International Journal of Natural and Engineering Sciences 3(3):63-71, 2009
ISSN: 1307-1149, www.nobel.gen.tr

GIS and RS Based Location Determination for GSM Transmitters to Minimize the Negative Effects of Electromagnetic Pollution for Improving Quality of Urban Places

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Received: July 01, 2009
Accepted: August 07, 2009

ABSTRACT

It is a common discernment that, today; mobile phones have become the most inevitable tools for human comfort and communication. As a result, an enormous number of innovations to satisfy the needs of mobile communication quality show up every day. However, there is another aspect of the matter related to the environment and human health. Both mobile phones and GSM transmitters are the sources of electromagnetic pollution. Consequently, it is considerably necessary to minimize the negative environmental and health effects of the electromagnetic fields of GSM networks, while offering the best quality and uninterrupted mobile phone services. This study proposes a geographical information system (GIS) and remote sensing (RS) supported method to determine the best and most suitable locations for erecting GSM transmitters on land, so that the coverage area is wider, the number of necessary stations is minimized and the electromagnetic pollution is decreased. Also decreasing the negative effects of electromagnetic waves caused by GSM transmitters helps healthy urban spaces and can be used as space quality parameters. Main themes of the method embrace a multidisciplinary working frame.

In this article a multidisciplinary frame based method proposing a GIS supported location determination is explained. This method aims to minimize the number of base stations needed for GSM operations.

Key Words: Electromagnetic pollution, electromagnetic modeling, human health, location determination, geographic information system (GIS), remote sensing (RS).

INTRODUCTION

Though not visually noticeable, today, electromagnetic pollution, due to its negative effects on human health, takes one of the preliminary places among other environmental pollutions. Within this context, mobile phones and GSM transmitters are the mostly discussed items of the electromagnetic pollution. This is why; the design of these phones should focus on minimizing the electromagnetic pollution, rather than to bring forward the outcomes such as long life, high performance and size. At any place where mobile phones are in use, GSM transmitters too, as electromagnetic interference sources, have negative effects on human health.

When GSM transmitters and human are taken, respectively as the electromagnetic transmission source and the living beings affected by the transmission, the simplest method for the solution of the problem appears to operate mobile phones through the possible minimum number of GSM transmitters, located at the least populated areas.

Today's problems can be easily solved with the help of developments in GIS technologies. According to these developments, users can discover the data that will be used for problem solving in an interactive way. Thus, users can perform synchronized mapping studies [1, 2, 3].

This paper focuses on a multidisciplinary method embracing planning, cartography, and electronic engineering experiences. The method explained in this paper proposes a technique for location determination of GSM transmitters and is based on joint use of satellite remote sensing [4] and GIS technologies to create a geographic database to establish an essential infrastructure for determining electromagnetic propagation.

LITERATURE REVIEW

Many scientists from different disciplines make researches, experiments and studies regarding electromagnetic propagation, modeling and various effects of electromagnetic waves. Recently, GIS has also been an essential technique to understand and model the travel paths of electromagnetic waves and thus better analyze and visualize the propagation. In this part of the article, a brief literature review about modeling and effects of electromagnetic waves, and 3D modeling techniques using GIS and RS capabilities are given.

Pellerin and Wannamaker [5] discuss the state of art in modeling and inversion of 1D, 2D, and 3D earth conductivity structures. In their research, Endo and Noguchi [6] develop an accurate result providing method for a three-dimensional subsurface and topography, which is derived from Maxwell's equations. Haber *et al.* [7] focused on solving and fast simulation of 3D electromagnetic problems. Hursan and Zhdanov [8] explain the integral equation method as an efficient tool to model 3D electromagnetic problems. Zhdanov *et al.* [9] explains an integral equation as a powerful tool for forward electromagnetic modeling. Kuvshinov *et al.* [10] describes a fast integral equation approach for modeling electromagnetic fields in 3D spherical earth. There many other researches on 3D electromagnetic modeling issues carried out by researchers such as Hohmann [11], Constable *et a l.* [12], Eaton [13], Wang and Hohmann [14], Buselli and Williamson [15], Smith [16], Weller *et al.* [17], Sasaki [18], Avdeev *et al.* [19], etc.

One of the most important research fields related to electromagnetic fields is the environmental and public health. Though articles on the health issues increase rapidly, some researches underline that the number of scientific researches to prove the association between some major health hazards and especially the low frequency electromagnetic fields are still inadequate. Stevens and Savitz [20] are two of the researches who question in their article whether electromagnetic fields and cancer issue is worthy of study or not.

Kavet [21], on the other hand, explains that epidemiologic studies have produced evidence suggestive of a possible link between electromagnetic field exposure and cancer of several types. In his paper, he provides a perspective that holds key findings in the electromagnetic field literature against the background of important models and established principles in cancer biology. Repacholi [22] also discusses the health hazards of low-level electromagnetic fields and the research needs in his paper. Repacholi and Greenebaum [23] from World Health Organization (WHO), additionally, underline the gaps in knowledge requiring more research to improve health risk assessments related to exposure to static and electromagnetic field electric in their research article regarding the international seminar on the biological effects and related health hazards of ambient or environmental static and extremely low frequency electric and magnetic fields. The researches specify in their article that the working groups of the seminar concluded that the literature does not establish that health hazards are associated with exposure to low-level fields. Koivisto *et al.* [24] described the effects of mobile phone exposure on human cognitive functions and focused on the negative effect of mobile phone on working memory.

Otto and Mühlendahl [25], also underline that there are presently no scientific data supporting the concept of a special vulnerability of children and adolescents to high-frequency electromagnetic fields in their article about the children's environmental health. They note that static fields produce health effects only in very rare and exceptional circumstances at extremely high field intensities. They also emphasize that low-frequency electromagnetic fields were classified as "possibly carcinogenic to humans", with respect to childhood leukemia, by the International Agency for Research on Cancer.

Nittby *et al.* [26] explain that they investigated in a rat model the long-term effects of protracted exposure to Global System for Mobile Communication – 900 MHz radiations. The results of the experiments suggest significantly reduced memory functions in rats after GSM microwave exposure. Many other authors gives results of rat and small animal experiments which were performed to determine the effects of electromagnetic waves in their articles; such as Belyaev *et al.* [27], Cassel *et al.* [28], Martens *et al.* [29], Yamaguchi *et al.* [30], Andrews [31], etc.

Litvak *et al.* [32] focus on the presentations and reports of working groups of an international seminar on health effects of exposure to electromagnetic fields in the frequency range from 300 Hz to 10 MHz, which was organized in June 1999 in the Netherlands and they give recommendations for further research aims at improving health risk assessments in the mentioned frequency range.

Stacy *et al.* [33] from the University of Essex, focus on the negative health effects of the mobile phones. In their paper the writers question the relation between the electromagnetic fields from everyday objects such as mobile phone base stations and the idiopathic environmental illness and whether short-term exposure mobile phone base station signals increase symptoms in individuals. They also explain their method that is based on an open air the provocation test of 56 self-reported sensitive and 120 control participants. During this research Stacy et al obtain subjective measures of well being and symptoms as well as physiological measures of blood volume pulse, heart rate, and skin conductance. Similarly, Röösli *et al.* [34] study the statistics of the health problems as a result of exposure to electromagnetic fields in order to gain a better knowledge of the anxieties of complainants.

In their paper the researches give information about the questionnaires distributed and explain that in 394 of the 429 returned questionnaires persons reported symptoms. Bamiou *et al.* [35] focused on the effects of mobile phones on peripheral audio vestibular functions in the article titled “Mobile Telephone Use Effects On Peripheral Audio vestibular Function: A Case Study Control”. Czyz *et al.* [36], Tuschl *et al.* [37], Eliyahu *et al.* [38], Tillmann *et al.* [39], and Neubauer *et al.* [40] are also some of the researches who study the environmental and health effects of the electromagnetic fields.

Besides electromagnetic propagation and the issues related, there are many studies carried out to discuss the technologies regarding spatial data, remote sensing, photogrammetric applications and geographical information systems. For example, Lee [41], Richards [42], Grasso [43] and Doyle [44] explain their methods to create various space and satellite data sets for planning purposes in their articles. Schiewe and Siebe [45] touch on creating cartographic database from orthophotos. Koua *et al.* [46], on the other hand, underline the advantages and methods of visualization applications and 3D models.

Ogao and Kraak [47] emphasize the significance and advantages of visualization techniques and define visualization operations for temporal cartographic animation design. Moellering [3], Koua and Kraak [48], Verbree *et al.* [49] and Kraak [1, 2] focused on visualization of geospatial datasets, visualization methods and 3D GIS topics in their articles.

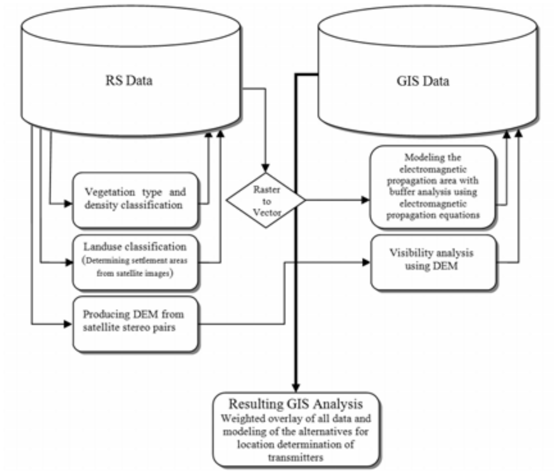
MATERIALS AND METHODS

The basis of the method is modeling the land and the barriers on it, such as buildings and vegetation, in a computer supported environment, and consequently detecting the spots with the most convenient optical visibility on land. The method is graphically illustrated in Figure 1, based on the following steps:

Satellite Imagery Analysis and RS Data Model: Remote sensing data: Image processing of satellite imagery

- o Vegetation type and density classification
- o Land use classification (Determining settlement areas via satellite images)
- o Producing digital elevation model (DEM) from satellite stereo pairs

- GIS data:
  - o Visibility analysis using DEM
  - o Modeling the electromagnetic propagation area with buffer analysis using electromagnetic propagation equations
- Resulting GIS analysis: Weighted overlay of all data and modeling of the alternatives for location determination of transmitters



Figs. 1- Method of the study.
Satellite Imagery Analysis and RS Data Model

Satellite imagery and all data related to the pilot project will be analyzed and resolved. The results will be verified with ground truth field survey and interpreted using RS and GIS techniques. The model produced for determining electromagnetic propagation should include also the following information layers produced from satellite images:

- Landuse information of the study area
- Vegetation type and density map extracted from multispectral satellite images
- DEM extracted from satellite stereo pairs

Vegetation type and density classification: Before the vegetation density analysis, study area should be classified into vegetation types using supervised classification technique. Afterwards, vegetation densities are calculated for each different vegetation type, using different linear models.

In this study, ground truth information needed for supervised classification analysis was determined during field surveys to the test area. Three different vegetation types, namely shrub, steppe and forestry as well as naked areas were detected in the test area. 1/25000 scale national base maps were used for ground truth study. Visual interpretation of test area’s satellite images revealed the heterogeneous structure of vegetation types. Using multispectral values (Bands 5, 4, 3), statistical analysis was made in the test areas, to calculate the means, standard deviations for each band and the covariance matrix. Class samples were first accuracy tested using minimum distance classifier.

$$x \in j \ , \ \text{if} \ \ d_j = \sum_{i=1}^{n} \frac{(X_i - \bar{X}_i^j)}{\sigma_i^j} \ = \ \min \ (d_i),$$

$1 \le i \le N$, N =number of classes
n = number of bands,

$\overline{X}_i^j$, mean of class j in band i

σ_i^j , standard deviation of class j in band i

The outliers were excluded from the training sample set for each class. Pure class samples were statistically analyzed to compute the class mean vectors and covariance matrices to be used in computation of the Mahalanobis distance. For each pixel, Mahalanobis distances were computed and the pixels were classified into the class of minimal distance, provided the pixel is not apart more than three times the standard deviation.

x∈j if $d_j = (X - \overline{X}_j)^T C_j^{-1} (X - \overline{X}_j)$ = min (d_i) , $1 \le i \le N$

C_j^{-1} , inverse covariance matrix for class j

^{T} , transpose

Vegetation density in the study area was calculated using the following steps:

NDVI was calculated using near infrared and visible red wavelengths, corresponding to bands 4 and 3 of Landsat TM.

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

The basis of vegetation index calculations depends on the high vegetative reflections in the near infrared band and no reflection in the visible red. It is clear that no vegetation exists where vegetation index is below 0, therefore the study interval was limited to range (0,1) and negative index values were set to zero and ignored. Vegetation index values in the range (0,1) were stretched to (0,255) for ease of monitoring and processing on image analyzing devices, to assume the values, $NDVI^s$, according to this equation.

$$NDVI^S = \frac{NDVI - NDVI_{\min}}{NDVI_{\max} - NDVI_{\min}} * 255$$

Test areas were masked on the vegetation index image to prepare the necessary input data for the linear model. Regression analysis was made between the vegetation density values marked during field survey and vegetation indices calculated in equation given above.

Vegetation index values for each vegetation type were taken as independent variables, while the vegetation density values determined during field survey were taken as dependent variables in calculation of constant regression coefficients for each vegetation type.

Different test areas from each vegetation type, forest, shrub and steppe were used in the regression analysis to provide correlation between regression coefficients and to achieve regression accuracy. Vegetation densities were finally grouped into 4 classes from low to high. These classes were used as an input for weighted overlay in the final step.

Landuse classification: In large areas, supervised classification methods are used to determine the land use and land types. However, these methods require fieldworks to collect the land data for creating input information. On some occasions, it is impossible to collect data in some areas where the land is rough, inaccessible or either a private or a military property resulting in entry prohibitions. In addition, for a high classification precision, it is important that different land use classes are separable according to a particular evaluation criterion, after the collected land data is overlaid with the satellite imagery and analyzed in a spectral space. Another reasonable method for working out the land classification question is to make unsupervised land classification and then to separate the resulting classes into land use groups. Thus, no class confusion will take place, since the spectrally divisible classes are determined by the method. Vegetation availability and density can be considered as a criterion to determine the different land use types by grouping the sets. In the unsupervised classification method, considering the values of a good deal of multi dimensional imagery item, natural groupings are taken as basis and divided into groups. In measuring space, items with similar grey values are put into the same class, while the items with different grey levels, which are thoroughly separated from each other, are set into different classes. Consequently, in the multi dimensional satellite imagery, classes, which are naturally grouped due to their spectral reflection proximities, but are not known which class they represent, are obtained. Creating expressive land use classes entails comparisons with larger scale images or maps, or fieldworks made to gather land data. Though group separations in the set of two-dimensional data are visually noticeable, it is not possible to distinguish the spectral groupings in the set of three or more dimensional data such as the satellite images. However, statistical method applications make it possible to distinguish the groupings in the two-dimensional data space [41, 42, 43, 44].

In this study, in order to determine the settlement areas and density of these areas, land was classified into land use classes with fuzzy k-means grouping algorithms. Afterwards, using NDVI analysis, considering their digital values, the data sets were separated into different groups in such a way that each group shows a considerably different NDVI value from the preceding one. This difference provides easy discrimination of groups on land, and classification of the land covers into the land use classes with the known NDVI values.

Grouping methods were developed in order to determine the natural and basic structure of the data. K-mean value grouping method, which was applied in this study, was made with iterative optimization.

(1) First set centers, V_i are determined. $1 \le \boldsymbol{i} \le \boldsymbol{N}$, $\boldsymbol{N}$ = number of classes

(2) For each set vector, $X^k_{i,j}$ membership grade is calculated and put in the closest centre:

$$u\{ij\} = \frac{1 / d^2 X_j V_i}{\sum_{k=1}^{k} 1 / d^2 (X_j V_k)} \quad ; \; d = \text{Euclid distance}$$

$$(X^{k}_{ij} \in C^{k=1}_{i})$$

(3) New set centres are determined. $V_{i\,new}$, iteration begins:

$$V_{i\,new} = \frac{\sum_{j=1}^{N} u\{ij\}^{2\,Xj}}{\sum_{j=1}^{N} u\{ij\}^{2}}$$

(4) New set mean values are compared with the previous ones.

In the end, if all membership grade between all k sets is ***u{ij}* >= *u{kj}*** then i set is grouped into $\boldsymbol{X_j}$ class and iteration ends.

In this study, using the 5, 4, 3 bands of Landsat TM imagery and fuzzy k-means algorithm, land types were determined. 4th and 3rd bands were preferred because of their capability to detect the vegetation cover. As a result of the grouping algorithm, mean values were calculated using formula given above. Considering the possible different land use types, with fuzzy k-means, it has been assumed that 16 set numbers would be sufficient.

Created sets were grouped according to their mean NDVI values and set into appropriate classes. Sets obtained with fuzzy k-means grouping method were reduced to class numbers that differ according to the NDVI values. As to this, sets with close NDVI values to each other, have been put into the same class. Then, among these classes, settlement areas and settlement densities were determined. Settlement densities were grouped from low to high.

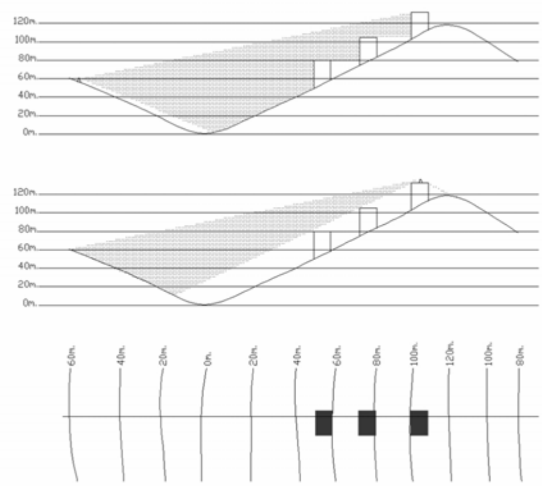
Producing DEM from satellite stereo pairs: Digital elevation model of the study area is very important for determining the electromagnetic propagation. Elevations needed to produce the model of the electromagnetic propagation were extracted from stereo satellite images to include the ground cover and building into DEM. For electromagnetic propagation modeling using digital elevation model of the area, it is possible to use the 1-30 meters resolution satellite images depending on the target precision. Ikonos and Landsat imagery was used for this study. In this process, orthoimages was prepared using satellite data. Scanned aerial photographs and satellite imagery is very useful for the orthoimage generation as a data source [45].

GIS Data

Visibility Analysis using DEM: Visibility analysis can be defined as calculating the geometric visibility of discrete spots determined on the digital DEM or the spots lined along a line. The most commonly utilized visibility analysis methods are as follows:

- Determination of the spots visible from one area,
- Determination of the visibility of two spots to each other
- Determination of the areas visible from all spots along a line,
- Determination of each spot target visible from each area, etc.

Figure 2 displays the areas that can be observed from various spots on the land. As the figure itself explains, there is not any direct relation between the maximum visibility and view height. Though the viewpoint in the figure above is lower than the one in the figure below, it has a larger visibility of the land. The analysis used in this study is based on the determination of the spots having the maximum visibility on land, and geometric calculation of the minimum number of spots having the optical visibility of the possible largest area. However, reaching the proper conclusion depends on the actuality and precision of the physical barriers on land, such as current vegetation, buildings and DEM. If it is suggested to use the satellite images to establish DEM, then it is inevitable to use the high-resolution satellite images.



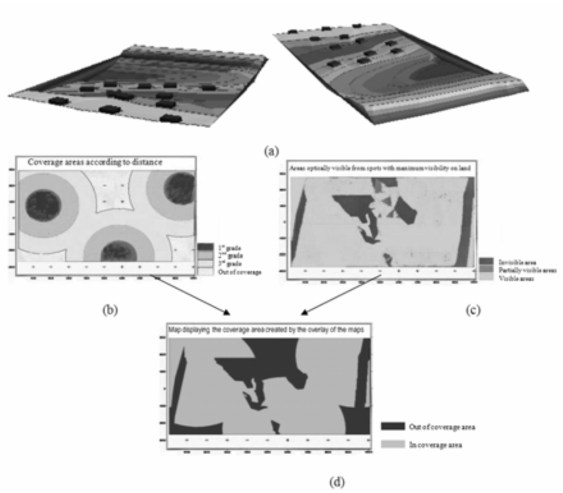
Figs. 2 Cross-sections of the areas according to their optical visibility from different view spots on land.

Modeling the electromagnetic propagation using buffer analysis: Figure 3 shows the overlay process of the coverage area of the GSM transmitters focused on the distance via DEM. In this study, GIS analysis was made with ArcGIS software. For this aim, DEM, including the structural items on land, was produced, and then the optical visibility of the GSM transmitters and thus coverage areas were detected according to their effect. In the detection of the coverage area, the distance that the waves are estimated to travel was calculated regarding the free space propagation. Then graded buffer analysis, depending on this distance, was made. The decline in the effect of the electromagnetic wave radiation depending on the atmospheric conditions was neglected for this study. The formula below was used for calculating the free space propagation:

$$L_f = 32.5 + 20\ Logf + 20\ Logd\ [dB]$$

In the formula, the unit value for f is MHz, while d is in kilometers.

Afterwards, the areas where the GSM transmitters are capable of spreading their frequency were determined and graded according to their decline in the effect, by comparing the optical visibility and coverage area maps. When human health is considered, the main method to minimize the negative effects of the GSM transmitters is to provide the possible maximum coverage area size with the possible minimum number of GSM transmitters. Another solution to this question is to increase the distance between the interference source and the victim as much as possible. From this aspect, one of the other preliminary cautions to be taken while utilizing GIS for this study is to guarantee that the areas within the study area with crowded populations, such as trade areas, settlement areas, hospitals, education compounds, are outside of the probable GSM transmitter construction territory. Shortly, if a spot has maximum optical visibility, but it is located at a particular distance to such highly populated areas depending on the parameters previously mentioned, then it is necessary to exclude this spot from evaluation of the model to be implemented via the GIS.



Figs. 3 Different direction views of the land (DEM views) and coverage area determination process. (a) 3D views of the area, (b) 1st map Coverage areas of the GSM transmitters according to distance and other factors (buffer analysis), (c) 2nd map Areas visible from the spots with maximum optical visibility on the land where GSM transmitters may be located (optical visibility analysis), (d) 3rd map overlay of 1st and 2nd maps in GIS (overlay).

Resulting GIS Analysis

In the final stage of the study, weighted overlay was performed and alternative locations for transmitters were modeled. The weighted overlay method sample is illustrated in Figure 4.

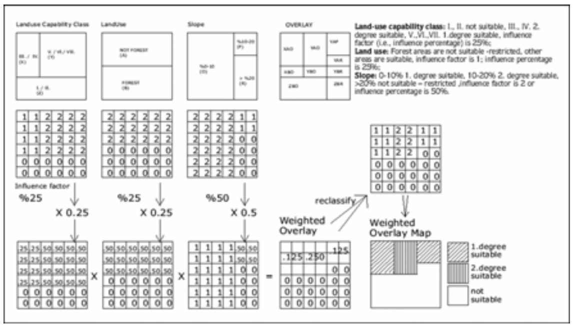


Figure. 4 A hypothetical sample explaining weighted overlay method [50]

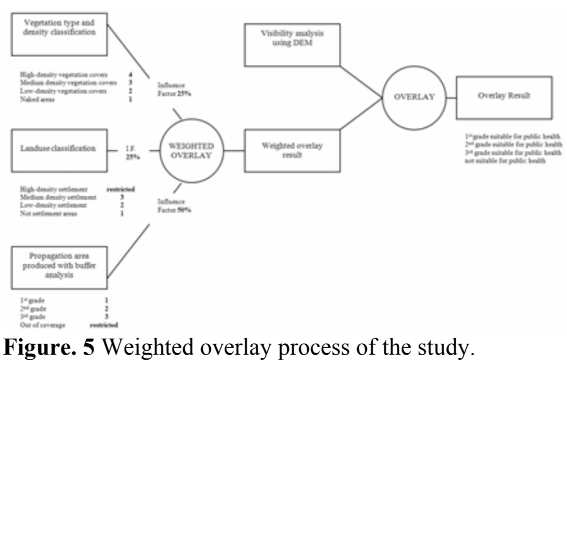


Figure. 5 Weighted overlay process of the study.

RESULTS and DISCUSSION

The method in this study is based on declining the number of mobile phone GSM transmitters to an optimum level and minimizing the negative effects on human health by locating the GSM transmitters on lands with the minimum potential risk. From this point of view, this method is of great importance for GSM operator companies. Through this method, GSM operators may provide maximum output with the minimum possible number of GSM transmitters and gain considerable economical savings. Moreover, the negative effects on human health caused by the GSM transmitters will be minimized with this method.

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