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Development of Spectrum Management Tool Using Open-Source Geographical Information System (GIS) Software

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ABSTRACT

Background: Mobile communication is one of the fastest evolving technologies in the world. With the availability of new services and applications, the demand for spectrum access is increasing. However since the spectrum is a limited source, a proper planning to accommodate this demand is required. Proprietary spectrum management software is expensive and not a cost effective solution in a long run. It is also too rigid to adapt with the mobile communication rapid evolution. There is a need for low cost home-grown spectrum management tool that can assist regulatory body in spectrum management process. The tool must be able to help in managing existing spectrum and also for new spectrum planning. This paper outlines the use of open-source resources to develop the proposed tool. The tool incorporates and embeds the rules and regulations specified by Malaysian authority. The home-grown tool is able to carry out spectrum planning and management for 2G, Global System for Mobile Communications (GSM), and 3G, Universal Mobile Telecommunications System (UMTS) networks.

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INTRODUCTION

In today's society, mobile communication has become one of the basic needs of living. With the development of mobile devices such as smartphone and tablet computer, people are accessing the internet anytime, anywhere. They stream media online, uploading and downloading files and accessing social media sites from their devices. This attracts more people to go mobile and increases the number of subscribers in telecommunication network. Subsequently, more spectrum bandwidth is needed to cater the increasing number of users in mobile communication. However, since radio frequency (RF) spectrum is a limited resource, a proper planning is needed to increase the spectrum access (Chandra, 2009). Fundamentally, spectrum access can be increased by increasing the number of base station. Installing new base station requires detail planning since interference can happen between base stations. Interference can lower the quality of service (QoS) in the network and can lead to signal corruption.

Adjacent channel interference and co-channel interference are two types of interference that commonly occur in mobile network (Schiller, 2003). Adjacent channel interference happened when the adjacent channels overlapped with each other. This occurs when the adjacent channels are occupied by two different providers. A simple solution to mitigate this is by building the adjacent channels BS far away from each other. Another common interference is the co-channel interference. Since RF spectrum is a scarce resource, the same frequency channel has to be reuse in order to increase the spectrum availability. However, interference can happen if the co-channel BSs are built within the reuse distance. In order to mitigate this problem, the distance between the co-channel BS must be set farther than the reuse distance. The reuse distance is much dependent on the cell radius and network cluster size.

Spectrum planning is carried out by national regulatory bodies. They regulate and coordinate the spectrum according to their spectrum plan. Most regulators manage the spectrum coordination using proprietary spectrum management software. In Malaysia, spectrum planning is managed by Malaysian Communications and Multimedia Commission (MCMC). According to Latef and Hassan (2011), a less effective spectrum management system might be in placed. Proprietary software are typically expensive and rigid ie non customisable. Mobile

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technology is constantly changing without any sign of stopping. Using proprietary software can be very costly in a long run. Regulatory bodies need to spend hundred thousands of dollars to pay the developer just to keep up with the changes. It is now evident that there is a need to develop a home-grown spectrum management tool that not only cost effective but also can adapt to new technology in mobile communication. This can be achieved by using open-source resources. Open-source technology evolves very quickly as there is less restriction in its development. It is also a lot easier and quicker for applications to be built using open-source resources as it is very adaptable with new technology as compared to proprietary resources (Acuna *et al.*, 2012). This paper proposed the use of open-source geographical information system (GIS) software to develop a home-grown spectrum management tool. With rapid evolvement of open-source resource, an advance and flexible tool can be developed.

This paper is structured as follows. Section 2 outlines the research scope and methodology. Section 3 discusses the path loss models and its implementation. Section 4 summarizes the proposed tool overall design and development. Section 5 highlights the results and findings of the research. Section 6 concludes the research of this paper. Section 7 offers recommends and suggestions for future development.

Research Scope and Methodology:

The proposed spectrum management tool is aims to help regulatory bodies to manage radio spectrum. Spectrum planning, interference identification, and spectrum management and monitoring are among the common tasks in spectrum management system (SKMM, 2007). The current development of the research is focusing on cellular network particularly Global System for Mobile Communications (GSM) and Universal Mobile Telecommunications System (UMTS) networks in Malaysia. The current prototype of the proposed tool is able to assist in spectrum planning and interference identification. The tool is also developed only using open-source resources without having to depend on commercial resources.

A. Methodology :

The activities in Fig.1. serve as the guideline for the development of proposed spectrum management tool.

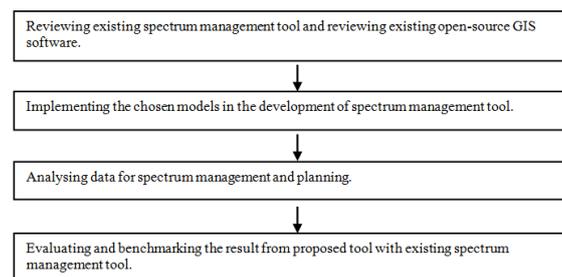


Fig. 1: Research methodology flow chart.

Path Loss Modeling and Implementation:

Propagation distance determines the cell coverage area of base station. Propagation distance can be calculated using RF propagation path loss model. There is no restriction on how extensive RF propagation path loss modelling should be. In this research, the proposed tool implements the available standard path loss models which are Hata model for GSM900 and Cost-231 Hata model for GSM1800 and UMTS2100 (Blaunstein and Christodoulou, 2007). The path loss for GSM900 is calculated using Hata model equation as given:

$$LP(dB) = 69.55 + 26.16 \log_{10}(f_c) - 13.82 \log_{10}(h_{tr}) - a(h_{re}) + (44.9 - 6.55 \log_{10}(h_{tr})) \log_{10}(d) - K. \quad (1)$$

Where:

d= distance between base station and mobile station in km.

f_c = carrier frequency in MHz.

h_{tr} = Base antenna height in meter.

h_{re} = Mobile antenna height in meter.

$$a(h_{re}) = \begin{cases} (1.1 \log_{10}(f_c) - 0.7) h_{re} - (1.56 \log_{10}(f_c) - 0.8), & \text{open, suburban and small city area} \\ 3.2(\log_{10} 11.75(h_{re}))^2 - 4.97, & \text{large city } (f_c > 400) \end{cases} \quad (2)$$

$$K = \begin{cases} 4.78(\log_{10}(f_c))^2 - 18.33.78(\log_{10}(f_c)) + 40.94, & \text{open area} \\ 2[\log_{10}\left(\frac{f_c}{28}\right)]^2 - 5.4, & \text{suburban area} \\ 0, & \text{medium - small City and large city } (f_c > 400) \end{cases} \quad (3)$$

The path loss for GSM1800 and UMTS2100 can be calculated using Cost-231 equation as given:

$$LP(dB) = 46.3 + 33.9 \log_{10}(f_c) - 13.82 \log_{10}(h_{tr}) - a(h_{re}) + (44.9 - 6.55 \log_{10}(h_{tr})) \log_{10}(d) + C \quad (4)$$

Where:

d = distance between base station and mobile station in km.

f_c = carrier frequency in MHz.

h_{tr} = Base antenna height in meter.

h_{re} = Mobile antenna height in meter.

$a(h_{re})$ = equation (2)

$C = 0$, medium city and suburban areas or

$C = 3$, metropolitan areas

By rearranging terms (1) into (5) and (4) into (6), the propagation distance can be represented by:

$$d = \text{antilog}_{10} \left(\frac{LP(dB) - 69.55 - 26.16 \log_{10}(f_c) + 13.82 \log_{10}(h_{tr}) + a(h_{re}) + K}{44.9 - 6.55 \log_{10}(h_{tr})} \right) \quad (5)$$

$$d = \text{antilog}_{10} \left(\frac{LP(dB) - 46.3 - 33.9 \log_{10}(f_c) + 13.82 \log_{10}(h_{tr}) + a(h_{re}) - C}{44.9 - 6.55 \log_{10}(h_{tr})} \right) \quad (6)$$

Ideally RF propagates in free space. However in really, there are external factors from the environment that will influence the RF propagation. Foliage, weather conditions, man-made structures and hills are among the RF propagation obstructers. These obstruction will induce additional effects mainly reflection, scattering and diffraction. While the chosen path loss models empirically include the loss due to area types, this is still not enough to model the actual propagation. The proposed tool includes diffraction loss effect due to terrain in the overall path loss calculation. This research considers the single knife-diffraction effect modelling to illustrate this effect and the loss is calculated using equations (2) or (4). The Fresnel-Kirchhoff diffraction parameter, v has to be determined first. The value of v can be calculated using equation (7) for situation in Fig.2 or equation (8) for situation in Fig.3. which then simplified into Fig.4 (Seybold, 2005).

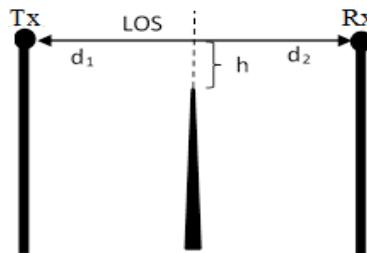


Fig. 2: Transmitter, Tx and receiver, Rx are n same height.

$$v = h \sqrt{\frac{2(d_1 + d_2)}{\lambda d_1 d_2}} \quad (7)$$

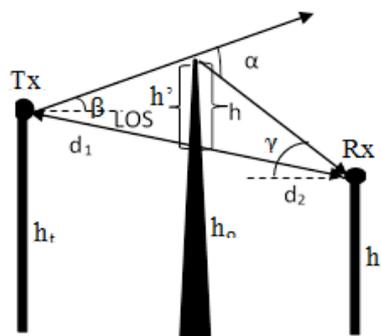


Fig. 3: Transmitter, Tx and receiver, Rx are not in same height.

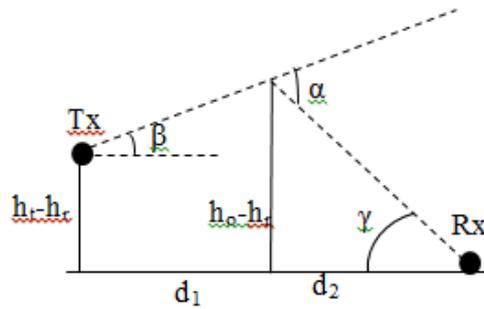


Fig. 4: Simplified version of Fig.3.

$$v = \alpha \sqrt{\frac{2d_1d_2}{\lambda(d_2 + d_2)}}, \text{ where } \alpha = \beta + \gamma \tag{8}$$

The threshold value for the path loss is determined by the receiver sensitivity. It can be calculated using the equation:

$$LP_{max} = P_T + G_{TO} - R_s \tag{9}$$

Where

LP_{max} = Losses in dB

P_T = Transmitted Power in dBm

G_{TO} = Total gains in dB

R_s = Receiver sensitivity in dBm

Since the research is focusing on cellular network in Malaysia, the rules and regulations outlined by MCMC has been adopted in the proposed tool. MCMC has assigned specific blocks of channels to cellular service providers in Malaysia. They are expected to abide the assignment shown in Fig.5. and Fig.6. for GSM networks and Fig.9. for UMTS2100 network (SKMM, 2012).

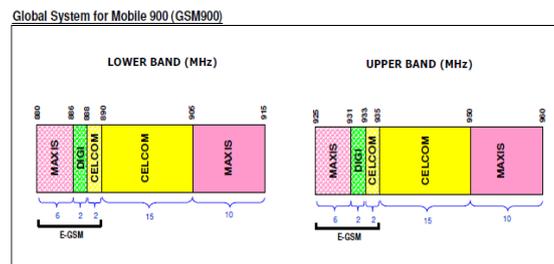


Fig. 5: GSM900 Frequency Band Assignment (SKMM, 2012).

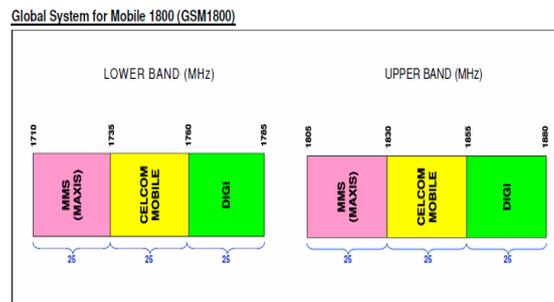


Fig. 6: GSM1800 Frequency Band Assignment (SKMM, 2012).

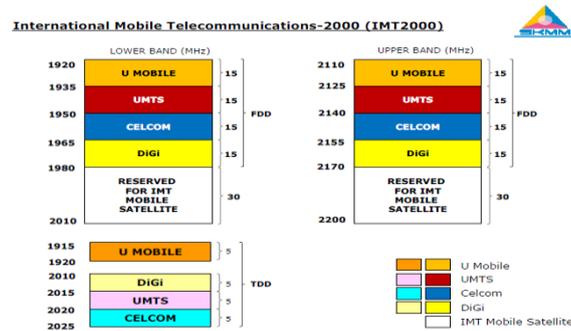


Fig. 7: IMT2000 (UMTS2100) Frequency Band Assignment (SKMM, 2012).

Software Design and Development:

This paper intends to outline the usage of open-source resources in the development of the proposed spectrum management tool. The emergence of open-source GIS has led to its usage in several communication research fields such as works by (Shu *et al.*, 2011), (Alexandris and Giannikos, 2010) and (Umar *et al.*, 2011). GIS is a tool that is mainly used for managing spatial data and displaying the data on the map (Quantum GIS, 2013). An open-source GIS, Quantum GIS (QGIS) 2.2.0, Valmiera has been chosen as the GIS platform. The tool is developed in the form of a QGIS plugin using PyQT programming language. The tool has a user-friendly graphical user interface (GUI) and is easy to navigate. Data are stored inside the database and hard disk. The tool uses an open-source database management system (DBMS), PostgreSQL with PostGIS extension to manage the spatial data. The overall architecture of the proposed tool is described in Fig. 8.

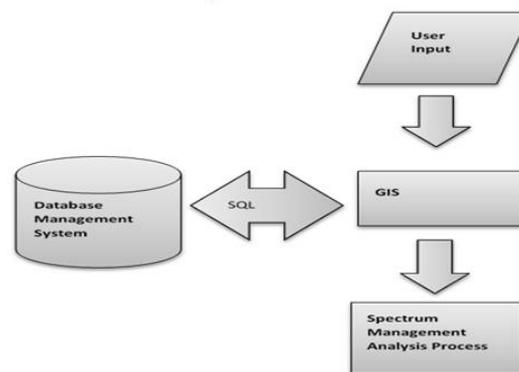


Fig. 8: Tool's overall structure.

The development process of the developed tool is adapted from the Boehm spiral software process model. Four basic quadrants of the spiral model in Fig. 9 have been iterated cyclically throughout the development process (Pressman, 2010). At the current stage, a prototype for the proposed tool has been completely developed. The tool takes the path loss value, which is a continuous data, as the output for displaying the coverage area on the map. The first procedure entails a task where the tool will determine the propagation distance of the base station. Next, path loss values for a square area, which are based on the propagation distance, are calculated. Diffraction loss is then implemented, depending on whether users choose to include knife-diffraction loss for the calculation. Finally, a raster image will be drawn as the output. The coverage area shape is determined according to the chosen base station antenna type. The flow chart of the process is depicted in Fig. 10. A simple adjacent and co-channel interference algorithm has also been implemented using the adjacent cell distance and reuse distance separation techniques.

Preliminary Results and Discussion:

The proposed tool is developed under a plugin labelled as Malaysia Spectrum Management Tool "Malspectrum" shown in Fig. 11. The plugin is made accessible from the plugin menu or by clicking on the Malspectrum plugin's icon as shown in Fig. 12. Several layers are initialized and loaded into the plugin in order to make the plugin functional. The layers include the base station layer, terrain layer, area type layer, which contains the information whether the base station is situated in open area, suburban, small city, and medium-large city, and also map layer.



Fig. 9: Boehm' Spiral Model Basic Quadrant.

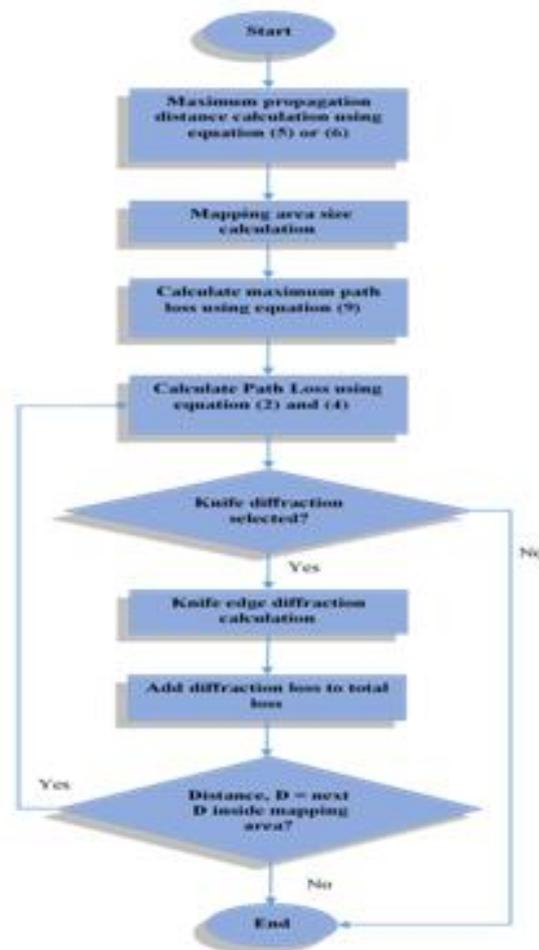


Fig. 10: Flow chart for calculation coverage area display of proposed tool.

The main features of the developed tool are its capabilities to display spectrum coverage area on the map and identify interference. In the earlier version prototype, the output for spectrum coverage area was represented using vector polygon data type. Since the output is in continuous data, vector data cannot display the coverage area accurately. The current prototype implements raster data to represent the output. Using different colour codes, a colourful and meaningful map can be displayed. The red colour represents smaller path loss while the blue colour represents the higher path loss. Fig.13 demonstrates cell coverage without knife-diffraction loss effect while Fig.14 demonstrates its inclusion. From the figures, it is clear that without diffraction loss, the cell coverage will be in the perfect shape. However, this is not very useful for spectrum management. MCMC can use these result for initial decision. The results can be useful for initial investigation pertaining to the spectrum availability

in specific area. The tool provides a simple adjacent cell and co-channel interferences identification. It can be useful in planning new base station to avoid interference. The tool also offers antenna pattern library which the pattern can be displayed on the map accordingly.

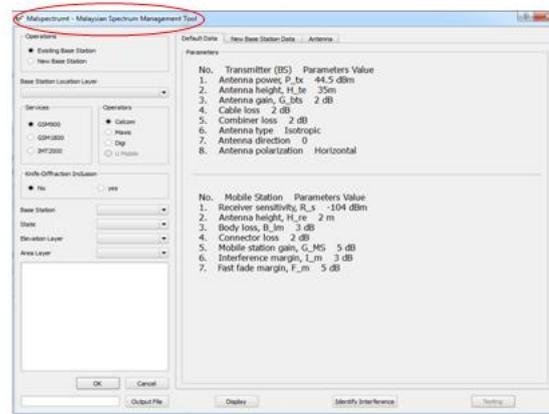


Fig. 21: Spectrum Display GUI.

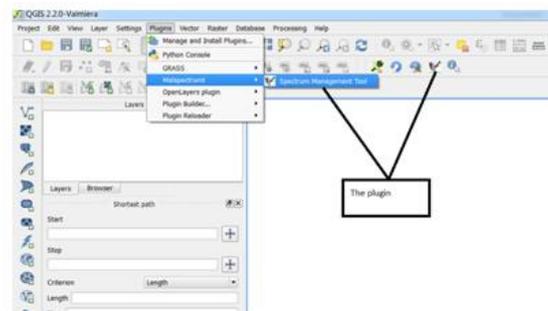


Fig. 32: Plugins pop-up menu on menu bar.

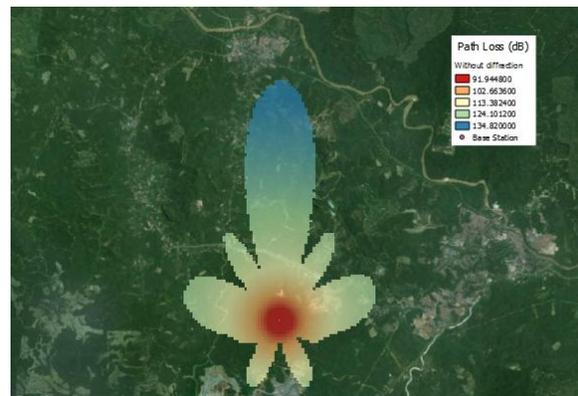


Fig. 43: Cell coverage without diffraction loss.

Conclusion:

The prototype of Malspectrum is presented in this paper. The tool is created using open-source resources which basically reduce the development cost to minimal. The tool is developed as QGIS plugin and connected to PostgreSQL DBMS which is used to store the spatial data. The tool follows the rules and regulations enforced by MCMC and focuses on GSM and UMTS networks. Two main features of the proposed tool have been highlighted which are displaying spectrum coverage area using chosen propagation models and identifying interference using simple adjacent cell and co-channel interference algorithm. The proposed tool is flexible and can be developed further to accommodate new mobile communication technologies.

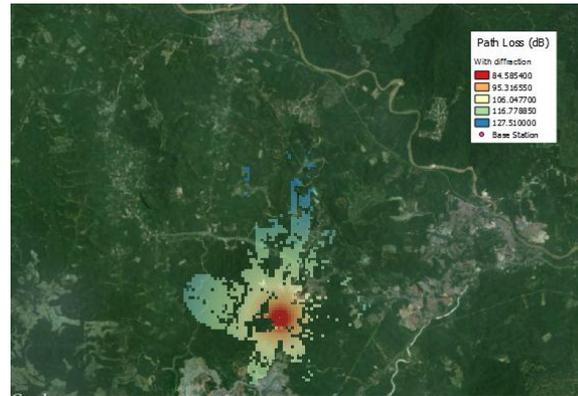


Fig. 54: Cell coverage with diffraction loss.

Future Work:

The current prototype only has path loss as the unit measurement for output. The next prototype can include received power and field strength as measurement units. Other propagation models such as Walfisch-Ikegami model, Consultative Committee on International Radio (CCIR) model, or Longley-Rice model can be included in the proposed tool in addition to the existing propagation models. Detail multi-path effects can also be designed and included for better accuracy. The tool can be enhanced further to include more functionality such as LTE network, energy harvesting or display RF radiation level.

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