

Mobile Communication Signal Selection Algorithm for Signal of Opportunity Navigation

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Abstract— At present, the satellite navigation and positioning system can provide a high precision positioning service to end users in outdoor environments. But in urban canyons, high-rise buildings, urban tunnels, tree canopy covered areas, and other environments with weak signal such as military base and other special places with signal disturbance or spoofery, effective positioning or positioning results cannot to be trusted. Hence, it is very important and meaningful to use the existing radio signals (“signal of opportunity”) in the environment for positioning. Among the existing types of signals, mobile communication signals have more obvious characteristics for signal of opportunity navigation and thus has received more attention. This paper aims to solve the problem of signal selection in the application of mobile communication signals to navigation and positioning. This done by using characteristics such as signal carrier frequency, received signal strength and geometric position distribution to model, evaluate and systematically analyze the influence of each factor on positioning performance. Finally, based on a comprehensive evaluation method, a signal selection algorithm is designed while putting the signal type, signal carrier frequency, received signal strength, geometric position of the signal source and other factors into consideration. GSM and LTE signals are used in an actual environment to analyze, verify and extract the parameters required for the selection algorithm, also a comparative verification analysis was carried out with cluster and sub-optimal selection algorithm. The positioning accuracy of the proposed model proves both the reliability and the effectiveness of the proposed algorithm for comprehensive evaluation of signal source selection.

Keywords— Mobile Communication Signals, Navigation and Positioning, SDR, Signal Source Selection

I. INTRODUCTION

In view of the shortcomings of the existing satellite navigation and positioning systems, and in order to achieve accurate navigation and positioning at any time or place, a new radio navigation technology – signal of opportunity navigation technology was proposed [1][2]. Signals of opportunity(SOPs) refers to radio frequency (RF) signals commonly stored in the environment which mainly include Mobile Communication signals, WIFI, Digital Television Broadcast, AM / FM, and Low Earth Orbit satellite (LEO) signals. Though not designed for navigation, these signals can be freely utilized for positioning purpose. Among popular SOPs mentioned above, mobile communication signal gets the most attention due to its opportunistic signal navigation characteristics. In our living environment there are a large number of mobile

communication signals of different frequency bands which can be used for navigation and positioning. Hence, mobile communication signal positioning refers to constantly receiving effective communication signals in the environment, extracting signal features from them, calculating and realizing high-precision navigation and positioning[3][4].

In most navigation and position application, real-time access and high precision in positioning is required. The prediction and selection of appropriate signal source, extraction of corresponding signal characteristics and determination of the signal source to be involved in positioning solution is an essential technological research issue in mobile communication signal navigation and positioning. Signal selection is a problem which needs substantial attention and suitable solution in related systems in order to reduce positioning time, receiver work load and maintain positioning accuracy. Additionally, the signal selection problem in navigation and positioning are mainly divided into two research areas: Signal evaluation index/indicator and Selection algorithm. Signal evaluation index involve the standards used to determine and evaluate signals i.e selection principles, while the selection algorithm determines the signal sources to be used in positioning. An appropriate algorithm not only solves for the optimal signal source combination, but also is required to have a minimum time and space complexity.

There are mainly two types of research on the evaluation of indicators for signal selection:(1) The traditional signal source evaluation method based on geometric dilution precision (GDOP), this studies how to reduce the amount of calculations and time for positioning ; (2) The exploration and use of new signal source evaluation index method, this searches to introduce new ways to reduce computation and achieve higher positioning accuracy. To illustrate on the use of the first method, [5] assumes that all signal sources involved in positioning have the same pseudo-distance error, and GDOP is used as the evaluation index to select satellites. Literature [6] uses Newton's identity in symmetric polynomial theory to give close GDOP solutions for more than four satellites, which reduces a large amount of computation in GDOP inversion process. And in[7], three different satellite navigation and positioning systems (GPS, Beidou and Galileo) have different pseudo-range errors as the weighted geometric precision factor

is used as the evaluation index.

Current signal selection algorithms can be roughly classified into the following three categories: (a)Directly calculated contribution of signal source; (b)Direct use of geometric relationship; (c)Use of cluster algorithm. Literature [8] verified the optimal positioning performance when the signal source position relation was uniformly distributed, and proposed a step-wise signal selection algorithm, which in using GDOP, can solve the analytic expression quicker. [9] proposes a fast selection algorithm for satellite navigation, which selects satellites according to the distribution characteristics of satellite elevation angle and azimuth angle. It verified that the GDOP value of the signal source selected by this method is close to the minimum GDOP, and the amount of calculation is smaller.

This paper is organized according to the following: The second section describes the architecture of the mobile communication signal positioning system. The third section elaborates on the mobile communication signal selection algorithm design which is based on a comprehensive evaluation mechanism. In the fourth section, the actual experiments are performed to obtain the verification and performance analysis, in order to prove the feasibility and effectiveness of the proposed selection algorithm.

II. MOBILE COMMUNICATION SIGNAL POSITIONING SYSTEM

A. Mobile communication signal positioning system architecture

Mobile communication signals are ground level radio signals of various frequency and structure which originates from mobile communication base stations in the environment. In existing mobile communication signal positioning and navigation research, software defined radio (SDR) platform is adopted as the receiving platform for its capability to perform frequency scans and signal demodulation. Data analysis and other functions, can also be achieved by programming the software. Using this platform, information required for navigation and position estimation which includes time, signal strength, signal source position details, channel parameters and other signal characteristics can be extracted. Other data processing such as ranging, line-of-sight and non-line-of-sight identification, coordinate solving, information fusion, trajectory tracking e.t.c, is conducted using a high-performance computer(PC). The system architecture of the software defined radio platform for navigation and positioning is shown in Fig. 1, and its physical picture is shown in Fig. 2.

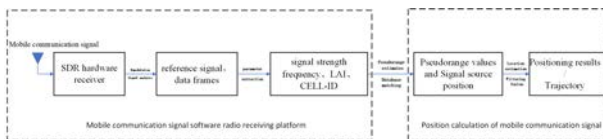


Fig. 1. System architecture of the software defined radio platform for navigation and positioning.

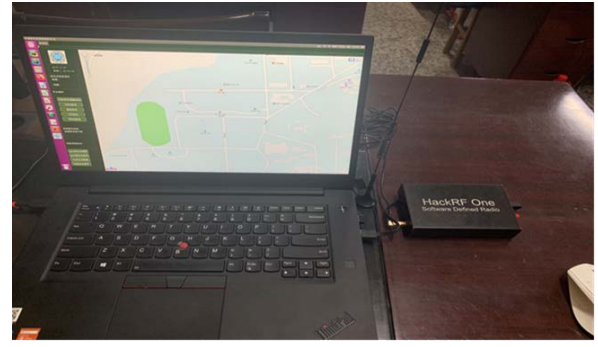


Fig. 2. Physical picture of the mobile communication signal based SDR platform for navigation and positioning.

B. Description of the mobile communication signal selection problem

Assuming an environment contains randomly distribution multiple signals, we can describe the signal selection problem using a vector of Boolean variable type. Hence, vector z is defined as:

$$z = [z_1, z_2, \dots, z_M], z_i \in \{0, 1\}^M \quad (1)$$

If M signal sources exist in the environment, then based on the vector z , we can determine which signal source is to be selected. When the i th element of vector z is equal to 1, the i th signal source is adopted as a member of the subset of selected signals.

C. The mobile communication signal evaluation factor Model

From a navigation and positioning outlook, this paper will model and analyze the evaluation factors that affect accuracy while using mobile communication signals.

a) *Receiving frequency*: In an ideal environment, interference, reflection, refraction, diffraction and other signal transmission phenomenons will not occur. Signal propagation distance in such environment is directly related to the transmitting power and signal frequency. This is a free space propagation model. Path loss can be expressed as:

$$PL(dB) = A + 20 \lg(d)(km) + 20 \lg(f)(MHz) \quad (2)$$

In Equation (2), A is the strength of the reference received signal, D is the propagation distance, F is the signal frequency, and PL is the path loss value. For mobile communication signal navigation systems, signal switching affects positioning accuracy and real-time performance of receiver; For the receiver, when the transmitting signal parameters are the same with the transmitting position, the low-frequency signal spreads farther and its signal intensity is stronger when the signal is received, which is conducive to the development of navigation and positioning system.

b) *Received signal strength*: With regard to collectively received signals of different carrier frequencies transmitted by different base stations at the same location, frequency screening is more suitable because they are of the same signal type and also possess similar transmission parameters. Taking

mobile communication signal as an example, the different signal frequencies to be screened must be that of the same mobile service operator whose signal transmission parameters are the same. But for received multiple signals with different or inconsistent transmission parameters, although the same physical location, they cannot be directly screened based on frequency. At this stage, it is invaluable to make selections based on the received signal strength. Because mobile service operators have a database which makes accessing signal parameters such as based station longitudinal and latitudinal information possible, frequency can be filtered prior to signal reception thus directly reducing the receiver's work load.

c) *Geometric distribution*: With positioning purposes in mind, this paper analyzes the geometric position distribution of signal sources to better describe its influence on the system. It is best that the signal sources involved in the positioning solution are as dispersed as possible and can surround the receiver from all sides, that is, the signals involved in the positioning form a convex hull around the receiver. To describe the cost function of geometric structure of any signal source, the redundancy of position distribution between signal source i and j is first defined as shown in equation (3).

$$Red_{sij} = \cos(2\theta_{sij}) \quad (3)$$

Where θ is the angle of the line-of sight vector between two signal sources, and the position distribution redundancy Red is between ± 1 . When the two signal sources are located on the same side of the receiver and collinear with the receiver, the positioning value of the two signal sources relative to the receiver is low. R in taking up the maximum value is said to be equal to 1. Also, assuming the line-of sight vector between the two signal sources and the receiver is 90° , the two signal sources can provide a better spatial structure for the receiver, at which point Red is -1. According to this theory, the smaller the position distribution redundancy between any two signal sources is, the better the geometric position. Distributed redundancy can be calculated using equation (4):

$$\theta_{sij} = a \cos\left\{\frac{U_{si} \cdot U_{sj}}{\|U_{si}\| \cdot \|U_{sj}\|}\right\} \quad (4)$$

Here $\cdot$ means dot product, and $\|\cdot\|$ is the demonstration range. The sum of the redundancy of signal source i and other N signals is defined as the cost function of position distribution of signal source i , as shown in (5):

$$Red_{si} = \sum_2^{n+1} Red_{sin} \quad (5)$$

Thus, the geometric position distribution modeling of each signal source is completed. Also, the spatial deployment structure of the signal source can be independently described using the cost function of the location distribution. For this reason GDOP or jointly expressed signal source combination volume etc, is not needed. This makes it a more preferable alternative for direct used in subsequent researches on the switch and selection of mobile communication signals for positioning.

III. COMPREHENSIVE SELECTION ALGORITHM.

A. Mobile communication signal reception, analysis and information acquisition

The mobile communication signal based software defined radio platform for navigation and positioning is used to receive the mobile communication signals in the environment. GSM and LTE signals are used for verification in this paper. With the software radio platform, signals are received, transmitted to PC for analysis, extraction of mobile communication signal parameters, and information matching for needed signal selection and positioning.

B. Downlink carrier frequency filtering of mobile communication signals

In frequency filtering of mobile communication signals with same signal identification where signal carrier frequencies have different downlinks, if two or more signal sources are of the same position (i.e. number of signal sources are at the same position relative to the system), only one source will be allowed to participate in the system's positioning. When other parameters except carrier frequency are the same, we select the lowest downlink signal frequency source as shown in equation (6).

$$f = \min[f_1, \dots, f_n] \quad (6)$$

C. Receive signal strength screening

Furthermore, considering signals from different systems with different transmitting parameters but the same transmitter location whose downlink signal frequency can not be used to measure the performance of signals (assuming there are L different signals at the same location). Received signal strength filtering can be applied in this case according to equation (7) below.

$$RSSI = \max[RSSI_1, \dots, RSSI_L] \quad (7)$$

D. Determining the evaluation index and sets

The evaluation index refers to the factors that affect the navigation and positioning system of mobile communication signals, and the evaluation set is an objective composition of that which is been evaluated(signals). Here, signal source filtered based on downlink frequency and received signal strength are assumed to have m evaluation objects and N evaluation indexes.

E. Constructing a fuzzy evaluation matrix for mobile communication signals

According to the value of the evaluation index after modeling, the matrix contains M evaluation objects and N evaluation indexes. The evaluation matrix X is constructed as shown in equation (8).

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (8)$$

In this paper, the m evaluation objects are simply m signal sources. The evaluation index selected are a composition of both the position distribution cost and ranging error of mobile communication signal sources. The cost function of geometric position distribution of signal source t is shown in the formula below.

$$J_t = \sum_j \cos 2\theta \quad (9)$$

Equation (10) shows measurement error from signal source t to the receiver

$$\Delta r = r_t - \sqrt{(x_t - x_u)^2 + (y_t - y_u)^2} \quad (10)$$

Equally important to note is that indexes with different dimensional sizes cannot be directly used. So evaluation indexes need to be standardized to obtain fuzzy matrix:

$$R = (r_{pq})_{m \times n}, r_{pq} \in [0, 1] \quad (11)$$

The standardization process can differ depending on whether the index is positive or negative.

Standardization process of a positive index value (the greater the value of the positive index, the better the system performance) :

$$r_{pq} = \frac{x_{pq} - \min_q \{x_{pq}\}}{\max_q \{x_{pq}\} - \min_q \{x_{pq}\}} \quad (12)$$

Standardization process of a negative index value (the smaller the negative index value is, the better the performance):

$$r_{pq} = \frac{\max_q \{x_{pq}\} - x_{pq}}{\max_q \{x_{pq}\} - \min_q \{x_{pq}\}} \quad (13)$$

At this point, a smaller signal source position distribution cost function value will invariably result in better selection performance, producing high navigation and positioning accuracy results. Similarly, a smaller ranging error will provide a higher positioning accuracy with better performance in mobile communication signal systems. Hence, including negative index standardization is also necessary.

F. Entropy weight method Application

The system entropy value can reflect the current degree of uniformity or chaos a system by calculating its standardized index matrix weight. A low entropy value of a certain index indicates a relatively high chaotic state of the mobile communication signal of that index. Ideally, entropy can represent uncertainty in signal selection, and when the probability of an index is higher, its influence is greater. At this point, entropy can be used to calculate the weight of the index. The smaller the entropy is, the higher the correlation degree will be, resulting in a greater weight value. The calculation process is shown in equations (14) to (17)

$$H_p = -k \sum_{q=1}^n f_{pq} \ln f_{pq} \quad (p = 1, 2, \dots, m) \quad (14)$$

$$f_{pq} = r_{pq} / \sum_{q=1}^n r_{pq} \quad (15)$$

$$k = 1 / \ln n \quad (16)$$

$$w_p = \frac{1 - H_p}{m - \sum_{p=1}^n H_p} \quad (17)$$

Here w is the weight value of each evaluation index, and where

$$0 \leq w_p \leq 1, \sum_{p=1}^n w_p = 1 \quad (18)$$

G. Comprehensive evaluation value of each mobile communication signal source

To calculate the comprehensive evaluation value of each signal source, we construct a weight value matrix $P = [w_1, \dots, w_m]$. Then, all the comprehensive evaluation value of each signal source can be calculated according to a fuzzy transformation $Q = R \cdot P$. Each element in matrix Q is the comprehensive evaluation value of each signal source respectively. Finally, the specified number of signal sources is selected according to actual demand, determining the signal subset. When all this is done, signal selection of the comprehensive evaluation algorithm is completed.

IV. MEASUREMENT AND ANALYSIS

In order to comprehensively analyze the characteristics of mobile communication signals, this paper uses the same test platform for signals of different type in the same experimental environment, to analyze the performance of the algorithm on GSM and LTE signals after signal selection.

A. Test platform and actual measurement environment

a) Test platform:

- Mobile communication positioning and signal reception platform: constitutes of the HackRF One software radio equipment which supports a full frequency band of 10MHz-6GHz;
- Receiving antenna: An omni-directional receiving antenna which supports the full frequency band of 800MHz to 2700MHz;
- Mobile communication signal positioning software processing platform: High performance laptop computer.

b) *Actual Measurement Environment*: This experiment is based on the received signal strength of GSM and LTE signals, seeking to verify the measurements in actual environment. The testing road location is Xiangtan University, Bo Xue Road. During the testing process, the navigation and positioning platform was placed on a trolley and the device was pushed forward slowly at a walking speed. Subsequently, both GSM and LTE signals were collected as the comprehensive, cluster, and sub-optimal selection algorithm were formed to perform signal source selection. After selection, signal sources are used on SDP algorithm to solve for position results.

B. Performance Analysis of Different Signal Selection Algorithms

a) *GSM signal selection algorithm performance comparison:* Conventionally, in analyzing the performance of the three selection algorithms, this paper compares three factors: algorithm accuracy ranking, algorithm accuracy ranking cumulative probability distribution and average positioning accuracy (RMSE), as shown in Fig. 3, Fig. 4 and Table I respectively. Fig. 3 and Fig. 4 show that the selection results of the comprehensive evaluation selection algorithm ranks higher, with 0.75 in performance (in the top 50%), the cluster selection algorithm has a value of only 0.6, and the sub-optimal selection algorithm, a value of 0.56. The comprehensive evaluation selection algorithm is far superior to the cluster and sub-optimal selection algorithm. As SDP algorithm is also applied for position solutions after the use of each aforementioned algorithm, from Table 1 we can observe that the average positioning accuracy of the comprehensive selection algorithm is more desirable for its better performance.

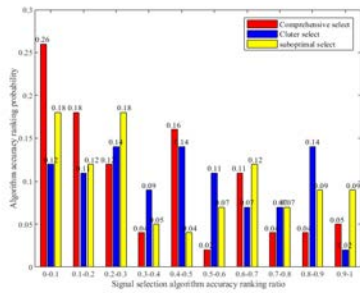


Fig. 3. Precision ranking distribution of three selection algorithms for GSM signals.

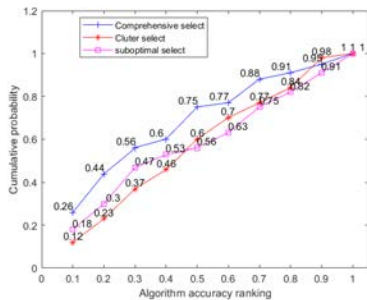


Fig. 4. Cumulative probability distribution of accuracy ranking for three selection algorithms for GSM signals.

TABLE I

ACCURACY RANKING OF THE CUMULATIVE PROBABILITY DISTRIBUTION OF THE THREE SELECTION ALGORITHM FOR GSM SIGNALS.

Algorithm	Average positioning accuracy
Comprehensive selection	128.6m
Cluter selection	209.1m
Sub-optimal selection	187.9m

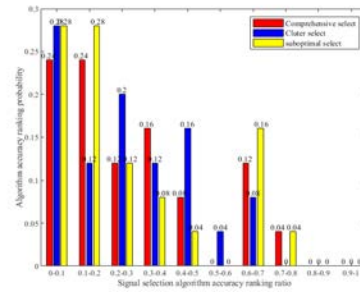


Fig. 5. Algorithm precision ranking distribution of three LTE selection algorithms.

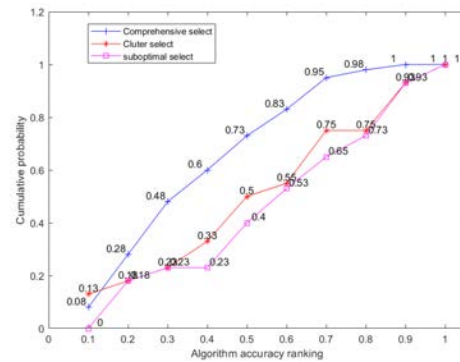


Fig. 6. Accuracy ranking of the cumulative probability distribution of the three selection algorithm for LTE signals.

b) *LTE signal selection algorithm performance comparison:* Combined with Fig 5 and Fig 6, it can be seen that the selection results of the comprehensive selection algorithm rank higher, higher with a value of 0.73 (in the top 50%) in performance, 0.5 for the cluster selection algorithm, and a value of 0.4 for the sub-optimal selection algorithm. It is further verified that the comprehensive selection algorithm is far superior to the cluster selection and sub-optimal selection algorithm. Again, the position estimation RMSE of the SDP algorithm of the three selection algorithms was compared, and after using the comprehensive selection algorithm, the average positioning accuracy of the SDP algorithm was 69.9m, that of the cluster selection algorithm was 82.2m, and sub-optimal selection was 76.3m.

Specifically judging based on RMSE value, LTE signals possess a value smaller than that of GSM signals, but has a higher positioning accuracy after its algorithmic selection.

TABLE II

RMSE COMPARISON OF POSITIONING ACCURACY OF THREE LTE SELECTION ALGORITHMS IN THE TESTING ENVIRONMENT.

Algorithm	Average positioning accuracy
Comprehensive selection	69.9m
Cluter selection	82.2m
Sub-optimal selection	76.3m

Judging by ranking and cumulative probability distribution of the selection algorithm, received LTE signals used on comprehensive selection algorithm produce 98% of positioning accuracy results ranked within 0.7.

V. CONCLUSION

This paper briefly introduces the navigation and positioning framework of mobile communication signals through the analysis of its system and performance when utilised. It also briefly introduces the advantages and improvements needed in traditional selection algorithm or scheme by analysing the importance and necessity of signal source selection. The core research content here is using independently developed radio navigation and positioning software platform for mobile communication signals, we extracted various signal parameters used in signal selection, performed database matching and information conversion in order to facilitate direct use in signal selection, navigation and positioning. By analysing and selecting the indexes/indicators that needs to be considered in the selection of mobile communication signals, and modeling the evaluation, we were able to design and finally propose a mobile communication signal selection algorithm which is based on comprehensive evaluation mechanism.

It is also desirable to note that the algorithm is not limited by the mobile communication signal type used in the process. Signal reception and measurement in an actual environment helped to verify this while using the radio signal software platform.

Finally, we verified the feasibility and effectiveness of the proposed algorithm and compared the comprehensive evaluation algorithm with traditional signal selection algorithm.

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