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Real-Time Human Trajectory Dataset Capture Model (RT-HTDCM) using GPS and Assisted-GPS Technologies: African Perspective

Paulinus O. Ugwoke[1, 3,*], Hyacinth C. Inyiama[2], and Godwin A. M. Ikekeonwu[1]

1. Department of Computer Science, University of Nigeria, Nsukka, Nigeria.
2. Department of Computer & Electronic Engineering, Nnamdi Azikiwe University, Awka, Nigeria.
3. Digital Bridge Institute (*International Centre for Communications Studies*), Abuja, Nigeria.

* E-mail of the corresponding author: okeyugwoke@yahoo.com

Abstract

Movement is one of the characteristics of human beings that allow them change their location with time in their environment to obtain essential requirements of life and also take part in other social life activities. A moving person always leave trajectory (trace) through which he/she passed. But it is often difficult for people to divulge information about their trajectories. However, the information is often needed or required, for business, security, social, etc, reasons to monitor their trajectories and infer what led them through these trajectories. With the recent development in Telecommunications and ICT (Information & Communications Technology) in combination with Global Positioning System (GPS) technology, traces of moving persons can be recorded digitally on real-time using GPS-enabled devices such as Smartphones, PDAs, Pads, and Cameras assigned to them. In this paper, we proposed a model for developing real-time human trajectory dataset capture software that uses GPS and Assisted-GPS Technologies on Smartphones for tracking and recording of such movement traces of individuals in African developing country, Nigeria. Some smartphones installed with the model (RT-HTDC software) were tested in geographical areas of Federal Capital Territory (FCT), Abuja, Nigeria, and samples of date/time-stamped location points of these smartphone-users were captured and recorded. These location points if connected sequentially can form trajectories (traces) of smartphone-users.

Keywords: GPS, Assisted-GPS, Smartphones, location-log, Trajectory, Moving Objects

1. INTRODUCTION

It is natural for person(s) or group of persons, ship(s), car(s), aeroplane(s), truck(s), motorcycle(s), etc, to move from one location to another for some reasons. Therefore, a hunter wandering in the forest searching for animals, a wine tapper moving from one palm tree to another in order to tap palm wine, a truck moving goods from one location to another, a ship sailing from one location to another, an aeroplane flying from one city to another, a community health professional moving from one household to another for immunization, a motorcycle or bicycle rider navigating left and right of the road in order to beat traffic jam, a herdsman with his animals wandering in field in search of food, individuals or group of individuals such as families, friends, politicians, police, etc, moving from their respective homes to places such as worship houses, schools, clubs, farms, offices, etc, and vice versa, are all examples of moving objects existing either in the air, on the earth, or in the sea. This is because the hunter, aeroplane, truck, wine tapper, rider, health professional, motorcycle, herdsman, police officer, politician, etc, are entities whose respective locations or other geometric attributes changes over time. Location, however, represents where in the air, on the earth, or in the sea these objects of interest are positioned.

Moving objects however, do leave traces as movement paths through which they passed. A path is never made instantly but requires a certain period of time. These movement paths (also called trajectories) if visible have helped in the past to trace these objects, but sometimes they may be invisible or may have been affected by weather conditions such as wind, rain, storm, etc. If we observed a moving object, i.e., a person, over a period of time, the (increasing) sequence of time points or epochs, $t_i(1 \le i \le n)$, where n is the total number of time points at which locations of the object are recorded form the time series, $\{t_1, t_2, \dots, t_i, \dots, t_n\}$, for the particular observation.

It is usual for the location of a moving object to be described using a co-ordinate system such as latitude and longitude. Then a triple (x_i, y_i, t_i) represents the latitude (x_i) and longitude (y_i) of object at time (t_i). We therefore describe a particular observed movement of the object by giving the trace or sequence (called a trajectory) of such triple: $\{(x_1, y_1, t_1), (x_2, y_2, t_2), \dots, (x_i, y_i, t_i), \dots, (x_n, y_n, t_n)\}$; where $(t_i < t_{i+1})$ and $(1 \le i \le n)$. This shows that a trajectory is a (continuous) sequence of locations ordered according to the time they were visited. Figure 1, presents graphically the trajectory, ***TR***, of a person's movement, in 3 dimensional space-time view,(x, y, t), where its base (*x*- and *y*- coordinates) represents spatial dimensions (geography) and the vertical line (*t*- coordinate), perpendicular to the base, represents time.

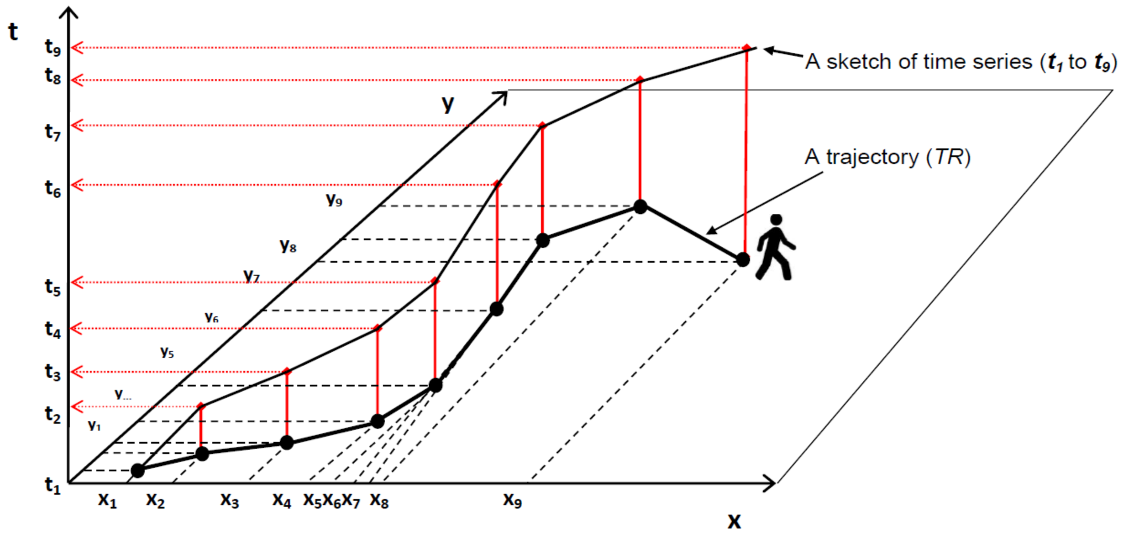

Figure 1: A trajectory

The thicker line in Figure 1 shows the projection of locations of a person's movement in two-dimensional space (x- and y- coordinates*)*, while the thin line shows the graph of (increasing) sequence of time points or epochs $\{t_1, t_2, t_3, \dots, t_9\}$ at which his locations are recorded.

In recent years, owing to the tremendous advances in Information & Communications Technology (ICT) infrastructures in combination with Global Positioning System (GPS) technology, massive amounts of trajectory data can be generated and recorded on real-time locally or to a server computer by various types of sensors and devices such as GPS-enabled smartphones, cameras, PDAs, and pads carried by people; GPS receivers on cars, trucks, and airplanes; sensor tags such as Radio-frequency identification (RFID) tags attached to animals, cargos, and merchandise, etc. More so, Smart cards such as bank cards and transportation cards are sensor cards which can be swipped on machines whose locations are usually fixed and known. Gang *et al* (2013) explained that, usually, trajectory data of mobile devices (i.e., smartphones, cameras, etc.) approximately reflect traces of their owners whereas vehicle's trajectory depicts not only the trajectory of the vehicle itself, but also that of its driver and passengers. According to Zheng and Zhuo (2011), there is a tremendous demand for location tracking of moving objects by various location-based services (LBSs) such as fleet management, traffic information services, transportation logistics, etc; where (Dahunsi and Dwolatzky, 2012) discussed some of the LBSs that have been adapted to the needs of Africa such as route planning, fleet and asset management, location based voting, traffic monitoring and management, route/security information, people tracking, etc. These mentioned LBS according to Dahunsi and Dwolatzky (2012) will attend to either short or long term needs of subscribers. These LBSs demand need to be given consideration, this is because, by observation, it is obvious that greater percent of people move about in their hands, bags, or pockets with at least one or more mobile devices such as smartphones, cameras, PDAs, etc, which are good platforms for their locations data capture.

Nowadays, GPS on smartphones is no longer an emerging trend, but almost a must-have feature. Mobile phones like Apple iPhone, RIM Blackberry, HTC, Samsung Galaxy, Sony Ericsson Xperia, Nokia N-series, Windows phones, etc, are all examples of Smartphones that can offer positioning functionalities with embedded GPS sensors.

Current technologies, ICT & Telecommunications, have globally made mobile phones become basic human needs just like clothing, shelter, food, etc. It was estimated according to International Telecommunication Union (ITU) (Wordpress, 2013) that by the end of 2013, there will be nearly as many mobile subscribers worldwide as there are people on Earth, with more than half of these subscriptions in the Asia-Pacific region. In Africa, Mobile phones have become a major source of communications and means of conveying information among individuals in rural and remote areas of the continent (Dahunsi and Dwolatzky, 2012).

In sub-Saharan Africa (Aker and Mbiti, 2010), access to and use of mobile telephony has increased dramatically over the past decades; there are ten times as many mobile phones as landlines, and 60 percent of the population has mobile phone coverage. According to Paul Kagame, President of Rwanda, at the Connect African Summit in 2007, said: *"In 10 short years, what was once an object of luxury and privilege, the mobile phone, has become a basic necessity in Africa"*. Mobile phone subscriptions increased by 49 percent annually between 2002 and 2007, as compared with 17 percent per year in Europe. According to Ericsson mobility report of November, 2013 (Ericson, 2013), it was estimated that majority of basic mobile phones subscriptions have reached its peak in 2012; and will be slowly declining from around 4.5 billion in 2013 to around 3 billion in 2019, while total smartphone subscriptions will reach 1.9 billion at the end of 2013 and are expected to grow to 5.6 billion in 2019. One of the main reasons given for this is a notable increase in Asia Pacific, Middle East, and Africa subscriptions, as people will be likely to exchange their basic phones for smartphones as a result of availability of smartphones in a lower price ranges. Labrooy (2013) also revealed that Smartphone use in Africa is on the rise, and major mobile makers and distributors are starting to pay attention to the emerging African market by producing devices that cater to the needs of the developing region. Smartphone penetration in Africa is estimated between 17-19%, though rates vary wildly from country to country. Nigeria, which is the Africa's most populous nation, has a smartphone penetration as high as 41%. According to Ittelecomdigest(2014), Nigeria is rated one of the fastest growing telecommunications market in the world and tops the ladder in Africa with over 120 million mobile subscriptions. Emmanuel Revmatas of Samsung Electronics, West Africa, explains the sudden influx of smartphone use in the country, saying: *"The advent of new privately owned submarine cables and their landing on the coast of many East and West African nations, including Nigeria, have significantly reduced the cost of Internet access and increased the adoption of smartphones on the Continent*."

The challenge now is how will smartphone uptake affect the future of Education, Security, Social life, Business, Transportation, etc, in Africa's developing nations? Therefore, in this research work, we took advantages of availability of GPS-enabled smartphones and other GPS-enabled mobile devices in conjunction with the adoption of Location-Based Services in Africa to develop a real-time trajectory data capture model that will assist or guide researchers, developers, etc, in designing and implementing locations data capture software which will enable them record trajectory dataset of people in their choice geographical study domain. We discovered from our literature review that software design and implementation of similar works (Movebank; Microsoft GeoLife, 2012) from other developed countries were not revealed. This has posed a serious challenge to most researchers from the Africa's developing nations who want to collect trajectory dataset for some use in their geographic areas. These trajectory dataset if collected, stored and analyzed may help in discovering hidden patterns and relationships which may contain useful knowledge. This knowledge may be useful in strategic decision making in the areas of business, surveillance and national security, transportation, etc. This research work shows the implementation procedure of real-time trajectory dataset capture by applying Object Modelling Technique.

The rest of this research paper is organized logically as follows: section 2, *technological background*, introduces and describes different technologies (i.e., GPS, Assisted-GPS, GPS receivers, etc) associated with this area of research; section 3, *problem definition*, formally defined the problem and the structure of the expected result; section 4, describes the methodology adapted and software development process used; Section 5 describes the result obtained; section 6,is the review of the related work, and section 7, is the conclusion of the research.

2. TECHNOLOGICAL BACKGROUND

2.1. Global Positioning System (GPS) & Assisted GPS

For thousands of years, our ancestors have navigated by reading objects that are in their eye sight such as the moon and stars in the night sky to keep from getting lost. They determine their location by recognizable natural or man-made geographic landmarks such as hills, streams, mountains, buildings, and other erected monuments. Today, things are much easier, we find ourselves staring at GPS receiver's screen or computer screen rather than star, hill, building, or mountain gazing to determine our locations (McElroy *et al*, 2007; Andrej and Mojca, 2006). Identifying mobile GPS receiver's user locations require location-aware or positioning technologies. These technologies can be categorized as local, network-based, and handset-based. The local positioning technology (Tsalgatiduo, 2003) refers to positioning that is based on short distance signal transmission and mostly operates in indoor environments such as large buildings, shopping centres, etc., where satellites and mobile network positioning methods are not applicable or may not work appropriately. The positioning methods used in this case include, Wireless Local Area Networks (WLAN), Bluetooth technology, Radio Frequency Identification (RFID) or Infrared Data Association (IrDA) technology. However, the network based (i.e., network dependent) technology depends on the ability of a mobile device to receive signal (i.e., outdoors or indoors) from its' mobile network covering its geographical area of presence. On the other hand, the handset-based (i.e., network independent) technology which mostly work outdoors can provide location identification information even in the absence of mobile network coverage, through the use of GPS (Giaglis *et al*, 2003).

GPS is a worldwide space-based navigational system which is composed of three major segments, Satellites (space segment), Ground stations(control segment) and Receivers(user segment) that determines the location (latitude, longitude, & altitude) and time information of a GPS receiver in all weather conditions, anywhere on or near the Earth, 24 hours a day, every day, by computing the time difference where there is an unobstructed line of sight for signals from four or more GPS satellites (Wikipedia, 2013c). The Space segment of GPS is a constellation of 27 Earth-orbiting satellites (24 satellites in operation and 3 extra satellites in case one fails). The U.S. military developed and implemented this satellite network as a military navigation system, but later opened it up to everybody (both the military and civilians) to use for free (Howstuffworks, 2013). A GPS receiver is a device that receives GPS signals (where there is a clear view of skies & signals from at least four satellites), figure out the distance to each other, and use this information to determine the device's geographical location on or near the Earth. This implies that these requirements exclude operation in indoor environments. This operation is based on a simple geometry known as trilateration; the process of determining absolute or relative locations of points by measurement of distances using the geometry of circles, spheres or triangles (Wikipedia, 2013d). Conversely, to compute the location of a mobile device in a closed environment, such as a building, taking information from pseudo-satellites, requires an indoor GPS system such as Assisted-GPS.

Assisted-GPS (A-GPS) is the current technology for GPS-phones (smartphones) that combined the features of network-based and handset-based technologies to give a better accuracy of 5 to 10 meters (IAMAI, 2008; Giaglis *et al*, 2002). Assisted-GPS helps to overcome some of the drawbacks of the pure GPS such as cost, power consumption, speed and time to determine location, and the line-of-sight requirement such as number of satellites in view, by shifting much of the processing burden from the handset to the mobile network (Giaglis *et al*, 2002). However, the challenge of using A-GPS phones is that they function poorly when out of range of their carrier's cell towers and also the cost of acquiring the device is high compared to non-GPS enabled phones. Others can navigate worldwide with satellite GPS signals as well as a dedicated portable GPS receiver does, upgrading their operation to A-GPS mode when in range. Still, others have a hybrid positioning system that can use other signals when GPS signals are inadequate (Wikipedia, 2013e).

2.2. GPS receivers

2.2.1. Dedicated GPS navigation devices

Dedicated GPS navigation devices are devices that are strictly built for receiving GPS signals only. These GPS devices (Wikipedia, 2013e) have various degrees of mobility such as hand-held, outdoor, or sport receivers. They have replaceable batteries that can run them for several hours, making them suitable for hiking, bicycle touring and other activities far from an electric power source. Other receivers, often called mobile are intended primarily for use in a car, but have a small rechargeable internal battery that can power them for an hour or two away from the car. Special purpose GPS navigation devices for use in a car may be permanently installed and depend entirely on the automotive electrical system. There are many different types of dedicated GPS navigation devices from different manufacturers which include Navman products, TomTom products, Garmin products, Mio products, Navigon products, Magellan Navigation consumer products, TeleType products, etc.

2.2.2. GPS-enabled mobile devices

Currently, hand-held or mobile devices such as mobile phones (i.e., smartphones), cameras, PDA (Personal Digital Assistance), etc, do come with inbuilt GPS capability, where GPS is a feature rather than the main purpose of the device. Those devices are the majority, and may use technology such as Assisted-GPS (i.e., network-based GPS) or network independent or both. Mobile computers such as smartphones are high-end programmable mobile phones, built on a mobile operating system (OS), (i.e., Google's Android, Apple's iOS, Nokia's Symbian, RIM's BlackBerry OS, Samsung's Bada, Microsoft's Windows Phone, Hewlett-Packard's webOS, embedded Linux distributions such as Maemo and MeeGo, etc), with more advanced computing capability and connectivity than feature phones (low-end mobile phones) that have less computing ability (Wikipedia, 2013a). In smartphones, apart from programmability, which allows subtle control over events taking place in the phone, the main technical characteristics of interest are their relatively sophisticated sensing capabilities, increasing storage capacity, and built-in networking. Smartphones can be programmed to actively interact with other devices to record a variety of behavioral data on their movements and communication on real-time. According to (Engineersgarage, 2013), they have application programming interfaces (APIs) on them for running third-party applications which can allow those applications to have better integration with the phone's OS and hardware. API is a particular set of rules (codes) and specifications that software programs can use to communicate with each other. In early 2013, according to Sundaytrust (2013), worldwide sales of smartphones exceeded those of feature phones, and as of July 18, 2013, 90 percent of global handset sales are attributed to the purchase of iPhone and Android smartphones.

3. PROBLEM DEFINITION

Given a set of m Smartphones, $\Theta^{\text{smartphone}} = \{smtphone_l \mid 1 \leq l \leq m\}$, and a set of n Smartphone-users, $\Omega^{\text{user}} = \{user_i \mid 1 \leq i \leq n\}$ moving in (x, y)-plane such that one(1)/'more than one' Smartphone(s), $smtphone_{l_c^* \in l:\langle i \rangle}$, is/are mapped to a Smartphone-user, $user_i$. Let the symbol, Ξ, be the function that maps Smartphone(s) to Smartphone-user, i.e., Ξ: $\Theta^{smartphone} \rightarrow \Omega^{\text{user}}$; this is expressed as a rule which assigns to every Smartphone, $smtphone_{l_c^* \in l:\langle i \rangle}$, in $\Theta^{\text{smartphone}}$ exactly one Smartphone-user, $user_i$, in Ω^{user}. The domain and codomain of Ξ are sets, $\Theta^{\text{smartphone}}$ and Ω^{user}, respectively.

If Ξ maps Smartphone(s), $smtphone_{l_c^* \in l:\langle i \rangle} \in \Theta^{smartphone}$, to the Smartphone-user, $user_i \in \Omega^{\text{user}}$, then we write, $\Xi\left(smtphone_{l_c^* \in l:\langle i \rangle} \in \Theta^{smartphone}\right) = user_i \in \Omega^{\text{user}}$, $(1 \leq i \leq n, 1 \leq l \leq m,\ l^* \in l, 1 \leq c \leq m_i, \sum_i^n m_i \leq m)$, where m_i = total number of Smartphone(s) mapped to a User,

$user_i$; c = the counter that counts the number of Smartphone(s) mapped to a Smartphone-user; l^* = identification number of Smartphone mapped to a Smartphone-user; and we call $user_i$, the image of $smtphone_{l_c^* \in l:\langle i\rangle}$, and $smtphone_{\langle i,l^* \in l\rangle}$, the preimage of $user_i$; The *range* of Ξ is the set of all images of elements of $\Theta^{\text{smartphone}}$, i.e.,
$\Xi(smtphone_{l_c^* \in l:\langle i\rangle} \in \Theta^{smartphone}) = \{ \Xi(user_i) \mid user_i \in \Omega^{\text{user}} \}$.

The challenge is, how we can read and record (using assigned Smartphone(s), $smtphone_{l_c^* \in l:\langle i\rangle}$, for instance), a sequence of date/time-stamped smartphone-user's location points, $\{p_1, p_2, p_3, \ldots, p_k, \ldots\}$, in a log, $\boldsymbol{\Psi}$, (also called location-log) as he/she moves about with the assigned Smartphone(s) in a particular geographic area. In this research, 'location-log' and 'log' were used synonymously as both mean the same thing. Each location point, $p_k(1 \le k \le |\Psi|) = (smartphoneID, \mathrm{lat_k}, \mathrm{longt_k}, \mathrm{altit_k}, \mathrm{d_k}, \mathrm{t_k})$, contains, Smartphone identifier $(smartphoneID)$, coordinates (latitude ($\mathrm{lat_k}$), longitude ($\mathrm{longt_k}$), and altitude ($\mathrm{altit_k}$)), date ($\mathrm{d_k}$), and a timestamp ($\mathrm{t_k}$). The idea is to have a table called location-datatable, represented as $\boldsymbol{\Phi}^{\mathbf{DT}}$, which is a set of m location-logs, i.e., $\Phi^{\text{DT}} = \{\Psi_l \mid 1 \le l \le m\}$; where each location-log, Ψ_l, generated by a Smartphone, $smtphone_l$, contains sequence of location points which can be connected sequentially to form trajectories. However, each Smartphone, $smtphone_l$, is identified by a unique number known as IMEI (International Mobile-station Equipment Identity) whereas every Smartphone-user, $user_i$, is identified by its National Identification Number (NIN) assigned by his/her country; $(l, i, m, \text{and } n \in \mathbb{N})$; where m and n are respectively the total number of $Smartphones$ and $Users$ given.

Therefore, if $\{\Psi_{l^*:\langle imei_{l^*}\rangle} \mid 1 \le l^* \in l \le m\}$ denote a set of m *logs* of trajectories, where each *log*, $\Psi_{l^*:\langle imei_{l^*}\rangle}$, is generated by Smartphone, $smtphone_{l^*}$, identified by its unique IMEI, $imei_{l^*}$; then, each *log*, $\Psi_{l^*:\langle imei_{l^*}\rangle}$, is formally defined as a set, containing sequence of date-stamped trajectories, $TR_{j:\langle imei_{l^*}, d_j\rangle}$, being recorded at dates, d_j; i.e., $\Psi_{l^*:\langle imei_{l^*}\rangle} = \{ TR_{j:\langle imei_{l^*}, d_j\rangle} \mid 1 \le j \le totnum_{TR} \}$, $totnum_{TR} = |\Psi_{l^*:\langle imei_{l^*}\rangle}|$ is the total number of trajectories in the series, and each $TR_{j:\langle imei_{l^*}, d_j\rangle}$, is a single trajectory (with a subscripted identifier j $(1 \le j \le totnum_{TR})$) generated by Smartphone, $smtphone_{l^*}$, (with unique IMEI, $imei_{l^*} \in \mathbb{N}$, l^* $(1 \le l^* \in l \le m)$) on the date, d_j. $TR_{j:\langle imei_{l^*}, d_j\rangle}$ can be further defined as a set of date/time-stamped location points: $\{(imei_{l^*}, \mathrm{lat}_{j_k}, \mathrm{longt}_{j_k}, \mathrm{altit}_{j_k}, \mathrm{d}_{j_k}, \mathrm{t}_{j_k}) \mid 1 \le k \le len_{TR_j}\}$. It is often represented as a polyline, which is a sequence of connected line segments:
$TR_{j:\langle imei_{l^*}, d_j\rangle} = \mathrm{p}_{j_1}\mathrm{p}_{j_2} \ldots \mathrm{p}_{j_k} \ldots \mathrm{p}_{j_{len_{TR_j}}}$ $(1 \le j \le totnum_{TR}, 1 \le k \le len_{TR_j})$, where each point $p_{j_k} = (imei_{l^*}, \mathrm{lat}_{j_k}, \mathrm{longt}_{j_k}, \mathrm{altit}_{j_k}, \mathrm{d}_{j_k}, \mathrm{t}_{j_k})$ is a date/time-stamped location point which contains IMEI ($imei_{l^*}$), latitude (lat_{j_k}), longitude (longt_{j_k}), altitude (altit_{j_k}), date (d_{j_k}), and timestamp (t_{j_k}) . $len_{TR_j} = |TR_{j:\langle imei_{l^*}, d_j\rangle}|$, denote the length of a trajectory; it can be different from length of other trajectories in the series.

In this research, the above definition was followed to implement a date/time-stamped location data capture software and a database structure for storing *logs* (location-logs), Ψ_{l^*} $(1 \le l^* \in l \le m)$, in a Location-table(Location-datatable), Smartphone-users information in a User-table, and Smartphones information in Smartphone-table. The next section describes the implementation procedure using Object Modelling Technique (OMT).

4. RT-HTDCM: SOFTWARE DEVELOPMENT APPROACH

4.1. Software development methodology

The Software Development Methodology we adopted in this research is Object Modelling Technique (OMT). This technique is mainly used by system and software developers targeting object-oriented implementations by adhering to full life-cycle development process. The technique is easy to understand and implement; it is used in integrating the best ideas about the proposed system and allows developers to plan, manage and control software projects well. OMT incorporates the best techniques of other methodologies such as Booch and Jcobsen (Azyat *et al*, 2012). One of the key benefits of using this technique is that the object-oriented paradigm spans the entire development process (Hayajneh, 2013). The stages of OMT (system analysis, system design, object design, implementation and testing) are as shown in the Table 1.

Table 1: Object-oriented development process

OMT Stages	If not satisfactory: GOTO
1. **SYSTEM ANALYSIS** (Develop model of real world)	Stage 1
2. **SYSTEM DESIGN** (Develop basic architecture)	Stage 1
3. **OBJECT DESIGN** (Develop detailed model of system)	Stages 2, 1
4. **IMPLEMENTATION** (Translate design into programming)	Stages 3, 2, 1
5. **TESTING** (Test for errors, classes, etc.)	Stages 4, 3, 2, 1

4.2. High level system architecture design

Edsger Dijkstra pointed out as cited in (Azyat *et al*, 2012) that it pays to be concerned with how software is partitioned and structured as opposed to simply programming so as to produce result. This section produces the overview of the design features and the RT-HTDCM prototype architecture development. With reference to Figure 2, from left to right, the architecture is organized into three segments (Data capture & cleaning, Data storage, and Data applications). The first segment is the data capture which is composed of a cellular network infrastructure consisting of Base-Transceiver Stations (BTS) and Mobile Switching Centre (MSC), a network of GPS satellites in space, and GPS-enabled android based smartphones attached or assigned to individuals; each of these smartphones is uniquely identifed by its International Mobile-station Equipment Identity (IMEI) (Wikipedia, 2014b). The IMEI is usually found printed inside the battery compartment of the phone, but can also be displayed on-screen on most phones by entering *#06# on the dialpad. The second segment of the architecture consists of Cloud storage system (i.e., Google App Engine datastore) and Moving object database server, all wirelessly separated. The third segment is Location based service applications that query the trajectory dataset stored in the Cloud storage system.

A mobile application was developed using Java technology and installed on each participating android based smartphone (or phone client) attached to a user for tracking, capturing, cleaning, and storing of date/time-stamped locations of the user. Every user is identified by its National Identification Number (NIN) assigned to him/her by his/her country. In Nigeria for instance, Federal Government in 2013, mandated its National Identity Management Commission (NIMC) to register and assign a NIN to every citizen of Nigeria, whereas in 2011, Nigeria embarked on a compulsory Subscribers Identity Module (SIM) cards registration exercise with a view to capturing biometric data of all mobile phone users in the country and today, it is believed that over 120 million lines in Nigeria are duly registered and attached to individual owners. This registered information which is stored in a dedicated database may be needed or required some time, for business, electoral processes, national security, etc, reasons.

Recently in (The PUNCH, 2014), the Director General, Nigerian National Orientation Agency, Mr. Mike Omeri, cautioned Nigerians against buying used phones and pre-registered SIM cards from unknown sources as they might have been used for terrorist and other untoward activities by insurgents such as Boko Haram. He added that this information is necessary to save Nigerians (or members of public) the embarrassment of being apprehended for criminal activities committed with phones and SIM cards found in their possession; that any case of stolen phones and SIM cards are strongly advised to be reported to any security agents by members of the public.

Taking advantage of these NIN and SIM cards registration exercises, every user of this proposed application is however assigned at least a smartphone whereas the mobile application installed on the user's assigned phone automatically runs in the background on startup of the device without the user's knowledge. This was made invisible to the phone user so that he/she will not feel unsecure with the device which may lead to turning off the device. This mobile application can also be installed on any Android based mobile device that has a GPS, Wireless LAN, WiFi, etc. Date/time-stamped location data are captured by the mobile application using GPS & A-GPS technologies. GPS signals captured by GPS-enabled smartphones from set of GPS satellites serve as the major source of location data. Sometimes, the mobile device (smartphone) may not be able to receive GPS signals due to signal interruptions which might result from tall buildings, rocks, trees, when indoors, etc. Therefore, to ensure that the mobile device always get a GPS signal, it switches to Assited-GPS whenever signals are hard to receive directly from GPS satellites. This is generally achieved using BTS mast(s) the user may find himself/herself around.

To capture and store time-stamped locations, each smartphone installed with location-capture mobile application is assigned to a user. The mobile application creates a location-log (Ψ) on each GPS-enabled Smartphone installed. As the user moves about in a particular geographic area, the mobile application captures his/her locations, periodically (i.e., at every 30 seconds interval) via GPS satellites in space, and first stores (logs) them locally on its created location-log before transmitting them over wireless network (if internet is available) to the back-end database server known as cloud storage system (i.e., Google App Engine datastore). If there is no internet, the phone keeps the location data locally in its Log until there is internet connection. Locations dataset are captured & stored using a client-server model. The mobile operating system used is Android Operating System because of the open nature and flexibility it offers in terms of mobile software development. The mobile application has parameters which can be manipulated at the server-end in order to control how often location data are collected and reported. These location-logs stored in the cloud storage system can be used by LBS applications directly or when downloaded to a locally hosted moving object database (MODB) server. Google App Engine datastore and MODB serve as the main data storage for all numerous users' information and their location-logs collected/ gathered from the assigned smartphones. All data in the MODB and Google App Engine datastore are stored in a manner that allows for easy data queries by the LBS applications.

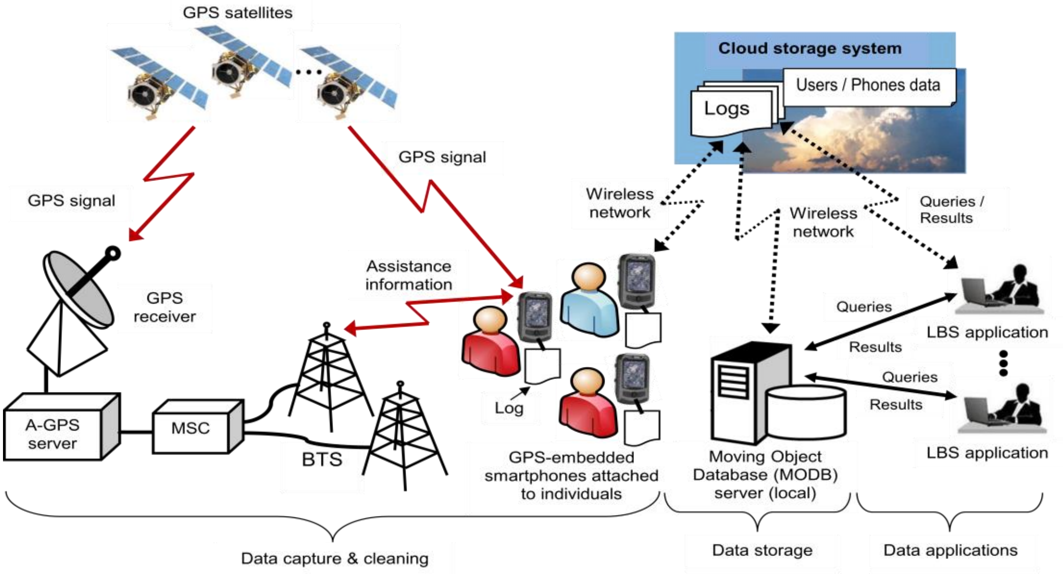

Figure 2: High level system architecture

4.3. System Use Cases

Use case analysis was used for understanding and modelling the functional requirements of RT-HTDCM. We used this technique because it is good at focusing on the functionality of a system and interactions of system components. Object Oriented Analysis & Design (OOAD) using Unified Modelling Language (UML) was used to model the use case diagram, Sequence diagram, etc. The identified use cases are Activate Device, Capture Location Coordinates, Save Location Coordinates, and Upload Location Coordinates while the actors are Mobile Client, Location Service, Upload Service, Online Web Service, and Online Database Web Service. Figure 3 presents these use cases graphically where Tables 2 to 5 presents the formal descriptions of the identified use cases.

4.3.1. RT-HTDC Use Case diagram

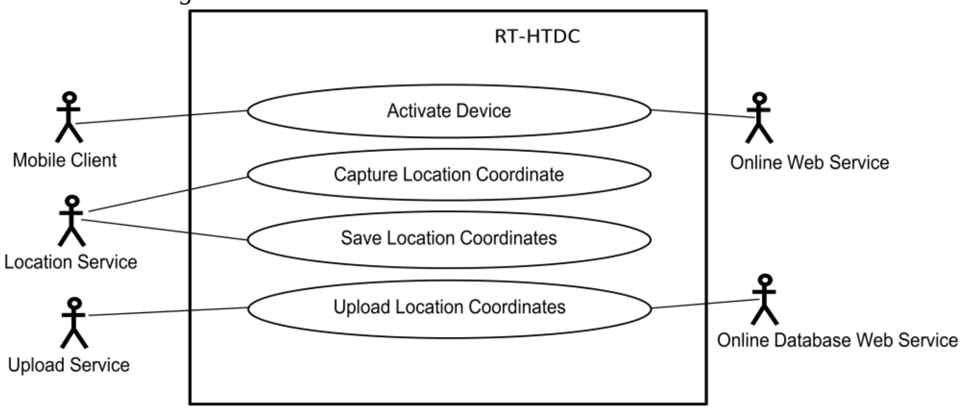

Figure 3: RT-HTDC Use Case diagram

4.3.2. RT-HTDC Use Case descriptions

Table 2: Use Case 1 - Activate Device description

Use Case Title:	*Activate Device*
Package:	*MOD*
Summary:	*Register and activate a device in order to start accepting location coordinates from it.*
Primary Actor:	*Mobile Client*
Secondary Actors:	*Online Web Service*
Inherits:	-
Includes:	-
Business Rules:	*Only activate mobile devices whose IMEI numbers are known to the system.*
Pre-condition(s):	*IMEIs of mobile devices for the survey are registered.*
Typical Sequence of Events:	
Actor Stimulus	**System Response**
1. MOD sends device IMEI to the Android Operating System.	2. The Android Operating System transfers IMEI to the online server and returns a response to MOD.
3. MOD sends the response to DBManager for local storage.	4. The DBManager stores activation response locally on the mobile device.
Post-condition(s):	*Mobile device has been identified using its IMEI number and activated for subsequent location coordinate reporting.*
Priority:	*Normal*
Alternative Sequences of Events:	
Alternative 1: Unknown IMEI supplied by mobile client at step 1	
Actor Stimulus	**System Response**
1. MOD sends device IMEI to the Android Operating System.	2.1. The Android Operating System waits for the Online server to check received IMEI against registered known IMEIs but cannot find a match. 2.2. Online server responds to the Android Operating System with an error message indicating unknown IMEI number.

Table 3: Use Case 2 - Capture Location Coordinates description

Use Case Title:	*Capture Location Coordinates*
Package:	*Capture Service*
Summary:	*Capture the user's current location coordinates*
Primary Actor:	*Location Service*
Secondary Actors:	-
Inherits:	-
Includes:	*Save location Coordinates*
Business Rules:	*Longitude, Latitude, Altitude, Accuracy, Date and Time must be captured at set intervals.*
Pre-condition(s):	*Device is on, GPS receiver is on and/or mobile network is available.*

Typical Sequence of Events:		
Actor Stimulus		**System Response**
1. MODService requests an instance of LocationManager from Android Operating System.		2. The Android Operating System provides an instance of the LocationManager.
3. MODService creates and starts a location coordinates capture timer.		4. The Android Operating System registers the location capture timer with the LocationManager
5. MODService requests for location update registration from the LocationManager.		6. The LocationManager registers and provides a location listener.
7. MODService requests for location coordinates at set intervals.		8. The LocationManager provides location coordinates.
9. MODService sends captured location coordinates for local storage.		10. DBManager saves captured location coordinates.
Post-condition(s):	*User's current location has been captured.*	
Priority:	*Highest*	
Alternative Sequences of Events:		
Alternative 1: GPS receiver off at step 1		
Actor Stimulus		**System Response**
1. MODService requests an instance of LocationManager from Android Operating System.		2.1. The Android Operating System detects GPS receiver is off. 2.2. The Android Operating System displays a dialog box with option to enable GPS receiver.

Table 4: Use Case 3 - Save Location Coordinates description

Use Case Title:	*Save Location Coordinates*	
Package:	*Local Data*	
Summary:	*Save all captured location coordinates to local database*	
Primary Actor:	*Location Service*	
Secondary Actors:	-	
Inherits:	-	
Includes:	-	
Business Rules:	*Ensure all location specific data captured at any instance is saved locally*	
Pre-condition(s):	*Device is on, location service is up and running, GPS & WiFi are on.*	
Typical Sequence of Events:		
Actor Stimulus		**System Response**
1. The Android Operating System sends location coordinates to local database.		2. DBManager accepts location data and persists in the local database.
Post-condition(s):	*Captured location coordinates are locally stored*	
Priority:	*Highest*	

Table 5: Use Case 4 - Upload Location Coordinates description

Use Case Title:	*Upload Location Coordinates*
Package:	*Updater Service*
Summary:	*Upload all captured and saved coordinates in local database of the mobile*

	device to online database server (Cloud storage system, i.e., Google App Engine datastore).		
Primary Actor:	*Upload Service*		
Secondary Actors:	*Online Database Web Service*		
Inherits:	-		
Includes:	-		
Business Rules:	*Do not remove a saved location coordinate record unless successfully uploaded online.*		
Pre-condition(s):	*Device is on, mobile data connection or Wi-fi connection is available.*		
Typical Sequence of Events:			
Actor Stimulus			**System Response**
1. The MODUpdater fetches available saved location coordinates and date& time set intervals.			2. The DBManager provides available saved location coordinates.
3. The MODUpdater requests if an internet connection is available.			4. The Android Operating System confirms the availability of an internet connection.
5. The MODUpdater uploads location coordinates to online database server.			6. The Android Operating System transmits location coordinates to online database web server (Google App Engine datastore) via Online Database Web Service.
7. The MODUpdater requests for removal of location coordinates from local database.			8. The DBManager removes uploaded location coordinates from local database.
Post-condition(s):	*Locally saved location coordinates have been successfully moved to the online database server.*		
Priority:	*Normal*		
Alternative Sequences of Events:			
Alternative 1: No location coordinates available at step 1			
Actor Stimulus			**System Response**
1. MODUpdater fetches available saved location coordinates and set intervals.			2.1. The DBManager finds no locally saved location coordinates. 2.2. The DBManager sends appropriate response indicating no records found.
Alternative 2: No internet connection available at step 3			
3. MODUpdater requests if an internet connection is available.			4.1. The Android Operating System confirms that no internet connection is available. 4.2. The Android Operating System sends appropriate response indicating no internet connection found.
Alternative 3: Online database server unable to save record at step 5			
5. MODUpdater uploads location coordinates to online database server.			6.1. The Android Operating System pushes location coordinates to online database server but server fails to respond. 6.2. The Android Operating System sends appropriate response indicating no response from server.

4.4. Sequence diagrams

Sequence diagrams are typically associated with use case realizations in the Logical View of the system under development. They focus on the sequential order in which messages are sent between objects. A sequence diagram is an interaction diagram that shows how processes operate with one another and in what order. It depicts the objects and classes involved in the scenario and the sequence of messages exchanged between the objects needed to carry out the functionality of the scenario. In our own case, there are three (3.) sequence diagrams to be considered, i.e., (a.) Activate Locations Coordinates, (b.) Capture Location Coordinates, and (c.) Upload Location Coordinates which are respectively represented in Figures 4, 5, and 6. The typical sequences of events for these use cases have been described in tables 2, 3, and 5 above.

Figures 4, 5, and 6 are read by starting at the top and working your way down. Time is meant to flow from the top progressively towards the bottom of the diagram. The dashed lines extending below the objects and actors are their lifelines, indicating that the instances exist over a period of time. The rectangles appearing on the RT-HTDCM's MOD lifelines (i.e., see Figure 4) are the activation bars. These appear on the lifeline when the instance is performing a task. The arrow from MOD to 'Android Operating System' is a message: It indicates that the MOD object is sending a message to the 'Android Operating System'. The name appearing in the label on each message is the message being sent. The (filled) arrow head used on the message arrows in Figures 4, 5, and 6 are used to indicate synchronous messages. Synchronous messages are like normal procedural logic, where a message is sent and the sender waits for the receiver to complete the message and return before the sender continues. Where the dashed arrow from the end of the 'Android Operating System' activation bar (i.e., see Figure 4) back to MOD indicates an explicit return.

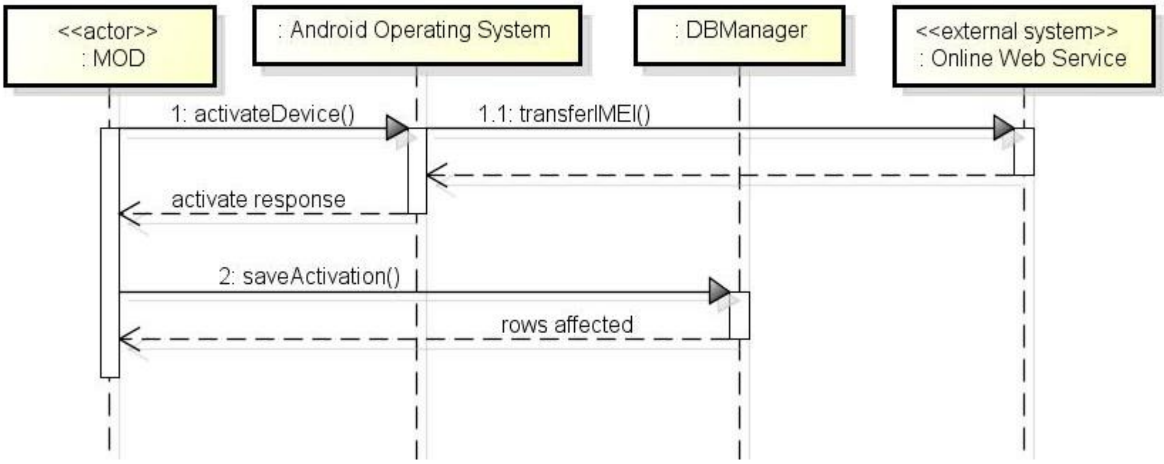

Figure 4: Activate Locations Coordinates sequence

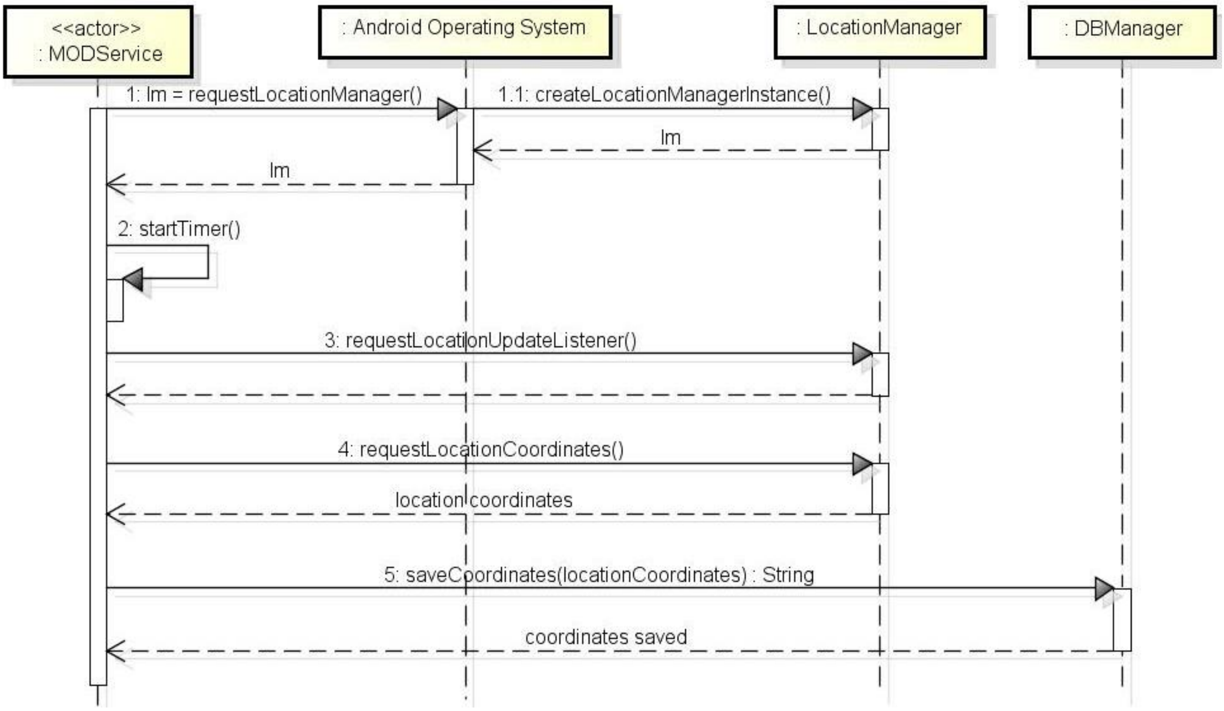

Figure 5: Upload Location Coordinates sequence

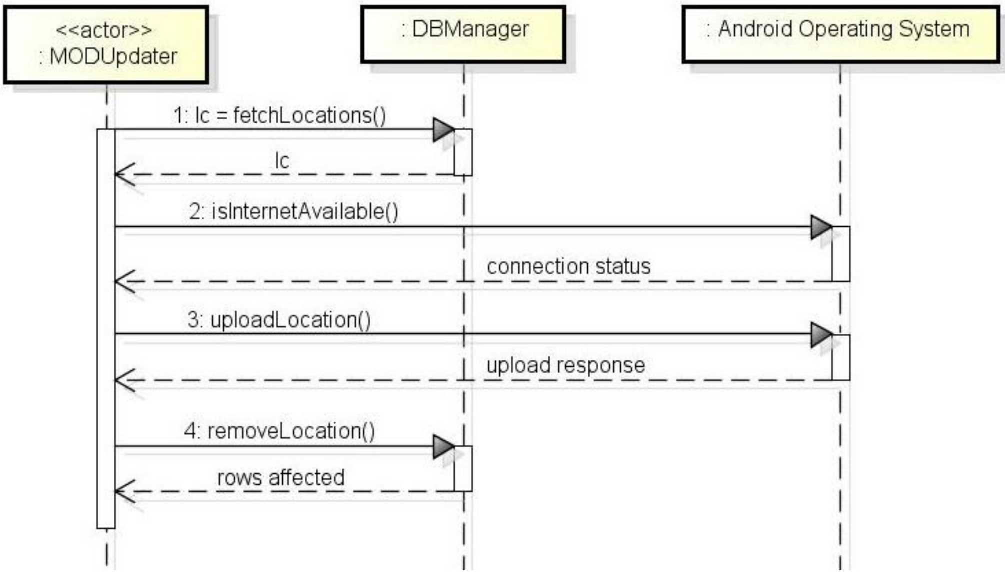

Figure 6: Capture Location Coordinates sequence

4.5. Class' responsibilities and associated collaborators

The Class' responsibilities with associated collaborators of Mobile Application subsystem and Server Application subsystem were described using Table 6 and Table 7 respectively. This shows the relationship of classes with their identified responsibilities and collaborators in accomplishing the tasks the system needs to accomplish as stated in the use case descriptions.

Table 6: Mobile Application Class' Responsibilities & Collaboration

Responsibilities	**Collaborators**
Location	
Holds all the location specific data	-
TableMeta	
Holds the meta-data for the local database	-
UserData	
Handles all direct interaction with the local database	-
DBManager	
Allows the storage, retrieval and update of data in the local database	MODUpdater, MODService, UserData, TableMeta
MODUpdater	
Ensures all locally captured and stored location coordinates are transmitted to the online database	Communicator, DBManager, Location
MODService	
Periodically captures and stores location coordinates	DBManager
Communicator	
Establishes connections and communicates with the online database server	HttpData, MODUpdater
MOD	
Co-ordinates the operation of the major services	MODUpdater, MODService
HttpData	
Holds http request and http response specific data	-

Table 7: Server Application Class' Responsibilities & Collaboration

Responsibilities	**Collaborators**
PMF(Persistence Manager Factory)	
Creates a connection to the datastore	-
LocationManager	
Creates, retrieves, and updates location specific data	PMF, Location
DeviceManager	
Creates, retrieves, and updates device specific data	PMF, Smartphone
UserManager	
Creates, retrieves, and updates user specific data	PMF, User
Location	
Holds location specific data	-
Smartphone	
Holds device specific data	-
User	
Holds user specific data	-
Controller	
Handles all communication between the client devices and the datastore	LocationManager, DeviceManager, UserManager, ResponseCodes, DirectoryResponse
ResponseCodes	
Holds all the response codes the server needs to communicate with clients	-
DirectoryResponse	
Holds all packaged data sent to the client	-
DateHandler	
Parses all date data received from clients	-

4.6. Proposed System class diagrams

The classes that make up RT-HTDCM as well as some information about the classes' behaviours and their relationships (or links) to other classes are shown in the Class diagrams (Figures 7 & 8). A class according to Richard (2010) is represented by a rectangle (or box) that has compartments. The top compartment is the class name; it can also describe the class' stereotype. The middle compartment holds the attributes, which is a list of the data members of the class. These will come from the responsibilities that describe things that the class knows or contains. The bottom compartment is for the operations, which is a list of the behaviors or actions that the class can perform. These will come from responsibilities that describe things that the class needs to be able to do.

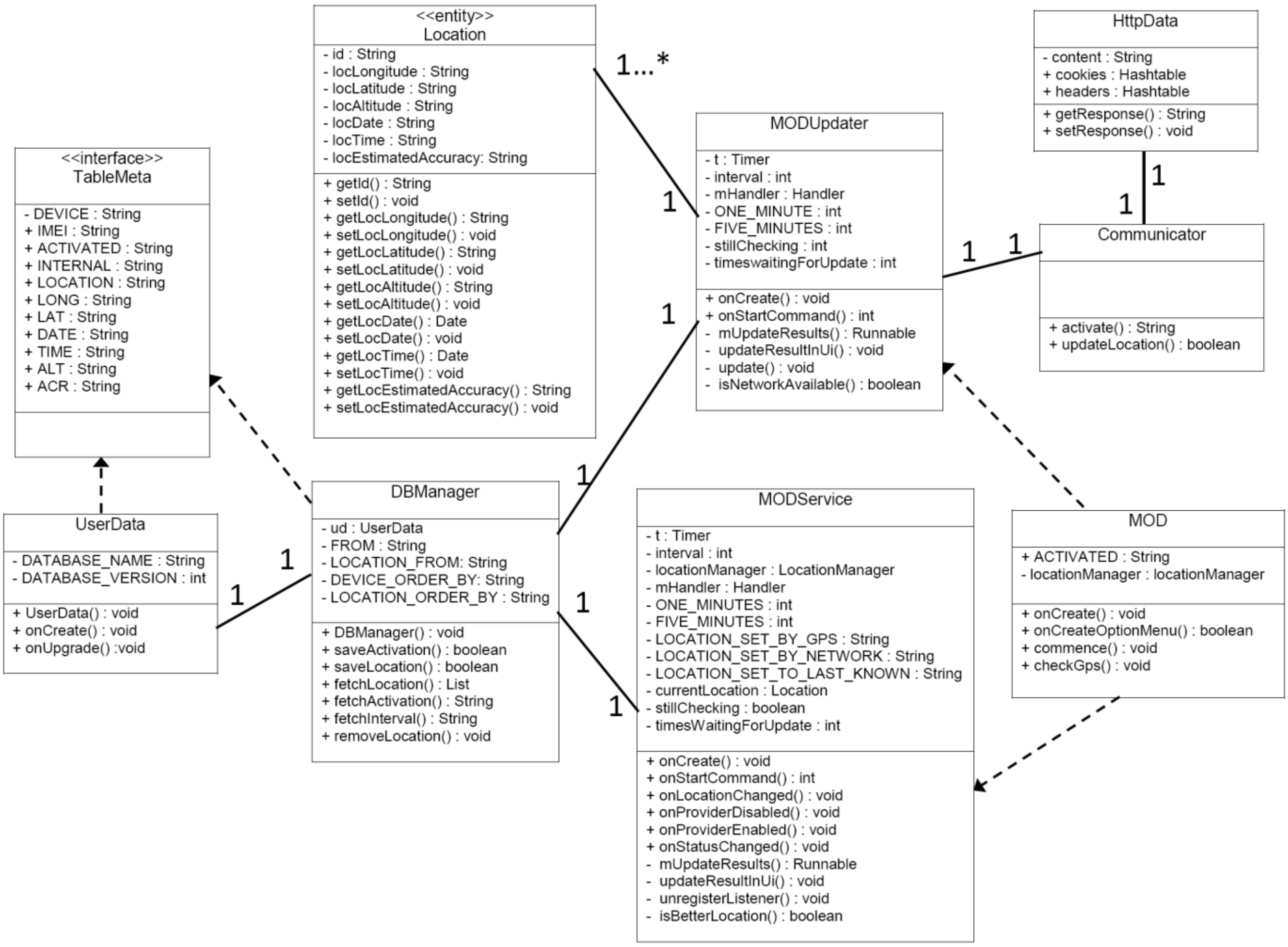

Figure 7: Mobile-Client class diagram

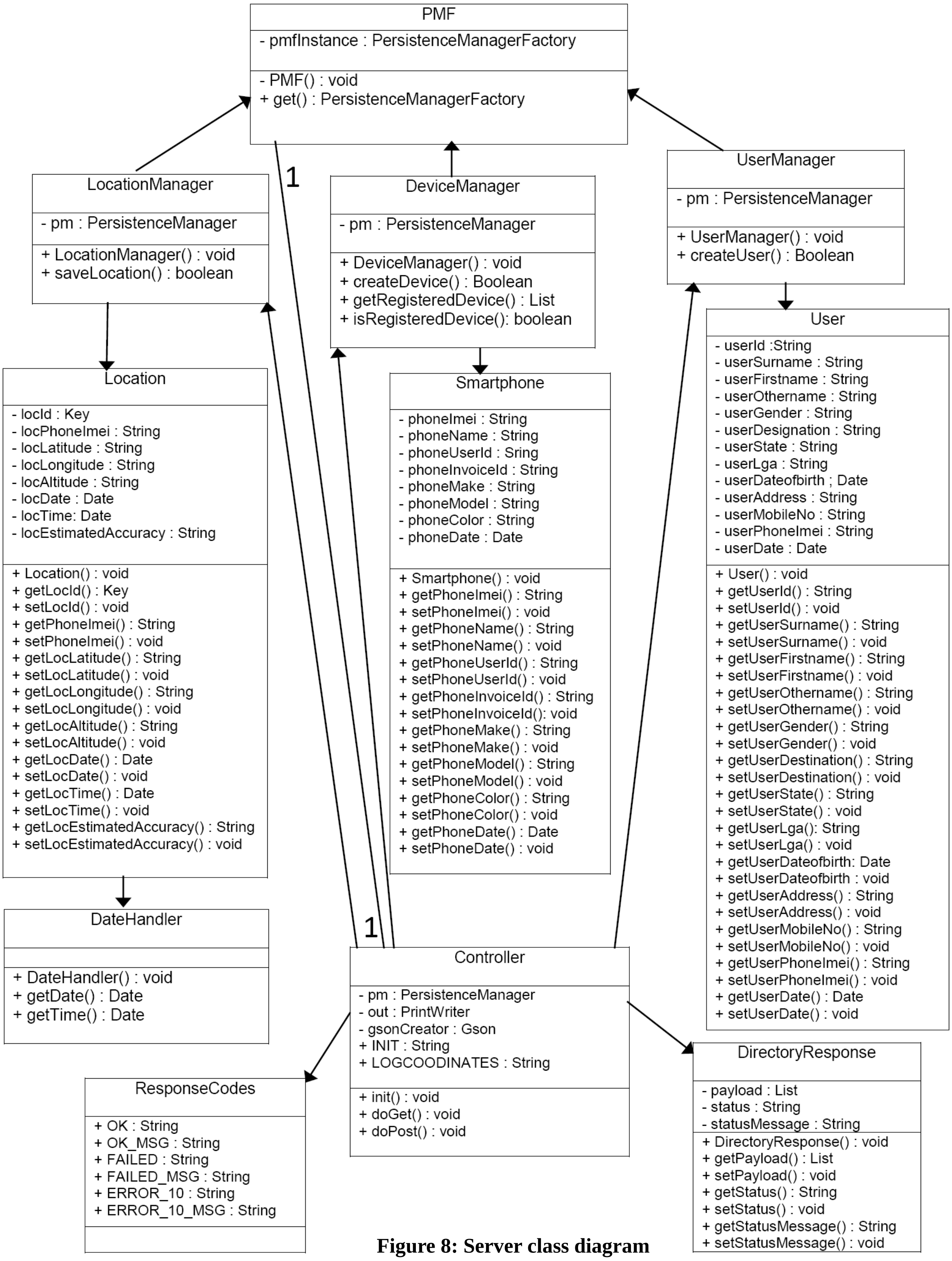

Figure 8: Server class diagram

4.7. Server Side Database: data dictionary

This database component of RT-HTDCM is for storage, each persistent class such as User, Smartphone, or Location as shown in Figure 8, is mapped to a table in the database as shown in Tables 8 to 10. These tables were implemented on Google App Engine datastore to store all Users, Smartphones, and Locations information. The data dictionary of the database which is usually called "Data about data" is a table of fields (or variables) definition and related information. The data dictionaries of the proposed data-tables are as shown in the normalized three (3) data-tables 8 to 10 (User, Smartphone, and Location). Fields in each of these tables are as outlined in their respective tables as shown below.

Table 8: User – This table stores general information about Smartphone users

S/N	Field Name	Data type	Validation	Description
1	userId	number(10)	Not null	PK, unique National Identification(ID) of the user, i.e., NIN
2	userSurname	varchar(20)	Not null	Surname of the user
3	userFirstname	varchar(20)	Not null	First name of the user
4	userOthername	varchar(20)	Not null	Other names of the user
5	userGender	varchar(10)	Not null	User gender
6	userDesignation	varchar(20)	Not null	Designation of the user
7	userState	varchar(20)	Not null	State of origin of user
8	userLga	varchar(20)	Not null	Local Govt. Area where the user came from
9	userDateofbirth	datetime	Not null	Date of birth of user
10	userAddress	varchar(70)	Not null	Address of user
11	userMobileNo	number(15)	Not null	Phone no(s) assigned to the user
12	userPhoneImei	number(25)	Not null	IMEI(International Mobile-station Equipment Identity) of the user's phone
13	userDate	datetime	Not null	The date this record was registered

Table 9: Smartphone – This table stores general information about Smartphones

S/N	Field Name	Data type	Validation	Description
1	phoneImei	number(25)	Not null	PK, unique identification(ID) no. of the phone which is IMEI no.
2	phoneName	varchar(20)	Not null	The name of the phone
3	phoneUserId	number(10)	Not null	The user that the phone is assigned to.
4	phoneInvoiceId	varchar(20)	Not null	The invoice identification no of the phone
5	phoneMake	varchar(20)	Not null	The maker of the phone
6	phoneModel	varchar(20)	Not null	The model of the phone
7	phoneColor	varchar(20)	Not null	The color of the phone
8	phoneDate	datetime	Not null	The date the phone was acquired

Table 10: Location – This table stores general information about Locations

S/N	Field Name	Data type	Validation	Description
1	locId	number(20)	Not null	PK, unique identification(ID) no. of the location
2	locPhoneImei	varchar(20)	Not null	Phone IMEI no
3	locLatitude	varchar(20)	Not null	Latitude in decimal degrees
4	locLongitude	number(10)	Not null	Longitude in decimal degrees
5	locAltitude	varchar(20)	Not null	Altitude in meters
6	locDate	varchar(20)	Not null	Date of location capture
7	locTime	varchar(20)	Not null	Time of Location capture
8	locEstimatedAccuracy	varchar(20)	Not null	Location estimated accuracy provided by GPS system in meters

4.8. RT-HTDCM implementation

This section describes the technologies used for developing the mobile phone application of RT-HTDCM. The System required the choice and use of several technologies. These technologies (i.e., Android Mobile Development Framework, Google App Engine, and Eclipse Integrated Development Environment) were used to achieve specific tasks and were all integrated to function as one system. They are as described below:

4.8.1. Android Mobile Development Framework

This was used to build the mobile application subsystem of RT-HTDCM. Android was chosen because most of its development tools are free and mobile application developed can be deployed directly on Android based devices without passing through any online approval process. According to Africatelecomit (2013), the Android operating system is being used in more and more devices because developers are allowed to do as they choose;

this is because of the open nature of Android platform. This open nature of Android platform has helped many communities of developers to focus on developing their own version of Android based Applications for others to use.

4.8.2. Google App Engine

This is the cloud platform used to host the datastore of the system. It is where the location-logs, users, and smartphone information are stored online. Google App Engine allows for the automatic scaling of storage to accommodate multiple users, and that is the reason why it was chosen for the cloud storage part of the system. Usage of resources on Google App Engine are utility based and allow for a lot of flexibility.

4.8.3. Eclipse Integrated Development Environment

Eclipse was used to write and manage all the Java codes developed for the mobile application and its interface with the cloud storage system. However, considering the fact that both technologies (i.e., Android and AppeEngine) are from Google, the recommended development environment from Google is Eclipse as it comes with several plug-ins to aid development on these platforms.

4.9. RT-HTDCM deployment

The end product of the development process produces an Android Application Package (apk) which contains the binaries of the mobile application. Therefore the apk file of RT-HTDCM can be installed on any device that has the following specifications: Operating System (i.e., Android 2.2 or higher), Mobile data connection (3G Network), Functional GPS and Wifi. The apk file can be deployed to a mobile device in the following ways:

Bluetooth: Using this technique, the apk file is being transferred from a host computer to any Android based device that has Bluetooth functionality.

Over wire: With this technique, the apk file is copied to the Android device' storage unit while the device is connected to the host computer's Universal Serial Bus (USB) port using device' data communication cable. Once any of the methods above is employed to deploy the RT-HTDCM's apk file, installation on the device just requires a single click and the application is fully installed, and a message is displayed showing that it has been successful installed.

5. RESULTS AND TESTS

The result of this research is a recorded date/time-stamped location history of people's movements which can be plotted as trajectories when needed. This shows that as people moves freely in space, their individual date/time-stamped location histories can be recorded by their assigned GPS-enabled smartphones or devices. The result is presented in a table known as location-datatable, $\mathbf{\Phi}^{\mathbf{DT}}$, which is a set of (logically represented) m location-logs, i.e., $\Phi^{DT} = \{\Psi_{l^*:\langle imei_{l^*}\rangle} \,|1 \leq l \leq \; m\}$; where each location-log, Ψ_{l^*}, is generated by a smartphone, $smtphone_{l^*}$ with IMEI = $imei_{l^*}$. The location based service (LBS) applications of these recorded location histories are enormous, these includes but limited to surveillance and national security, transportation, business, social networking, etc.

Note that the Location identification (locID) numbers does not increase in proportion to their corresponding location captured Time (locTime) values; This is because, the locID numbers are system generated numbers that are allocated to captured location records automatically during location-log upload from mobile device to cloud storage system (i.e., Google App Engine datastore).

Table 11, shows a sample Location-table in MODB with two sample location-logs. Each of the location-logs has sample trajectory datasets generated in one week (i.e., 7days) period in FCT Abuja, Nigeria by two test smartphones (Samsung Galaxy Grand_GT-19082 and Samsung Galaxy Mega_GT-19152) with IMEIs, 359038058233880 and 356899056665123 respectively. Locations dataset were successfully captured and stored in a database (Google App Engine Datastore and MODB) based on the availability of GPS, Cellular network, Wireless Local Area Network (WLAN), and WiFi on these smartphones. Figure 9, shows a snapshot of our result in Google App Engine Datastore. The data format of each field in these trajectory dataset as shown in Table 11, are described below:

Field 1 (LocID): Unique identification (ID) number of the location.
Field 2 (Phone IMEI): The International Mobile-station Equipment Identity (IMEI) of the Phone.
Field 3 (Latitude): Latitude, in decimal degrees, is defined as 0-90 degrees North or South of Equator.
Field 4 (Longitude): Longitude, in decimal degrees, is defined as 0-180 degrees East or West of Prime Meridian, which passes through Greenwich, England.
Field 5 (Altitude): Altitude (i.e., elevation) is represented in meters above sea level.
Field 6 (Date): Date of location capture as a string.
Field 7 (Time): Time of location capture as a string.
Field 8 (Estimated Accuracy): Location estimated accuracy provided by GPS system in meters. This Estimated Accuracy (Novatel, 2003), is often used to describe how good is location, time, and/or velocity acquired by GPS receiver compared with its true time, location, and/or velocity based on a constant standard. Therefore, Accuracy is the degree of closeness of an estimate to its true, but unknown value.

The location-datatable (Φ^{DT}) generated in this research is as logically represented below:

$$\Phi^{DT} = \{\Psi_{l^*:\langle 359038058233880\rangle}, \Psi_{l^*+1:\langle 356899056665123\rangle}, \dots \}$$

Where location-logs are formally represented as:

$$\Psi_{l^*:\langle 359038058233880\rangle} = \{TR_{j:\langle 359038058233880,\ 2014-02-04\rangle}, TR_{j+1:\langle 359038058233880,\ 2014-02-05\rangle}, \dots\}$$

$TR_{j:\langle 359038058233880,\ 2014-02-04\rangle}$ → Trajectory j generated by a Smartphone, $smtphone_{l^*}$, with IMEI($imei_{l^*}$) = 359038058233880 on the date 2014-02-04, etc.

$$\Psi_{l^*+1:\langle 356899056665123\rangle} = \{TR_{j:\langle 356899056665123,\ 2014-02-09\rangle}, \dots, TR_{j+2:\langle 356899056665123,\ 2014-02-11\rangle}, \dots\}$$

$TR_{j:\langle 356899056665123,\ 2014-02-09\rangle}$ → Trajectory j generated by a Smartphone, $smtphone_{l^*+1}$, with IMEI($imei_{l^*+1}$) = 356899056665123 on the date 2014-02-09, etc.

Table 11: Location-datatable(Φ^{DT}) with sample location-logs in MODB

LocID	Phone IMEI	Latitude	Longitude	Altitude	Date	Time	Estimated Accuracy
…	…	…	…	…	…	…	…
50007	359038058233880	9.0678405	7.4349385	467.0	2014-02-04	14:56:08	16.0
50008	359038058233880	9.0678620	7.4349064	484.0	2014-02-04	10:25:41	16.0
50009	359038058233880	9.0678137	7.4349278	472.0	2014-02-04	10:44:32	8.0
50010	359038058233880	9.0677976	7.4349331	473.0	2014-02-04	10:32:57	16.0
…	…	…	…	…	…	…	…
180045	359038058233880	8.9973987	7.5670413	0.0	2014-02-05	19:39:31	2834.0
180046	359038058233880	8.9973987	7.5670413	0.0	2014-02-05	19:40:01	2834.0
180047	359038058233880	9.0023775	7.5664390	0.0	2014-02-05	19:42:22	1951.0
180048	359038058233880	9.0053246	7.5704935	0.0	2014-02-05	19:44:19	2040.0
…	…	…	…	…	…	…	…
190009	356899056665123	9.0423089	7.5243641	588.4585734	2014-02-09	19:03:50	12.0
190010	356899056665123	9.0241273	7.5603896	480.3131896	2014-02-09	19:10:50	8.0
190011	356899056665123	9.0119950	7.5660030	0.0	2014-02-09	19:17:48	2205.0
200060	356899056665123	9.0578397	7.4872166	512.2752470	2014-02-09	8:53:49	16.0
…	…	…	…	…	…	…	…
110064	356899056665123	9.0678514	7.4349729	449.6971628	2014-02-11	07:13:12	16.0
130068	356899056665123	9.0678205	7.4352028	448.7883903	2014-02-11	07:14:42	12.0
140074	356899056665123	9.0676467	7.4356191	0.0	2014-02-11	07:10:43	28.0
140075	356899056665123	9.0674850	7.4326540	0.0	2014-02-11	07:11:42	2063.0
…	…	…	…	…	…	…	…

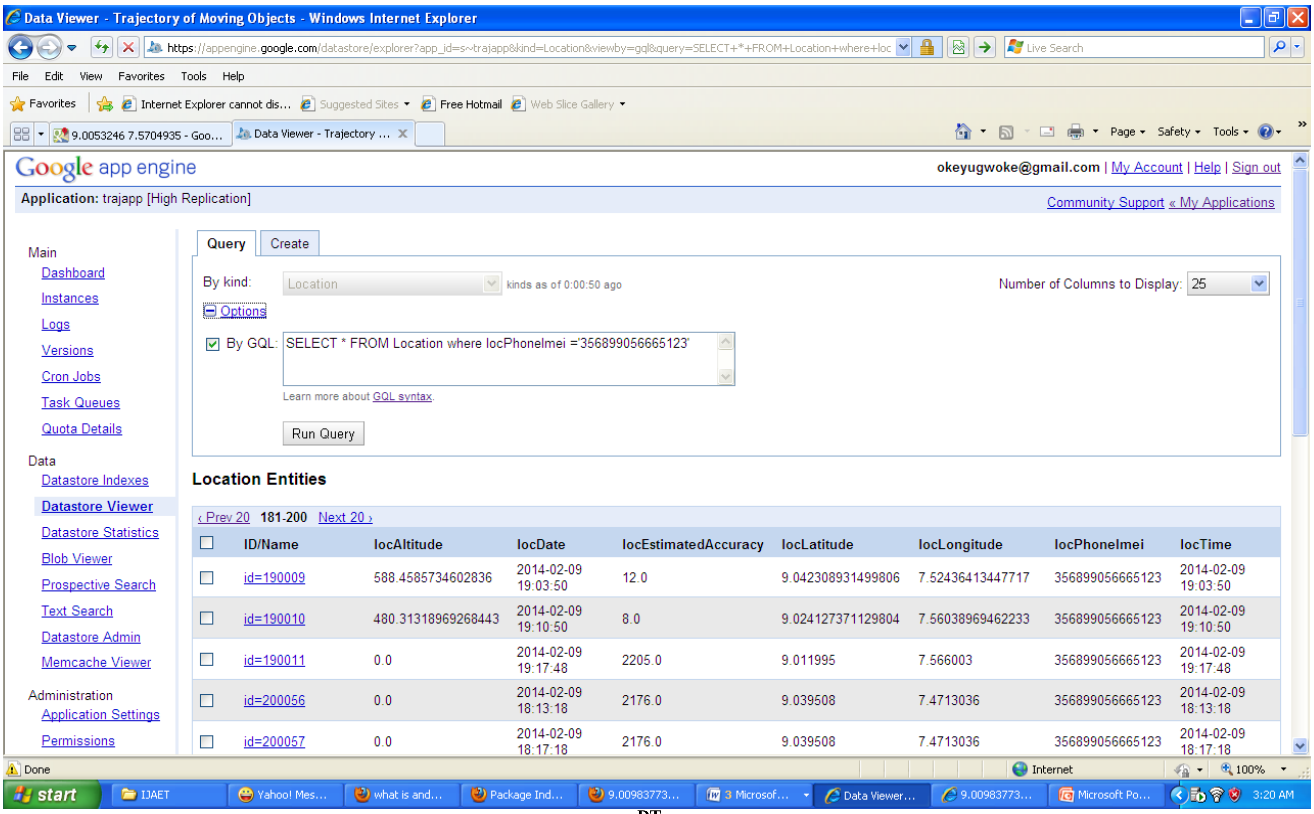

Figure 9: Snapshot of Location-datatable(Φ^{DT}) with sample location-log(s) in Google App Engine Datastore

From the location datasets shown in Table 11, we observed that the location datasets generated using GPS is more precise than the one of Assisted-GPS (i.e., network dependent). This was confirmed using the Estimated Accuracy column in the location-table. The smaller the Estimated Accuracy values, the more precise are the locations values.

6. RELATED WORK

Several studies had been done by some researchers on object tracking and positioning. Some of them focuses on different areas of object tracking such as Vehicle tracking (Kunal *et al*, 2012; Ramadan *et al*, 2012; Khalifa and Ibrahim, 2013; and Ali, 2013), Animal tracking (Movebank), and Human tracking (Microsoft, 2012; Griffin, 2012)

Kunal *et al*(2012), proposed a design of an embedded vehicle tracking system which is used for real-time tracking and reporting of any vehicle status on demand by using GPS and GSM (Global System for Mobile communication) technologies. The GSM modem here is used to send the position (latitude & longitude) of the vehicle from a remote location. Also, Ramadan *et al* (2012), Khalifa and Ibrahim (2013), and Ali (2013) implemented a similar design but incorporated an interactive web component which enables client determines his/her vehicles current location and status using Google Earth map.

Some databanks (Movebank; Microsoft GeoLife, 2012) have been implemented for reference and research purposes. Movebank is a free, online database of animal tracking data hosted by the "*Max Planck Institute for Ornithology"* to help animal tracking researchers to manage, share, protect, analyze, and archive their data. However, Microsoft GeoLife (2012) is a similar project carried out by Microsoft Research Asia towards collecting Human trajectory dataset using GPS technology. These trajectory dataset collected by 182 users in a period of over three years (from April 2007 to August 2012) using GPS-enabled mobile phones is a sequence of time-stamped locations, each of which contains the information of latitude, longitude and altitude. These databanks (Movebank; Microsoft GeoLife, 2012) would only serve researchers from the developed countries that are perhaps familiar with the geographical areas where the data were collected. It will be difficult for researchers from the developing country such as Nigeria to use these databanks for study in other to solve Nigerian or African related problems. Also, the software design and implementation of these databanks which could have helped the researchers in African developing countries to develop and implement similar databank were not revealed.

Griffin (2012), proposed a System for GPS Trajectory Collection, Processing, and Destination prediction. The study also proposed a number of defined algorithms to assist in the analysis and inference on the trajectory datasets. However, what a user does when a GPS receiver is invisible to satellites in the sky (e.g., entering a building) was not considered in their study. This implies that only outdoor environment was considered and Assisted GPS was not used. As opposed to this, our research considered both indoor and outdoor environments.

7. CONCLUSION

This paper presents a novel research about Real-Time Human Trajectory Dataset Capture (RT-HTDC) using GPS and Assisted-GPS technologies, which represents one of the first software applications in Africa that is developed to automatically track and store locations dataset of moving person(s). The contribution to knowledge presented in this paper includes RT-HTDC Model (RT-HTDCM) that will serve as a reference model for African researchers and software developers that perhaps want to develop or implement software solution(s) that will be capable of tracking and storing date/time-stamped locations of people's movement both indoors and outdoors on real-time in a choice geographical area(s). We have described a concise procedure used for full implementation of RT-HTDC using Object Modelling Technique (OMT) and Java technology. However, we also presented sample results (see, Table 11 & Figure 9) from two smartphones (Samsung Galaxy Grand_GT-19082 and Samsung Galaxy Mega_GT-19152) installed with RT-HTDC software and used by 2 users within one week (i.e., 7days) period in geographical areas of Federal Capital Territory (FCT), Abuja, Nigeria.

In future studies, we hope to conduct a GPS monitoring survey to record trajectory datasets of a certain number of persons in Nigeria for a period of time using GPS-enabled smartphones installed with our RT-HTDC software. We anticipate that such recorded big and rich trajectory datasets of people if investigated may reveal some hidden movement and behavioral information.

Similarly, following how RT-HTDCM was developed, tracking software of various kinds can be developed for different moving objects. This will make trajectory datasets of these moving objects such as vehicles, animals, trucks, ships, etc, to be collected and recorded on real-time, and make available for use when demanded. These recorded trajectory datasets of moving objects are often needed or required, for business, fleet management, traffic information services, transportation logistics, surveillance & national security, electoral processes, etc, in African developing countries.

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