further analysis. User management and authorization to upload or download will be controlled by this unit.

- **CDR anonymization system:** This system handles the anonymization process on CDR data. The system retrieves raw CDR data in csv format and processes it to remove all privacy related information that will then be uploaded to the cloud storage system. At this phase, anonymization is a command line application used to supply parameters such as path of input, path of output,

seed data and CDR format parser. Since the CDR data format may be different among data providers, specific CDR format parsers may need to be developed. Basic validation, error checking and removal are also included in the program.

- **CDR data analysis system:** This system handles deep analysis and maintains all CDR data from all data providers. It incorporates many modules such as: Input handling, Pre-processing, Big data processing unit and CDR Processing. Population estimation is a product of this system, however, the delivery of this system has not been included at this phase.

- **Data transferring (LCO->DAP):** Secure connections (VPN/SSL) should be used to encrypt all transferring data. Connections will be established and fully controlled by the local collaborator. Internet connections can be through a 3G mobile network, WiMAX, and fixed line connection. This connection can also be used for remote management and provisioning of the system. LCO may also upload data via secure FTP (SFTP).

## Appendix 2: Building points of interest (POIs) and road networks

Figure A2.1 illustrates the POIs data constructed for this project. It consists of 1 108 696 polygons, each of which represents a building. Area size of buildings is used to calculate the area of POI buildings, to which stay point locations are reassigned.

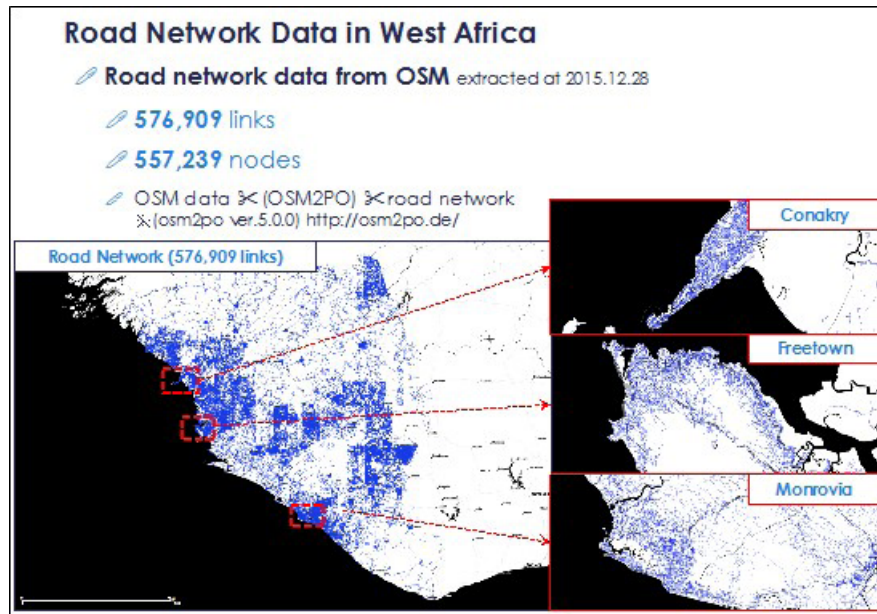### Figure A2.1: Building POI in West Africa
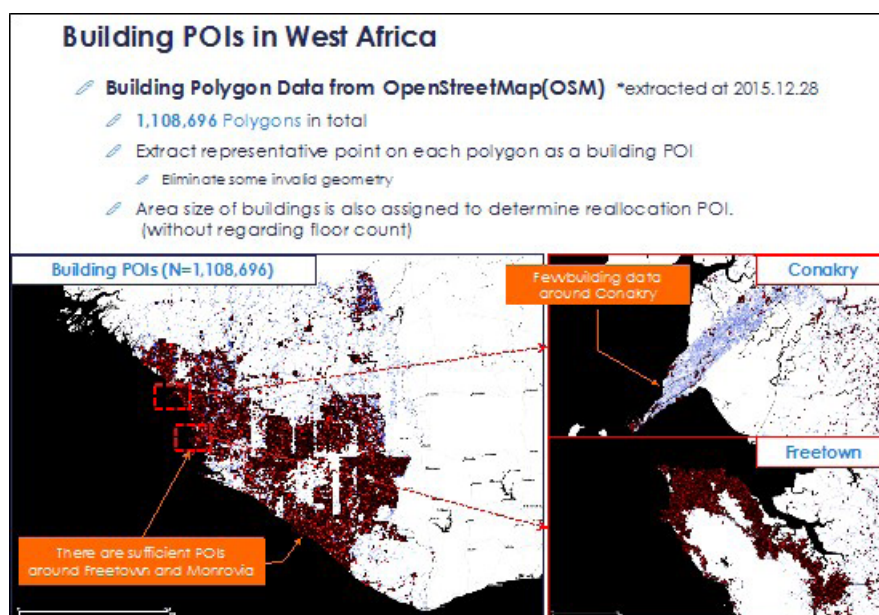


Source: ITU

The road network data constructed for this project is based on OSM (OpenStreetMap)[8] data as of 28 December 2015, and includes 576 909 links and 557 239 nodes.

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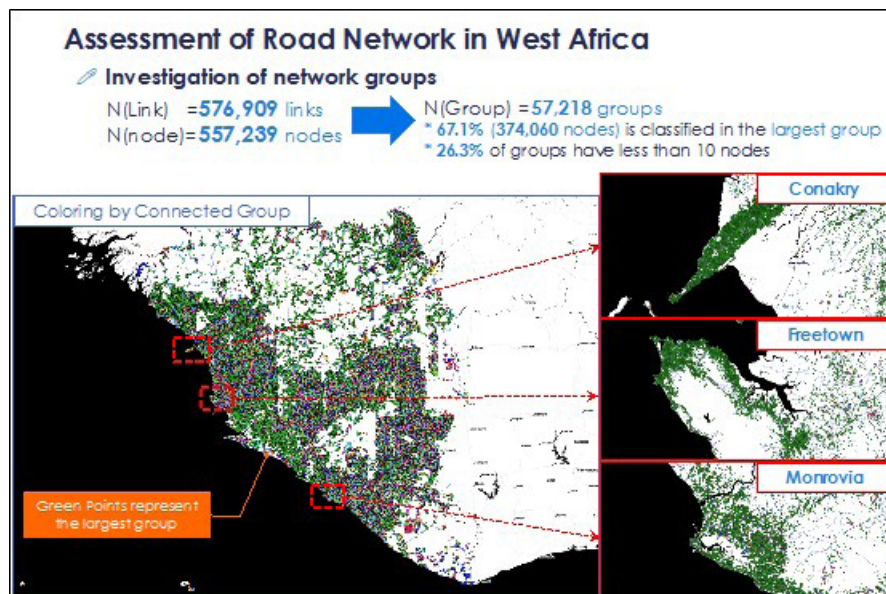[8]    https://www.openstreetmap.org/#map=5/51.500/-0.100

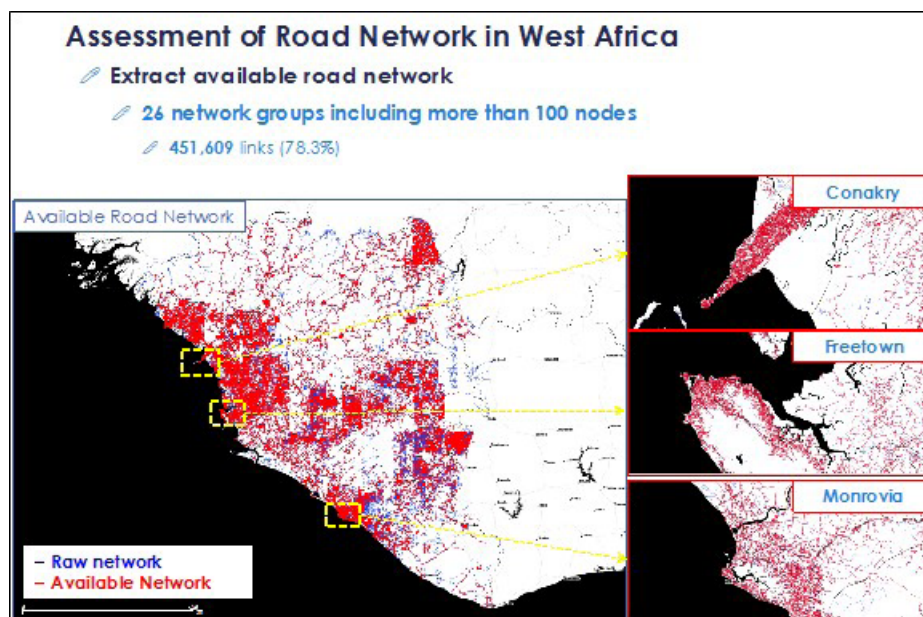Figure A2.2: Road network data in West Africa



Source: ITU

Figure A2.3: Road network assessment in West Africa



Source: ITU

Figure A2.4: Extract of road network in West Africa



Source: ITU

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