Field strength prediction of mobile communication network based on GIS

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This article describes GIS-based models successfully developed for predicting the coverage of Cityphone cellular network, visualizing the predicted signal strength, and analyzing the field strength coverage. In order to predict the signal coverage strength of communication network more accurately, the spatial and nonspatial databases of a mobile cellular network are combined by GIS and produce the necessary parameters. A GIS model named COST-231-Walfisch–Ikegami model (WIM) is developed for signal coverage prediction in Ho Chi Minh City. Radio-line-of-sight and nonradio-line-of-sight conditions can be determined by this model. In addition, in case of nonradio-line-of-sight conditions, average building height, building separation, building width, incident radio path, and road orientation with respect to the direct radio path were obtained using GIS. Road orientation loss, multiscreen diffraction loss, and shadowing gain were predicted more accurate by this model. The scale of maps in the experiment was 1:2000 and the average of floor height was 3 m because there were no exact building height measurements. Statistical results show that the path loss predicted by the COST 231 WIM overcame the real path loss of each cell station. And this method can be used for signal coverage prediction of mobile cellular network in urban areas. Compared to the current situation with the Ho Chi Minh City Posts and Telecommunications system, this model can be effectively applied to improve the Cityphone mobile network quality as well as capability. Developed GIS models can help designers in predicting cell station coverage using real spatial maps that make the results more reliable. This research can help network operators improve the network quality and capability with the best investment efficiently.

Keywords: mobile communication network; GIS model; field strength prediction

1. Introduction

Cellular mobile phones have become one of the most useful services nowadays. The amount of people who use mobile phones has increased dramatically in Vietnam especially in Ho Chi Minh City (HCMC) and Hanoi leading to a demand for increased mobile system capacities both quantitatively as well as qualitatively. There are many mobile phone systems in Vietnam using Global System for Mobile Communications, Code Division Multiple Access, and Personal Handyphone System (PHS). Cityphone is a cellular phone system using PHS, Vietnam Posts and Telecommunications launched in both Hanoi and HCMC in 2002 and 2003, respectively. Today, it is necessary to improve Cityphone system capability from both the quality and economic aspect in order to supply reliable services to customers. To address the requirements for optimizing the cell station network, currently, there is no appropriate tool to exactly evaluate or predict the field strength coverage areas in the system, all tasks are done manually. Geographic information system (GIS) technology is an effective solution that could deal with the problem by combining spatial data from base maps and nonspatial data such as cell station databases in order to assist the operator in storing, updating, displaying, analyzing, and performing other statistic work related to the network. The prediction of field strength is a new application of GIS in mobile cellular networks. This article targets the application of GIS in the telecommunication field, especially on cellular City phone networks and capability and quality issues (1–4).

In cellular mobile communications, especially in cellular network planning, the accuracy of field strength propagation prediction depends very much on propagation models. To deal with the difficulties of network planning engineers, GIS is a suitable tool for inputting, storing, modifying, and analyzing spatial databases to create the necessary spatial parameters for field strength prediction models (5, 6).

A number of researchers have reported the successful use of a GIS solution for telecommunications. It is necessary to overview technologies regarding the objectives mentioned in this article.

1.1. GIS in cellular mobile communications

Figures 1 and 2 present GIS integration of data and the telecom reality of GIS solutions for telecommunications.
The solutions were developed by Environmental Systems Research Institute (ESRI).

1.2. Wave propagation in mobile communication

Reflection, diffraction, and scattering are the three basic propagation mechanisms that impact propagation in mobile communication systems (13). Reflection occurs when a propagating electromagnetic wave impinges upon an object that has very large dimensions compared to the wavelength of the propagating wave. Figure 3 clearly shows reflection mechanisms, when rays are reflected by building and ground. Diffraction happens, when the radio path between the transmitter and receiver is obstructed by a surface that has sharp edges (see more details in Figure 4). Scattering occurs when the medium through which the wave propagates consists of objects with dimensions that are small compared to the wavelength, and where the number of obstacles per unit volume are large. Figure 5 presents somewhat of scattering.

1.3. Path loss models

There are two major classes of path loss models, the statistical or empirical model and site-specific models. The empirical models such as the Okumura et al. model, Hata model, COST-231-Walfisch–Ikegami model (WIM), or dual-slope model usually use the parameters determined from measurements while the site-specific methods include ray-tracing techniques such as the finite-difference time-domain (FDTD) model, moment method (MoM) model, or artificial neural network (ANN) model that mainly use ray tracing. The empirical models are simple, but the predictions are not very accurate. On the other hand, site-specific models are considerably more accurate than the empirical models, but they require specific information about the area of interest (7). The comparison among some of the main path loss models is presented in Table 1.

The Cityphone cellular network in HCMC currently uses microcell propagation, but the cell stations were designed basing on the building density categories. Cell radii were mainly assumed according to the area category which the cell station belongs. Consequently, the network operator cannot optimize the whole system effectively. To deal with the difficulties in optimizing current Cityphone network, we carried out this study to find the best solution in network propagation prediction.

Previous studies in cellular propagation indicate that in microcell prediction, COST-231-WIM, dual-slope, and ray-tracing models are adequate models for outdoor...
microcell field strength prediction. Basing on the condition in HCMC, COST 231 WIM is the most suitable model that can be used to optimize Cityphone cellular system in HCMC.

In addition, evaluating a cellular network propagation quality after installing the whole system is required. The step will be carried out by using field strength measurement to record signal strength at every test point within study area. The test point records will be displayed exactly on the network map together with their locations according to the coordinates recorded by GPS.

2. Some theory behind the field strength prediction

2.1. COST-231-WIM

The WIM has shown superiority to measure propagation data for frequencies in the range of 800–2000 MHz and path distances, alternatively called cell radius, in the range of 0.02–5 km. Figure 6 illuminates the symbols used in the formulae.

Parameters used in the model: frequency \( f \) (800–2000 MHz); base station height \( h_1 \) (4–50 m); mobile station height \( h_2 \) (1–3 m); distance \( d \) (0.02–5 km); height of building roofs \( h_r \); width of road \( w \); building separation \( b \); and road orientation with respect to the direct radio path \( \phi \).

The basic formula for the median propagation loss is given by formula (1):

\[
L_b = \begin{cases} 
L_0 + L_{\text{ts}} + L_{\text{msd}}, & L_{\text{ts}} + L_{\text{msd}} \geq 0 \\
L_0, & L_{\text{ts}} + L_{\text{msd}} < 0 
\end{cases}
\]

where \( L_0 \) = free-space path loss, \( L_{\text{ts}} \) = roof-top-to-street diffraction and scatter loss, \( L_{\text{msd}} \) = orientation loss due to the road orientation with respect to the direct radio path, and \( L_{\text{msd}} \) = multiscreen diffraction loss.

\[
L_0 = 32.4 + 20 \log d_{km} + 20 \log f_{\text{MHz}}
\]

\[
L_{\text{ts}} = -16.9 - 10 \log w + 10 \log f_{\text{MHz}}
\]

\[
+ 20 \log(h_1 - h_2) + L_{\phi}
\]

\[
L_{\phi} = \begin{cases} 
-10 + 0.354\phi, & 0 \leq \phi < 35^0 \\
2.5 + 0.075(\phi - 35), & 35 \leq \phi < 55^0 \\
4.0 - 0.114(\phi - 55), & 55 \leq \phi < 90^0 
\end{cases}
\]

\[
L_{\text{msd}} = L_{\text{obs}} + k_a + k_d \log d_{km} + k_l \log f_{\text{MHz}} - 9 \log b
\]

\( d_{km} \) is the link distance or cell radius in kilometers, \( f_{\text{MHz}} \) is the center frequency in megahertz, \( L_{\text{obs}} \) is the shadowing gain (negative loss) that occurs when the base station antenna height is higher than the rooftops, and \( k_a, k_d, k_l \) is a quantity that determines the dependence of the multiscreen loss \( L_{\text{msd}} \).

\[
L_{\text{obs}} = \begin{cases} 
-18 \log(1 + h_1 - h_t), & h_1 > h_t \\
0, & h_1 \leq h_t
\end{cases}
\]

\[
k_a = \begin{cases} 
54, & h_1 > h_t \\
54 - 0.8(h_1 - h_t), & d_{km} \geq 0.5, h_1 \leq h_t \\
54 - 1.6d_{km}(h_1 - h_t), & d_{km} < 0.5, h_1 \leq h_t
\end{cases}
\]

Figure 6. Wallisch–Ikegami model.
\[ k_d = \begin{cases} 18, & h_1 > h_r \\ 18 - 15(h_1 - h_r)/\ln 16, & h_1 \leq h_r \end{cases} \tag{8} \]

\[ k_t = \begin{cases} -4 + 0.7(f_{\text{MHz}}/925 - 1), & \text{for medium sized cities} \\ -4 + 1.5(f_{\text{MHz}}/925 - 1), & \text{for metropolitan centres} \end{cases} \]

In a line-of-sight situation where the base station antenna is higher than roof top level, there is no obstruction in the direct path between the base station and the mobile station. In the WIM, this propagation loss in dB is given by the Equation (10):

\[ L_{\text{WIM-LOS}} = 42.64 + 26 \log d_{\text{km}} + 20 \log f_{\text{MHz}}, \quad d_{\text{km}} \geq 0.02 \tag{10} \]

### 2.2. Outdoor field strength prediction

A method of outdoor field strength prediction based on the COST 231 WIM is proposed in this study. The field strength predicted values are calculated with WIM as shown in Figure 7.

GIS can be used to create the necessary spatial parameters for field strength prediction models. In addition, evaluating a cellular network propagation quality after installing the whole system is a required step for GIS. The step will be carried out by using field strength measurement to record signal strength at every test point within study area. The test point records will be displayed exactly on the network map together with their locations corresponding to the coordinate recorded. By using Arcview and/or ArcGIS spatial analysis, statistics, and script programming languages, the following tasks were carried out: A map that includes lines connecting with each cell station and its predicted points for path loss parameter calculations was created. The radio-line-of-sight (RLOS) and nonradio-line-of-sight (NRLOS) between cell stations and test points were checked. The test points belonging to each cell station were marked as RLOS or NRLOS to the corresponding cell station. Elevation, street, building, and cell station maps were the input data for field strength prediction.

In case of NRLOS, the parameters such as average building height, building width, and building separation distances, also angle correspond to the radio path and road orientation with respect to the direct of radio path had to be carried out in order to predict the field strength at the location (10, 11). The final predicted values were calculated by the following formula (11)

\[ P_r = P_t + G_t - L \tag{11} \]

where \( P_r \) (dBm) is received power, \( P_t \) (dBm) is transmitted power, \( G_t \) (dB) is transmitter antenna gain, and \( L \) (dB) is total path loss.

### 3. Field strength prediction experiment and results

#### 3.1. Data collection

Data were collected from Ho Chi Minh Posts and Telecommunications and include commune map, street map, house map, cell station map, and field strength driving test map. The maps are at the scale of 1:2000 in the Universal Transverse Mercator coordinate system, WGS84 datum, and zone 48 N. Figure 8(a) shows that the area terrain is almost the same, the elevation only varies from 3.32 to 4.56 m. Figure 8(b) shows houses with floor numbers in different colors. There are 7075 house units with the floors varying from 1 to 9 corresponding to 3 to 27 m in height. Cell stations are presented in Figure 8(c). There are 20 cell stations with 500 mW transmitter powers, using 9 dB, 10° and 20° downtilt omni antennas. Antenna heights vary from 15 to 24 m. Total 4451 field strength tested values together with their coordinates

![Figure 8](image-url)
were added to shape file using “add event theme” as shown in Figure 8(d). The recorded signal strength varies from 20 to 80 dBm. As all measurements were performed by canard, the data is incomplete; therefore, all the streets and lanes could not be covered.

3.2. Radio-line-of-sight

According to Rappaport (12), if an obstruction does not block the volume contained within the first Fresnel zone, then the diffraction loss will be minimal, and diffraction effects may be neglected. In fact, a rule of thumb used for design of line-of-sight microwave links is that as long as 55% of the first Fresnel zone is kept clear as presented in Figure 9, then further Fresnel zone clearance does not significantly alter the diffraction loss. In this case, \( h > 0.0785r_1 \) then RLOS, where \( r_1 \) can be calculated by the formula (12):

\[
    r_1 = \sqrt{\frac{\lambda d_1 d_2}{d_1 + d_2}}
\]

ArcView spatial analyst can be used to check RLOS condition of every test point by calculating the distance from the LOS line to building vertical cut plane. If any distance from building top edge to the LOS line \( r_2 \) is smaller than 0.0785\( r_1 \) or building height is larger than LOS line at the checked position, then there is NRLOS. Figure 10 shows the calculation.

Calculate \( r_1 \) and \( r_2 \) from the first building edge. Set \( d_1 \) as distance from the edge to mobile station location, \( h_i \) as building height, \( h_b \) as antenna height, \( h_m \) as mobile station antenna height, \( \alpha \) as angle formed by LOS line and horizontal direction, and \( d \) as distance from cell station to mobile station. Then:

\[
    \lambda = \frac{c}{f} = \frac{3 \times 10^8}{19 \times 10^8} = \frac{3}{19} \quad \alpha = \arctan \left( \frac{h_b - h_m}{d} \right),
\]

\[
    h_{bi} = d_3 \left( \frac{h_b - h_m}{d} \right) + h_m, \quad d_4 = \sqrt{d^2 + (h_b - h_m)^2},
\]

\[
    h_{bi} = h_{bi} - h_i, \quad d_4 = \frac{1}{\tan \alpha} (h_i - h_m), \quad d_{11} = d_4 \cos \alpha,
\]

\[
    d_{12} = (d_3 - d_4) \cos \alpha, \quad d_2 = d_{11} + d_{12},
\]

\[
    d_1 = d_2 - d_2, \quad r_1 = \sqrt{\frac{\lambda d_1 d_2}{d_1}}, \quad r_2 = h_{bi} \cos \alpha
\]

If \( h_i \geq h_{bi} \), then no RLOS; If \( h_i < h_{bi} \) and \( r_2 < 0.0785r_1 \), then no RLOS; and If \( h_i < h_{bi} \) and \( r_2 \geq 0.0785r_1 \), then RLOS.

3.3. Antenna gain at different radio paths

The network currently uses downtilt antennas so that the antenna gain has different values depending on the radio path. In LOS, \( \alpha_0 \) in Figure 11(a) was used. In NLOS, the largest \( \beta \) in Figure 11(a) was used.

\[
    h_{losi} = \left( \frac{d_2 (h_b - h_m)}{d} \right) + h_m
\]

If \( h_i \leq h_{losi} \), then \( \alpha_0 = \arctan \left( \frac{h_b - h_m}{d} \right), \quad \alpha = \alpha_0 \).

If \( h_i > h_{losi} \), then \( \beta_i = \arctan \left( \frac{h_b - h_m}{d_m} \right), \quad \alpha = 360 - \max(\beta_i) \).

Figure 12 presents the vertical pattern of 20° and 10° downtilt omni antenna and Table 2 gives the antenna gain correspond to the radio path angle \( \alpha \).

3.4. Road orientation with respect to the direct radio path

Part of streets picked up are shown in Figure 8(d). Figure 13 shows the calculation of road orientation angle \( \Phi \) with respect to the direct incident radio path. \( \Phi \) will be used to predict signal strength using the COST-231 WIM.

Assume \( a_1 \) is the azimuth of the line connecting from cell station antenna to test point. If \( a_1 > 180 \), then \( a_1 = a_1 - 180 \); assuming that \( a_2 \) is the azimuth of the street to which the test point belongs. If \( a_2 > 180 \), then \( a_2 = a_2 - 180 \) and \( a_3 = |a_2 - a_1| \); if \( a_1 > 90 \), then \( \phi = 180 - a_1 \), if \( a_3 \leq 90 \), then \( \phi = a_3 \). Field strength at a point will be calculated by the formula (14):

\[
    P_r = P_t - L + G_1 + 107
\]
where $P_r$ is the field strength at the receiver (mobile station) in dBμV; $P_t$ is the transmitted power at cell station in dBm; $L$ is the total path loss from cell station antenna to mobile in dB; and $G_t$ is antenna gain in dB, the gain depends on the radio path from the cell station.

### 3.5. Prediction results

The statistical results from calculated signal strength of 4451 points in Figure 8(d) correspond to the tested locations which are presented by each cell station in Table 3. The test point standard deviations are larger than that of the predicted field strength. The results show that the field strength prediction accuracy was better than the test field strength and prediction of propagation loss was more realistic.

The statistical results indicate that when comparing between predicted signal strengths and measured field strengths for each cell station indicate that the predicted

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| $x(\degree)$ | 20° downtilt gain /dB | 10° downtilt gain /dB | $x(\degree)$ | 20° downtilt gain /dB | 10° downtilt gain /dB |
|-------------|-----------------------|-----------------------|-------------|-----------------------|-----------------------|
| 1           | −3                    | −1.5                  | 21          | 9                      | −3.5                  |
| 2           | −4                    | −0.5                  | 22          | 8                      | −3.5                  |
| 3           | −5                    | 0.5                   | 23          | 8                      | −4.5                  |
| 4           | −6                    | 1.5                   | 24          | 7                      | −4.5                  |
| 5           | −6                    | 2.5                   | 25          | 7                      | −5.5                  |
| 6           | −5                    | 3.5                   | 26          | 6                      | −5.5                  |
| ……          | ……                    | ……                    | ……          | ……                    | ……                    |
| 20          | 9                     | −2.5                  | 40          | −8                     | −12.5                 |
path loss overcomes the driving test path loss so that the prediction model can be used to predict network propagation for the Cityphone system in HCMC and other urban areas.

In order to represent the signal strength coverage surface in the study area, it is necessary to choose the strongest signal strength among the cell stations at specific locations. Figure 14 shows the interpolated surface of the whole study area using max field strength value.

The max value of each grid cell can be determined by the formula (15).

\[ P_{ij}^{\text{max}} = \frac{|P_i - P_j| + P_i + P_j}{2} \]

where \( P_{ij}^{\text{max}} \) is the field strength value at a grid cell that belong to cell station \( i \)th and \( j \)th and \( P_i \) and \( P_j \) are signal strength values of station \( i \)th and \( j \)th at the grid cell location.

The results indicate that signal strength tends to be larger along the streets that are near the cell station and smaller in other directions. In addition, the current cell station distribution is too condense, so the possible hand-off area of cell stations is quite large, from around 80% to almost 100% of the cell station service area.

4. Results and discussion

The maps collected at the scale of 1:2000 with the resolution of 1 m satisfy field strength prediction purposes in microcell propagation, urban areas. GIS tool is very useful in dealing with spatial analysis and produced the necessary parameters to create the input values for the COST 231 WIM to predict signal strength at tested points. RLOS and NRLOS conditions can be distributed exactly at different locations based on terrain map and cadastral maps. GIS was the most important part that made the prediction more accurate.

The inverse distance weighted interpolation in GIS was used to estimate signal strength at locations near the tested points in order to create field strength surfaces for study area visualization. In addition, field strength surfaces were overlaid on 3D buildings to help network engineers to find out the reasons why there is stronger signal strength in some areas than others. GIS map calculation was also used to produce a signal strength surface for the whole study area by representing the maximum field strength value at every grid cell.

As compared to current situation in Ho Chi Minh Posts and Telecommunications, the models can be effectively applied to improve Cityphone mobile network quality as well as capability. Developed GIS models can help designers to predict cell station coverage using real spatial maps thus making the results more reliable. Finally, the models can help network operators improve the network quality and capability with the highest investment efficiently.

This article has successfully developed GIS-based models for predicting the coverage of Cityphone cellular network, visualizing the predicted signal strength, and analyzing the field strength coverage. The tasks were done in a part of HCMC, and there are some technical aspects of the experiment that need to be highlighted.

- GIS models are very useful for mobile communication, especially in cell coverage prediction.
- Maps with high resolution can help improve the prediction accuracy of microcell propagation.
- Without terrain and cadastral maps, the models cannot work effectively.

| Cell station | Points | Min (dBμV) | Max (dBμV) | Mean (dBμV) | Standard dev. (dB) | Min (dBμV) | Max (dBμV) | Mean (dBμV) | Standard dev. (dB) |
|--------------|--------|------------|------------|-------------|-------------------|------------|------------|-------------|-------------------|
| 8088141e61   | 169    | 20         | 80         | 39.3        | 13.7              | 18.4       | 59         | 36.5        | 10.9              |
| 8088141e62   | 241    | 20         | 80         | 45.4        | 21                | 21.9       | 61.6       | 41.3        | 11.3              |
| 8088141e63   | 294    | 20         | 80         | 32.8        | 13                | 19.8       | 61         | 34.5        | 9.8               |
| 8088141e64   | 246    | 20         | 40         | 30.7        | 9.7               | 16         | 63         | 35          | 11                |
| 8088141e65   | 155    | 22         | 80         | 45          | 13.9              | 24.8       | 63         | 43          | 7.7               |
|              |        |            |            |             |                   |            |            |             |                   |
| 8088141e78   | 217    | 20         | 80         | 37.2        | 13                | 16         | 69         | 32          | 10.9              |
The COST 231 WIM mainly uses average building height so that in cases lacking accurate building height, the average of 3 m floor height can be used. In this case, RLOS cannot be calculated with the highest accuracy. On the other hand, in urban areas, there will be less RLOS locations than NRLOS locations; thus, the use of 3 m floor height will not dramatically affect the overall result.

A driving test is very important in cellular network planning. It is a necessary step and must be carried out after cell station installation to warrant the network quality.

The COST 231 WIM is used for isotropic antennas, in case of using omni downtilt antennas, it is necessary to determine the main incident path from the transmission antenna to the receiving antenna in order to obtain proper transmission antenna gain.

The model detailed in this article has successfully demonstrated a method to calculate RLOS based on Fresnel zone theory.

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References
(1) Wagen, J.-F.; Rizk, K. Radiowave Propagation, Building Databases, and GIS: Anything in Common? A Radio Engineer’s Viewpoint. J. Plan. Design. 2003, 30, 767–787.
(2) Sun, H.; Wang L.; Wang T.; Fan R. Application of GIS in the Analysis of Field Strength of Radiowave Propagation. Sci. Surv. Map. 2007, 32(6), 59–64.
(3) Wittie, M.P.; Stone-Gross, B.; Almeroth, K.C.; Belding, E.M. Cellular Data Network Measurement for Mobile Applications. Proc. BROADNETS, 2007; pp. 743–751.
(4) Wang, J.; Chen, M.; Leung, V.C.M. A Price-Based Approach to Optimize Resource Sharing Between Cellular Data Networks and WLANs. Telecommun. Syst. DOI:10.1007/s11235-011-9451-2. 2011, 1–12.
(5) Li, D.; Li, Q.; Xie, Z.; Zhu, X. The Technique Integration of the Spatial Information and Mobile Communication. Editorial Board of Geomat. Inform. Sci. Wuhan Univ. 2002, 27(1), 1–6.
(6) Li, D.; Li, Q. The Technique Integration of the Spatial Information and Communication. Geomat. Inform. Sci. Wuhan Univ. 2001, 26(1), 1–7.
(7) Tapan, K.S.; Zhong, J.; Kyungjung, K.; Abdellatif, M.; Magdalena, S.P. A Survey of Various Propagation Models for Mobile Communication. IEEE Antennas Propag. Mag. 2003, 45 (3), 51–82.
(8) Rappaport, T.S. Wireless Communications Principle and Practice; Publishing House of Electronics Industry: Beijing, 2004.
(9) AWE. COST 231 Walfish–Ikegami Model A fast empirical Prediction Model for Urban Scenarios. [EB/OL]. http://www.awe-communications.com/Propagation/Urban/COST/index.htm.
(10) Lachat, E.; Wagen, J.-F.; Li, J. Effects of Building Heights on Predictions in Munich Using a Multiple Vertical-Knife-Edges Propagation Model. Proceedings IEEE 47th Vehicular Technology Conference; IEEE: New York, 1997; pp. 261–265.
(11) Lee, W.C.Y.; Lee, D.J.Y. Microcell Prediction in Dense Urban Area. IEEE Trans. Veh. Technol. 1998, 47(1), 246–253.
(12) Huimin, W.E.I.; Guomin, L.I.; Ning, B.A.O. Mobile Communication Technology; People Post Press: Beijing, 2006.
(13) Rappaport, S.T. Wireless Communications Principles and Practice, 2nd ed.; Prentice-Hall: Upper Saddle River, NJ, 2002.