

Network Coverage Mapping

Pradeepa G¹, Sudha R.V.², Dhivya Dharshini N³, Niroja K⁴ & Sri Praba S⁵

¹⁻²Assistant Professor, Department of Information Technology, Vivekanandha College of Technology for Women.

³⁻⁵Student, Department of Information Technology, Vivekanandha College of Technology for Women.



DOI: <http://doi.org/10.46759/IIJSR.2022.6215>

Copyright © 2022 Pradeepa G et al. This is an open access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Article Received: 20 March 2022

Article Accepted: 25 May 2022

Article Published: 17 June 2022

ABSTRACT

Mobile signal strength (coverage) maps are of great importance to cellular operators for network planning and operation are expensive to obtain, imperfectly reflective of call quality outcomes, and potentially constructed from biased samples. Users of smartphones utilize high-speed network services while commuting on public transit and hope to have a consistent, high-quality connection. Measuring and monitoring coverage and quality of service mean being able to assess reality and its representation. Data collection is a vital ingredient in this process. Finding Mobile signal strength and Mapping the Coverage areas using GIS through differentiating the Network. Due to the massive load demand on cellular networks and frequent changes in the underlying radio channel, users often experience sudden unexpected variations in the connection quality. To overcome variations, we create a Map to differentiate the signal strength with a regular update through the Received Signal Strength Indicator (RSSI) in QGIS Software using Python and XML plugins.

Index Terms: QGIS, Biased samples, Massive load.

1. Introduction

Along with voice, data communication has become an integral part of consumer needs. Peoples on the move with smartphones demand high-speed data service. Apart from these, consumer satisfaction with a greater quality of service also needs to be maintained. All of these brought attention to the scarce resource upon which the technology depends - The frequency Spectrum.

The evolution of the technology from the 1st to the 4th generation networks has all been based upon the more and more efficient use of the frequency spectrum over the capacity and throughput offered. First, the wireline data networks improved and higher data rates were possible. Wireless technologies provide ubiquitous access to mobile users, enabling consumers with a broad range of mobility and a variety of wireless multimedia services and applications.

Wireless access technologies provide data access through wireless media to consumer and business markets. The most common example of wireless access is a wireless local area network. Wireless access is also an attractive option to network operators in geographically remote areas with no or limited wired network. Citizens today aspire more and more to be informed, entertained, shop, transfer money and communicate using their mobile phones. Starting a conversation at home and continuing it over their car's speakers, sending out a request while traveling, and using that information once they arrive at their destination. Finishing up some work or getting a head-start while on public transport. Getting groceries or shopping online, paying for a taxi, or receiving their salary using mobile payment solutions. All actions that are now possible on mobile networks, coming to complement fixed networks.

In reality, however, a distinction must be made between those areas where networks enable access to all of the activities listed above, and those where only some of these activities are possible – not to mention the white

areas where the absence of network coverage makes it impossible to use one's device for any form of communication whatsoever. Network Coverage mapping is a process used to discover and visualize physical and virtual network connectivity via a group of interrelated tasks that facilitate the creation of a network map.

2. Measuring Mobile Network Performance

Measuring coverage means verifying whether a user can connect to their mobile network, establish and maintain a call for a set minimum period, achieve a specific data transmission speed, and access different services. Several parameters can be used to measure this coverage. If signal strength (signal range and quality) provides an initial indication, measuring service accessibility (ringtone within a certain time, time it takes to download several bytes of data, etc.) makes it possible to obtain a more accurate representation of coverage. By combining these different types of measurement we can eliminate, to some degree, disparities between operators' stated coverage and users' experience. Providing only information on signal range can, on the contrary, result in a situation where users are unable to access services despite a location being covered in theory. Quality of service can be measured using several criteria or indicators set by the regulator. These indicators or criteria make it possible to measure voice call performance (accessibility, integrity, continuity) compared to benchmark thresholds. Indicators for measuring mobile internet quality are more challenging to determine, given the heterogeneousness of data services.

The received signal strength indicator (RSSI) indicated the energy loss in the process of signal transmission; the RSSI value is associated with the size of signal attenuation. In the process of signal transmission, the smaller the RSSI value the less the attenuation. Usually, the RSSI ranking is based on the experience model or theory model. The RSSI ranging of model-based experience has shown that an offline database is built between a few RSSI values of nodes which are known location information and their distance of signal propagation; in the process of nodes location, the stored data in the database is constantly compared to implement nodes location.

The RSSI ranging model-based theory implemented nodes localization by determining the environmental parameters in the loss model of signal propagation and plugging the RSSI value which is received from receiving nodes into the model, to estimate the distance between nodes. There is a key to the former method; lots of measuring work off-line in the region is required; in addition, the location accuracy is limited by the number of nodes and measuring workload. The core of the latter method lies in researching critical parameters of the model detail by the accurate measuring of RSSI value; hardware conditions and actual environment can be better reflected; in addition, location accuracy and improved location performance can be enhanced.

Common methods of RSSI ranging are as follows, which are based on the theory model: the path loss model of free space propagation and the block model of logarithmic normal (Shadowing model), and so forth.

The path loss model of free space propagation is an ideal transmission case, it is known that there is an infinite vacuum around the antenna, the signal transmission energy is only related to the transmission distance, and there is a linear relationship between the signal transmission energy and transmission distance, this model does not affect obstacles and scattered reflection, and so forth. The path loss model is as follows:

$$\text{Loss}=32.44+10n\log_{10}(d)+10n\log(f) \quad (1)$$

In this formula, loss indicated the path loss of signal energy, d indicated the signal transmission distance (m), f indicated the wireless signal frequency (MHz), and n indicated the path attenuation factor in the actual environment. However, the application environment of the wireless sensor signal is not in free space, but in the actual environment such as industrial sites or indoor buildings; it needs to consider shade and absorbance by obstacles and the interference of scattered reflection, and so forth.

The attenuation characteristic of channels in the long-distance is following the lognormal distribution; it is commonly used by the block model of logarithmic normal; the path loss model is as follows:

$$\text{PL}(d)=\text{PL}(d_0)+10n\log_{10}(dd_0)+X\sigma \quad (2)$$

In this formula, $\text{PL}(d)$ indicated the path loss of receiving sign when the measuring distance is d (m), it indicated the absolute power value, and it is in dBm; $\text{PL}(d_0)$ indicated the path loss of receiving sign when the reference distance is d_0 ; n indicated the path loss index in a specific environment; it indicated the speed of the path loss, which is increased along with increasing distance; $X\sigma$ is in dB; it is a cover factor when the range of standard deviation σ is 4~10 and the mean value is 0; the larger the σ , the greater the uncertainty of the model.

The signal strength of receiving nodes is as follows:

$$\text{RSSI}=\text{Pt}-\text{PL}(d) \quad (3)$$

In this formula, Pt indicated the signal transmission power, $\text{PL}(d)$ indicated the path loss when the distance is d , and they are both in dBm. A indicated the signal strength which is received from reference nodes at the distance d_0 ; A is as follows:

$$A=\text{Pt}-\text{PL}(d_0) \quad (4)$$

The path loss model is as follows, which is measured at the real distance d (m):

$$P(d)=P(d_0)-10n\log_{10}(dd_0)-X\sigma \quad (5)$$

In this formula, $P(d)$ indicated the received signal strength when the measured real distance is d (m). $P(d_0)$ indicated received signal strength when the reference distance is d_0 , $X\sigma \sim N(0, \sigma^2)$.

We take the reference distance $d_0=1$ m; it can be obtained from formula (3) and formula (5).

$$\text{RSSI}=A-10n\log_{10}(d)-X\sigma \quad (6)$$

RSSI is regarded as the RSSI value of multiple times of measurement

$$\text{RSSI}=A-10n\log_{10}(d) \quad (7)$$

d is regarded as the undetermined distance

$$d=10(A-\text{RSSI})/10n \quad (8)$$

2.1. Acquisition of RSSI Data

Signal strength indicator (RSSI) is read from the register RSSI_VAI in the data packets which are received from sensor receiving nodes, a sensor node is set and regarded as a receiving device at intervals of 1 m, and RSSI data is measured at more than 400 times at every place, and each sensor node is received and recorded its signal strength value. Receiving nodes only can receive a few signal strength values beyond 25 m; parts of signal value are not detected, because the RSSI value of characterization signal attenuation is included in data packets, so it is meaningless to keep measuring. In this paper, the range of RSSI ranging is kept at 0~25 m. For example, the distance between sending node and receiving node is taken 5 m and 10 m, respectively, we have made statistics for collecting RSSI value and chosen more than 400 times of measurement to be a sample, although RSSI generally presented obvious non-stationary characteristics, the RSSI value in the certain distance is always fluctuated up and down between the constant real RSSI value, the closer distance from emission node, and the frequenter change of measurement value; on the contrary, the farther the distance from emission node, the gentler the change.

2.2. Shadowing Model

To exactly describe the actual measurement environment and ensure the accuracy of RSSI ranging, the parameters of the signal propagation model are needed to define. A indicated the received signal strength value when the reference distance is $d_0=1$ m and n indicated the path loss index. The determination of parameter A is as follows. $A=P(d_0)$, the radio frequency parameter A indicates the received absolute value of mean energy, which is received from the projection node when the distance is 1 m; it is in dBm. When the distance is 1 m, 500 groups of data are continuously measured; finally, there is a result that $A=117$.

The determination of parameter n is as follows. Environment factor n indicated, along with the increasing distance, the speed of signal loss in the process of the actual transmission. They are satisfied with the following relationship:

$$n=A-RSSI10*\log(d) \quad (9)$$

Where, n is obtained by generating more than 3000 groups of data in the range of 2~10 m.

3. GIS Description

GIS open source software has been growing, and the development and sharing of open source applications in environmental areas have significant benefits, namely the free distribution and the public availability of the code, allowing user customization. The Free and Open Source Software (FOSS) for GIS applications has several advantages, as new applications can be developed under them using open-source programming languages, such as Python, and different libraries (for instance, QGIS software, QGIS Application Programming Interface (API) and Qt API are commonly used in the development of new applications). Several GIS applications have been developed in different contexts, such as internet cafes, Telecom, Mobile Frequency, and others, combining different methodologies, making effective and improving the performance of the computing procedures. This trend was also, allowing the automatization of technologies and procedures

into agriculture practice. GIS software tools have been used in several studies to create the spatial variables required to predict agriculture production. The QGIS software is shown in fig.1.

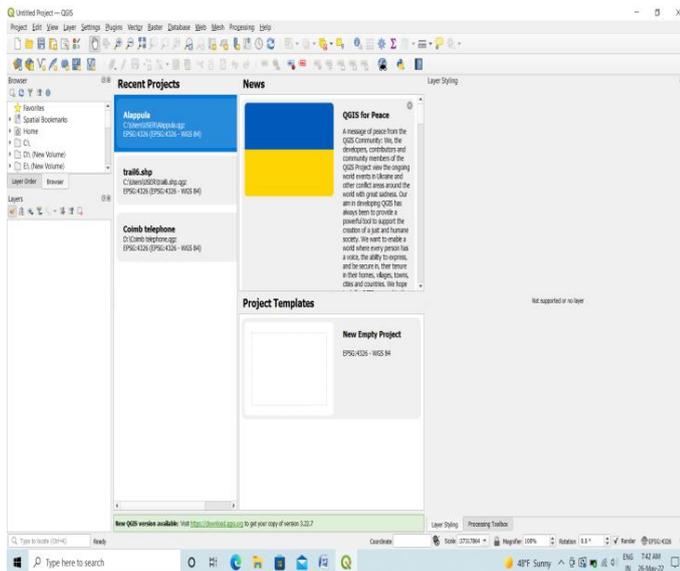


Fig.1.

4. Tools in QGIS

4.1. Vector Data

4.1.1. Point features

The first thing we need to realize when talking about point features is that what we describe as a point in GIS is a matter of opinion, and often dependent on scale. Let's look at cities for example. If we have a small-scale map, it may make sense to represent a city using a point feature. However, as we zoom in to the map, moving towards a larger scale, it makes more sense to show the city limits as a polygon.

4.1.2. Polyline features

Where a point feature is a single vertex, a polyline has two or more vertices. When two vertices are joined, a line is created. When more than two are joined, they form a 'line of lines', or polyline. A polyline is used to show the geometry of linear features such as roads, rivers, contours, footpaths, flight paths, and so on. Sometimes we have special rules for polylines in addition to their basic geometry. For example contour lines may touch (e.g. at a cliff face) but should never cross over each other. Similarly, polylines used to store a road network should be connected at intersections. In some GIS applications, we can set these special rules for a feature type and the GIS will ensure that these polylines always comply with these rules.

4.1.3. Polygon features

Polygon features are enclosed areas like the internet, Internet cafes, Telecom boundaries, and so on. Like polyline features, polygons are created from a series of vertices that are connected with a continuous line. However, because a polygon always describes an enclosed area, the first and last vertices should always be at the same place! Polygons often have shared geometry - boundaries that are in common with a neighboring

polygon. Many GIS applications can ensure that the boundaries of neighboring polygons exactly coincide. As with points and polylines, polygons have attributes. The attributes describe each polygon. For example, a dam may have attributes for depth and water quality.

4.1.4. Vector data in layers

Most GIS applications group vector features into layers. Features in a layer have the same geometry type (e.g. they will all be points) and the same kinds of attributes (e.g. information about what species a tree is for a tree's layer) as shown in Fig.2. For example, if we have recorded the positions of all the footpaths in a school, we will usually be stored together on the computer hard disk and shown in the GIS as a single layer. This is convenient because it allows us to hide or show all of the features for that layer in our GIS application with a single mouse click.

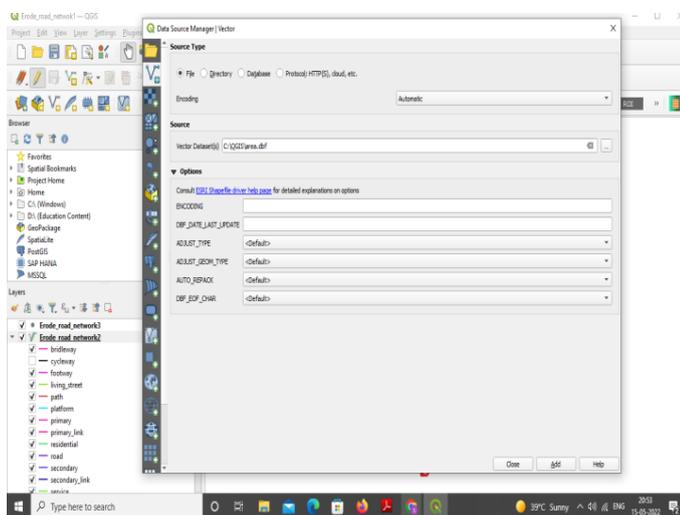


Fig.2.

4.1.5. Editing vector data

The GIS application will allow us to create and modify the geometry data in a layering process called digitizing. If a layer contains polygons (e.g. network, internet cafe), the GIS application will only allow us to create new polygons in that layer. Similarly, if we want to change the shape of a feature, the application will only allow us to do it if the changed shape is correct. For example, it won't allow us to edit a line in such a way that it has only one vertex. Creating and editing vector data is an important function of a GIS since it is one of the main ways in which we can create personal data for things we are interested in. As well as creating our data, there is a lot of free vector data that we can obtain and use.

4.1.6. Scale and vector data

Map scale is an important issue to consider when working with vector data in a GIS. When data is captured, it is usually digitized from existing maps, or by taking information from surveyor records and global positioning system devices. Maps have different scales, so if we import vector data from a map into a GIS environment, the digital vector data will have the same scale issues as the original map. Many issues can arise from making a poor choice of map scale.

4.1.7. Symbology

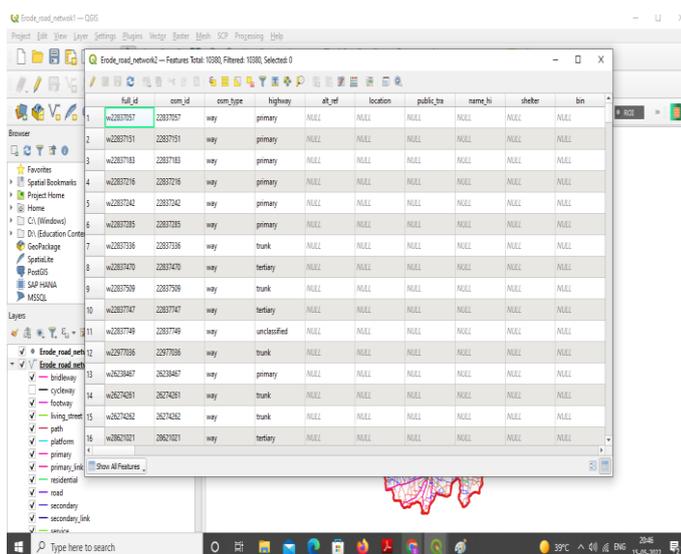
When we add vector layers to the map view in a GIS application, they will be drawn with random colors and basic symbols. One of the great advantages of using a GIS is that we can create personalized maps very easily. The GIS program will let us choose colors to suit the feature type. The GIS will also let us adjust the symbol used. So if we have a tree point layer, we can show each tree position with a small picture of a tree, rather than the basic circle marker that the GIS uses when we first load the layer. Symbology is a powerful feature, making maps come to life and the data in our GIS easier to understand.

4.2. Vector Attribute Data

Features are real-world things such as roads, property boundaries, electrical substation sites, and so on. A feature has a geometry that determines if it is a point, polyline, or polygon and attributes which describe the feature.

4.2.1. Attributes

Attributes for a vector feature are stored in a table. A table is like a spreadsheet. Each column in the table is called a field. The records in the attribute table in a GIS each correspond to one feature. Usually, the information in the attribute table is stored in some kind of database. The GIS application links the attribute records with the feature geometry so that we can find records in the table by selecting features on the map, and find features on the map by selecting features in the table. Each field in the attribute table contains a specific type of data such as text, numeric, or date as shown in Fig.3. Deciding what attributes to use for a feature requires some thought and planning.



full_id	com_id	com_type	highway	at_id	location	public_tr	name_tr	shelter	bin
w22837057	22837057	way	primary	NULL	NULL	NULL	NULL	NULL	NULL
w22837051	22837051	way	primary	NULL	NULL	NULL	NULL	NULL	NULL
w22837083	22837083	way	primary	NULL	NULL	NULL	NULL	NULL	NULL
w22837216	22837216	way	primary	NULL	NULL	NULL	NULL	NULL	NULL
w22837042	22837042	way	primary	NULL	NULL	NULL	NULL	NULL	NULL
w22837085	22837085	way	primary	NULL	NULL	NULL	NULL	NULL	NULL
w22837336	22837336	way	trunk	NULL	NULL	NULL	NULL	NULL	NULL
w22837470	22837470	way	tertiary	NULL	NULL	NULL	NULL	NULL	NULL
w22837509	22837509	way	trunk	NULL	NULL	NULL	NULL	NULL	NULL
w22837747	22837747	way	tertiary	NULL	NULL	NULL	NULL	NULL	NULL
w22837749	22837749	way	unclassified	NULL	NULL	NULL	NULL	NULL	NULL
w22837036	22837036	way	trunk	NULL	NULL	NULL	NULL	NULL	NULL
w26238487	26238487	way	primary	NULL	NULL	NULL	NULL	NULL	NULL
w26274261	26274261	way	trunk	NULL	NULL	NULL	NULL	NULL	NULL
w26274262	26274262	way	trunk	NULL	NULL	NULL	NULL	NULL	NULL
w2627021	2627021	way	tertiary	NULL	NULL	NULL	NULL	NULL	NULL

Fig.3.

4.2.2. Single Symbols

If a feature is symbolized without using any attribute table data, it can only be drawn simply as shown in Fig.4. A GIS application will normally allow us to set the symbology of a layer using a dialog box. In this dialog box, we can choose colors and symbol styles depending on the geometry type of a layer.

the GIS Application, we can open/choose to use Unique Value symbology for a layer. The GIS will scan through all the different string values in The attribute field and build a list of unique strings or numbers. Each unique value can then be assigned a color and style as in Fig.5

4.3. Data Capture

There are two key concepts to vector data, namely: geometry and attributes. The geometry of a vector feature describes its shape and position, while the attributes of a vector feature describe its properties such as color, size, age, etc. Word processors, spreadsheets, and graphics packages are all programs that let us create and edit digital data. Each type of application saves its data into a particular file format. For example, a graphics program will let us save our drawing as a .jpg JPEG image, word processors let us save our document as a .odtOpenDocument or .doc Word Document, and so on. Just like these other applications, GIS Applications can store their data in files on the computer's hard disk. There are several different file formats for GIS data, but the most common one is probably the 'shape file'. The name is a little odd in that although we call it a shape file (singular), it consists of at least three different files that work together to store our digital vector data, as shown in the table1.

Table 1

Extension	Description
.shp	The geometry of vector features is stored in this file.
.dbf	The attributes of vector features are stored in this file.
.shx	This file is an index that helps the GIS Application to find features more quickly.

Many GIS applications are also able to store digital data inside a database. In general, storing GIS data in a database is a good solution because the database can store large amounts of data efficiently and can provide data to the GIS Application quickly. Using a database also allows many people to work with the same vector data layers at the same time.

4.3.1. Creating an empty shapefile

Once we have planned what features we want to capture into the GIS, and the geometry type and attributes that each feature should have, we can move on to the next step of creating an empty shapefile. The process usually starts with choosing the 'new vector layer' option in our GIS Application and then selecting a geometry type which means choosing either point, polyline, or polygon for the geometry. Next, we will add fields to the attribute table. Normally we give short field names, have no spaces, and indicate what type of information is being stored in that field. Example field names may be 'pH', 'RoofColor', 'network frequency',

and so on. As well as choosing a name for each field, we need to indicate how the information should be stored in that field. The shapefile format allows us to store the numeric field information as either a whole number (integer) or a decimal number (floating point) The final step for creating a shapefile is to give it a name and a place on the computer hard disk where it should be created which is shown in Fig.6.

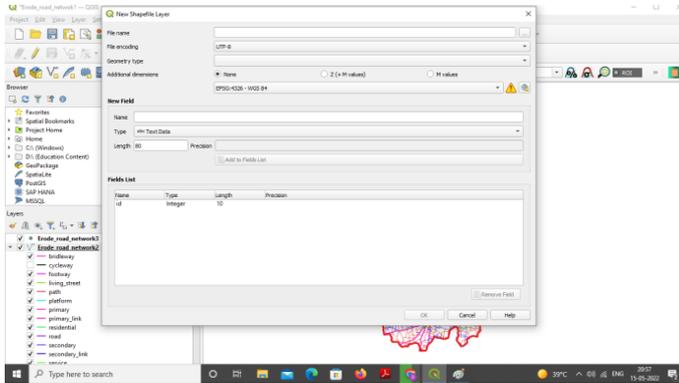


Fig.6.

4.3.2. Adding data to shapefile

We need to enable editing in the shapefile using the 'enable editing' menu option or toolbar icon in the GIS Application. Shapefiles are not enabled for editing by default to prevent accidentally changing or deleting the data they contain.

Next, we need to start adding data. There are two steps we need to complete for each record we add to the shapefile:

- Capturing geometry.
- Entering attributes.

The process of capturing geometry is different for points, polylines, and polygons. To capture a point, we first use the map pan and zoom tools to get to the correct geographical area where we are going to be recording data. Next, we will need to enable the point capture tool. Having done that, the next place we click with the left mouse button in the map view is where we want our new point geometry to appear. After we click on the map, a window will appear and we can enter all of the attribute data for that point. If we are unsure of the data for a given field we can usually leave it blank, but be aware that if we leave a lot of fields blank it will be hard to make a useful map from our data.

To capture a polyline the process is similar to that of a point, in that we need to first use the pan and zoom tools to move the map in the map view to the correct geographical area. We should be zoomed in enough so that our new vector polyline feature will have an appropriate scale. When we are ready, we can click the polyline capture icon in the toolbar and then start drawing our line by clicking on the map. After we make our first click, we will notice that the line stretches like an elastic band to follow the mouse cursor around as we move it. Each time we click the left mouse button, a new vertex will be added to the map. When we have finished defining our line, use the right mouse button to tell the GIS Application that we have completed our

edits. As with the procedure for capturing a point feature, we will then be asked to enter the attribute data for our new polyline feature. The process for capturing a polygon is almost the same as capturing a polyline except that we need to use the polygon capture tool in the toolbar.

4.4. Map Production

Map production is the process of arranging map elements on a sheet of paper in a way that, even without many words, the average person can understand what it is all about. Maps are usually produced for presentations and reports where the audience or reader is a politician, citizen, or learner with no professional background in GIS. Because of this, a map has to be effective in communicating spatial information. Common elements of a map are the title, map body, legend, north arrow, scale bar, acknowledgment, and map border which are shown in Fig.7.

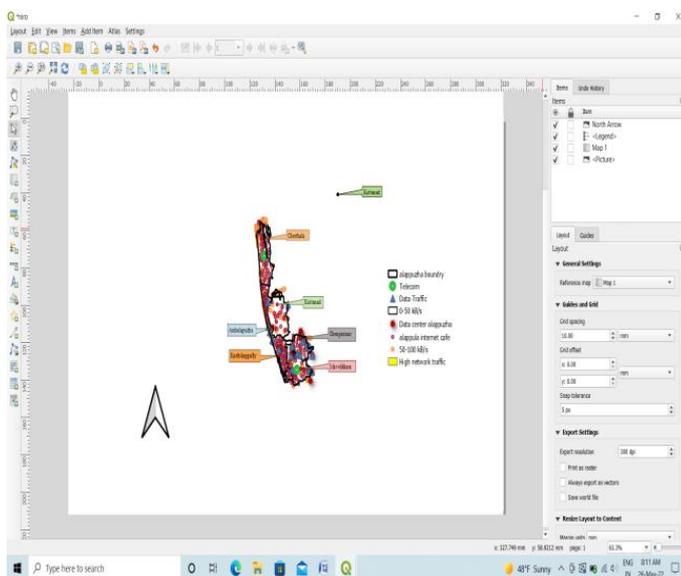


Fig.7.

4.4.1. Map title

The map title is very important because it is usually the first thing a reader will look at on a map. It can be compared with a title in a newspaper. It should be short but give the reader a first idea of what the map is about.

4.4.2. Map Border

The map border is a line that defines exactly the edges of the area shown on the map. When printing a map with a graticule (which we describe further down), we often find the coordinate information of the graticule lines along the border lines.

4.4.3. Map Legend

A map is a simplified representation of the real world and map symbols are used to represent real objects. Without symbols, we wouldn't understand maps. To ensure that a person can correctly read a map, a map legend is used to provide a key to all the symbols used on the map. It is like a dictionary that allows us to

understand the meaning of what the map shows. A map legend is usually shown as a little box in a corner of the map. It contains icons, each of which will represent a type of feature.

4.4.4. Scale

The scale of a map, is the value of a single unit of distance on the map, representing the distance in the real world. The values are shown in map units such as meters, feet, or degrees. The scale can be expressed in several ways, for example, in words, as a ratio, or as a graphical scale bar. Expressing a scale in words is a commonly used method and has the advantage of being easily understood by most map users. Another option is the **representative fraction (RF)** method, where both the map distance and the ground distance in the real world are given in the same map units, as a ratio. A scale expression as a graphic or bar scale is another basic method of expressing a scale. A bar scale shows measured distances on the map.

5. Conclusion

This paper presented the QGIS applicability in Network monitoring, with the advanced methods of data analysis. The developed solution implements all the requirements we proposed for that purpose and successfully achieves our objectives. The presented paper demonstrated how satellite images can be processed and visualized the Mobile Signal Strength using RSSI Algorithm through QGIS Software. A particular way of processing this data was also implemented, consisting of creating a signal strength grid covering the Earth to be displayed in a coverage map. The work now serves as a basis for others to build upon in the future. With more measurements in our database, it will be interesting to cross them over with external data, to perform studies such as the coverage within different geographical areas, the correlation of signal strength with the topographical information in a given area, or the location of public Wi-Fi hotspots.

Declarations

Source of Funding

This research did not receive any grant from funding agencies in the public or not-for-profit sectors.

Consent for publication

Authors declare that they consented for the publication of this research work.

References

- [1] Mamta Agarwal, Hyeyeon Kwon, Seungkeun Park, Hu Jin, "A survey on 4G-5G Dual connectivity: Road to 5G implementation" 18 January 2021 IEEE.
- [2] Habiba Elsherbiny, Ahmad M. Nagib, Hatem Abou-zeid, Hazem M. Abbas, Hossam S. Hassanein, Aboelmagd Noureldin "4G LTE Network Data Collection and Analysis along Public Transportation Routes" 12 February 2021 in GLOBECOM 2020 - 2020 IEEE Global Communications Conference.
- [3] Orlando S. Trindade, Taulant Berisha, Philipp Svoboda, Efstathia Bura, Christoph F. Mecklenbräuer, "Assessment of Treatment Influence in Mobile Network Coverage on Board High-Speed Trains" 03 September 2020 IEEE.

- [4] Riyam K. Marjan, Mohammed H. Aldulaimi, Rana Saeed Hamdi Al-Naseri, “Design and evaluation of Wi-Fi Network Heat map generator”, 2019 1st AL-Noor International Conference for Science and Technology (NICST).
- [5] Jie Chen “Network Analysis Based on 2/4G Common Coverage Research in Rural Area”, 2018 IEEE International Conference on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData).
- [6] Till Koebe "Better coverage, better outcomes? Mapping mobile network data to official statistics using satellite imagery and radio propagation modeling" Published: November 9, 2020.
- [7] Yisroel Mirsky, Yoram Haddad, Orit Rozenblit, Rina Azoulay, “Predicting wireless coverage maps using radial basis networks”, 2018 15th IEEE Annual Consumer Communications & Networking Conference.
- [8] Yunfeng Nie, Chongyi Chen, Changsheng Wang “Radio Coverage Mapping in Wireless Sensor Networks” 2014 <https://www.researchgate.net/deref/http%3A%2F%2Fwww.scirp.org%2Fjournal%2Fwsn>.
- [9] Jaymin D. Mankowitz; Andrew J. Paverd, “Mobile device-based cellular network coverage analysis using crowd sourcing”, IEEE EUROCON - International Conference on Computer as a Tool.
- [10] Jazmín Ponce-Rojas “A Geographic Information System Applied to Coverage Maps of 3G Cellular Communications Networks”, Published Online April 2011 <http://www.SciRP.org/journal/jgis>.