Modern radio engineering and telecommunication systems

Современные радиотехнические и телекоммуникационные системы

UDC 527.62
https://doi.org/10.32362/2500-316X-2025-13-1-68-75
EDN LSCIAO

RESEARCH ARTICLE

Formation of a database of auxiliary information for positioning in an environment with heterogeneous radio transparency

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Abstract
Objectives. A pressing problem for indoor positioning systems in the absence of access to global navigation satellite systems is low positioning accuracy. This is usually associated with uneven coverage of the work area due to its geometric features or the presence of massive obstacles and walls within its boundaries. This problem is frequently resolved by placing an excessive number of positioning system base stations in the work area. This approach generates a high cost for such systems, which in turn prevents their deployment. Therefore, research and development aimed at improving the accuracy of indoor positioning systems using a minimum number of stations is of great relevance. The author previously proposed a method of increasing the accuracy of indoor positioning by taking into account obstacles known at the design stage of the system. Consideration of such obstacles in calculating the location is achieved through the mechanism of preliminary splitting of radio beacons into groups, and the allocation of reference stations of these groups among the base stations. The aim of the work is to improve this algorithm by automating the stage of preparing information about the grouping of stations.
Methods. A computer simulation method was used, in order to confirm the operability of the algorithm to divide the stations of the positioning system into overlapping groups.
Results. The criteria for automatic station grouping and a universal algorithm for dividing stations into groups were developed, enabling the automated preparation of the minimum necessary initial data for a program implementing an algorithm for positioning in a zone of heterogeneous radio transparency.
Conclusions. Modeling of the proposed algorithm has confirmed its operability. The results obtained can be used as a significant addition to the previously proposed algorithm for taking into account obstacles when calculating distances to base stations.

Keywords: indoor positioning systems, station grouping algorithm, RSSI, trilateration

• **Submitted:** 22.12.2023 • **Revised:** 15.07.2024 • **Accepted:** 20.11.2024

For citation: Krizhanovsky M.N., Tikhonova O.V. Formation of a database of auxiliary information for positioning in an environment with heterogeneous radio transparency. *Russian Technological Journal*. 2025;13(1):68–75. https://doi.org/10.32362/2500-316X-2025-13-1-68-75, https://elibrary.ru/LSCIAO

Financial disclosure: The authors have no financial or proprietary interest in any material or method mentioned.

The authors declare no conflicts of interest.

НАУЧНАЯ СТАТЬЯ

Разбиение множества базовых станций локальной системы позиционирования на пересекающиеся группы

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Резюме

Цели. Актуальной проблемой систем локального позиционирования при отсутствии доступа к глобальным навигационным спутниковым системам является низкая точность позиционирования, связанная, как правило, с неравномерным покрытием рабочей зоны в связи с ее геометрическими особенностями или наличием в ее пределах массивных препятствий и стен. Обычно эта проблема решается путем размещения в рабочей зоне избыточного числа базовых станций системы позиционирования. Подобный подход порождает высокую стоимость таких систем, что в свою очередь препятствует их распространению. Поэтому исследования и разработки, направленные на повышение точности локальных систем позиционирования при использовании минимального числа станций, имеют большую актуальность. Ранее автором был предложен метод повышения точности локального позиционирования путем учета препятствий, известных на этапе проектирования системы. Учет таких препятствий при расчете местоположения реализуется за счет механизма предварительного разбиения радиомаяков на группы и выделения опорных станций этих групп среди базовых станций. Целью работы является усовершенствование этого алгоритма за счет автоматизации этапа подготовки информации о группировке станций.

Методы. Использован метод компьютерного моделирования для подтверждения работоспособности алгоритма разбиения станций системы позиционирования на пересекающиеся группы.

Результаты. Разработаны критерии автогруппировки станций и универсальный алгоритм разбиения станций на группы, позволяющий в автоматизированном режиме подготовить минимально необходимые начальные данные для программы, реализующей алгоритм позиционирования в зоне неоднородной радиопрозрачности.

Выводы. Моделирование предложенного алгоритма подтвердило его работоспособность. Полученные результаты могут использоваться как существенное дополнение к предложенному ранее алгоритму учета препятствий при расчете расстояний до базовых станций.

Ключевые слова: локальные системы позиционирования, алгоритм группировки станций, RSSI, трилатерация

• **Поступила:** 22.12.2023 • **Доработана:** 15.07.2024 • **Принята к опубликованию:** 20.11.2024

Для цитирования: Крижановский М.Н., Тихонова О.В. Разбиение множества базовых станций локальной системы позиционирования на пересекающиеся группы. *Russian Technological Journal*. 2025;13(1):68–75. https://doi.org/10.32362/2500-316X-2025-13-1-68-75, https://elibrary.ru/LSCIAO

Прозрачность финансовой деятельности: Авторы не имеют финансовой заинтересованности в представленных материалах или методах.

Авторы заявляют об отсутствии конфликта интересов.

INTRODUCTION

Positioning objects in confined spaces has become a common issue due to the growing popularity of robotization of various spheres of life. It has been resolved in various ways, using various combinations of components and algorithmic solutions for coordinate determination. As a rule, such systems are implemented on the basis of one of the common wireless data transmission interfaces, such as Wi-Fi [1–3], BLE[1] [4–6], ZigBee [7–9], UWB[2] [10–14], etc.

In indoor positioning, the problem of accuracy improvement is the most pressing, as confirmed by the fact that the largest number of publications is devoted to it. For example, [15] proposes increasing accuracy by purchasing more expensive components which is often not economically feasible for the consumer. In [16] accuracy improvement is provided by using two protocols (Wi-Fi and BLE) and two algorithms for coordinate calculation (trilateration [17] and matching [18]).

Another solution was proposed in [19], which discussed the possibility of reducing the average value of the positioning error by taking into account the loss of signal power when crossing obstacles, where information about the location in the working area is known in advance. It is proposed that at the stage of system development each particular case of the working area in which it is planned to carry out positioning of any objects be approached individually. In order to take obstacles into account, it is proposed that all base stations of the system used for positioning into groups be divided in advance. This is based on the known data on the coordinates of obstacles. Then the reference stations among them can be singled out. The division into groups is based on the principle of finding a group on the same side of the obstacles. A reference station is selected based on its proximity to the geometric center of the area occupied by a particular group of stations, bounded not necessarily by a closed contour of obstacles. According to the algorithm proposed in the paper, the positioning device first compares the signal levels from the reference stations of different groups. After determining the strongest signal in the calculation of distances based on the measurement of the received signal strength indicator (RSSI), the positioning device will be able to decide that all stations belonging to the group whose reference station has the strongest signal are on the same side of the obstacles with the object. Thus, the distance to these stations is calculated as if they were in line of sight.

The distance to the stations in line-of-sight according to the measured RSSI value is calculated according to the following relation:

$$\frac{P_{\mathrm{r}}(d_0)}{P_{\mathrm{r}}(d)} = \frac{d^n}{d_0},$$

wherein d_0 is the calibration distance, which is usually 1 m; $P_{\mathrm{r}}(d_0)$ is the RSSI value determined by the receiver at the calibration distance; $P_{\mathrm{r}}(d)$ RSSI value determined by the receiver during the measurement; d is the measured distance; and n is the coefficient of signal power loss which ranges from 2 to 4 for air, depending on the presence of obstacles.

From this equation, the expected RSSI value at distance d can be obtained as follows:

$$P_{\mathrm{r}}(d) = P_{\mathrm{r}}(d_0) - 10n\lg\left(\frac{d}{d_0}\right) \text{ dBm},$$

$$d = d_0 \cdot 10^{\frac{P_{\mathrm{r}}(d_0) - P_{\mathrm{r}}(d)}{10n}} \text{ m}.$$

For stations belonging to other groups, the distance from the object is calculated in accordance with the Motley–Keenan mathematical model [20]. Then the received power and distance to the signal source will be calculated according to the following formulae:

$$P_{\mathrm{r}}(d) = P_{\mathrm{r}}(d_0) - k_{\mathrm{W}}P_{\mathrm{W}} - 10n\lg\left(\frac{d}{d_0}\right) \text{ dBm},$$

$$d = d_0 \cdot 10^{\frac{P_{\mathrm{r}}(d_0) - k_{\mathrm{W}}P_{\mathrm{W}} - P_{\mathrm{r}}(d)}{10n}} \text{ m},$$

[1] Bluetooth low energy—Bluetooth technology with low power consumption.

[2] Ultra-wide band—A short-range, low-power wireless communication technology that uses ultra-wideband signals with extremely low power spectral density as a carrier.

wherein k_W is the number of the passed single-type obstacles (walls), and P_W is the loss of signal power when passing through a single-type obstacle (wall).

The modeling carried out in [19] confirmed a significant improvement of positioning accuracy by means of the trilateration method. It should be noted that the partitioning into groups and allocation of reference stations were performed "manually" at the developer's discretion.

The objective of this article is to improve the positioning algorithm proposed in [19] for positioning in the zone of inhomogeneous radio transparency by automating the process of dividing base stations into groups, selecting reference stations and introducing additional parameters for the realization of these actions. This objective is also to resolve possible ambiguities when making a decision on line-of-sight with stations which can arise when an object is located on the boundary of two groups of stations.

STATION GROUPING CRITERIA

The criteria for making a decision on combining several stations into one group should ensure the formation of groups consisting of stations located in the area. They should form a convex polygon without obstacles inside it, so that the positioned object located in the area occupied by a particular group of stations has mutual direct visibility with all stations of this group. If we divide the space into non-intersecting sectors occupied by groups, as in Fig. 1, then when using the method of line-of-sight determination as described in [19] (based on stations belonging to the group from whose reference station the signal of the highest amplitude is received) there may be cases of incorrect line-of-sight determination when the object is located on the boundaries of such areas.

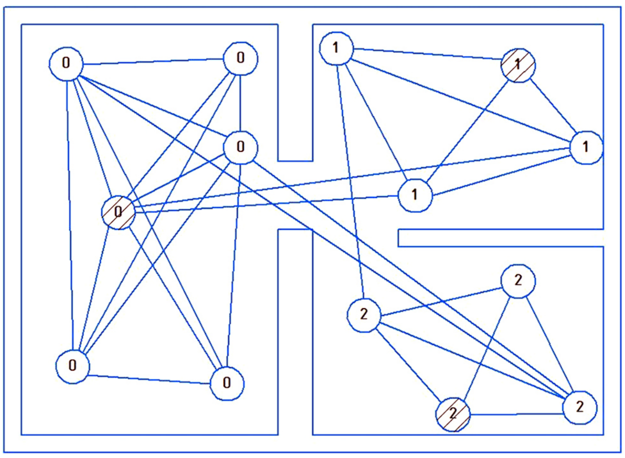

Fig. 1. Case of a work area map with stations divided into groups: shaded stations are reference stations; stations connected by lines are in line of sight

Among the stations from which the strongest signals are received by the object and which participate in the calculation of coordinates, there may be stations from the group for which an incorrect decision about the absence of line-of-sight will be made. An example of such a situation is shown in Fig. 2, where the positioned object located between two groups of stations is designated as PO.

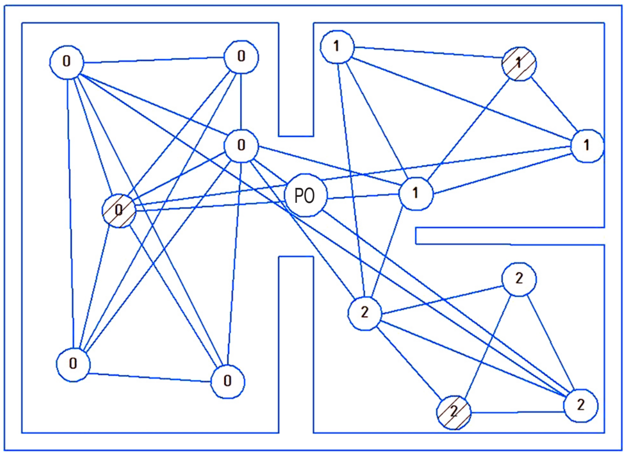

Fig. 2. Case of ambiguity in the definition of line of sight with stations

Figure 2 shows that the closest reference station is the station of group 0, but that the three closest stations are each from three different groups.

In such a situation, the range from some of the stations taken into account in the calculation will be calculated incorrectly. This will lead to significant errors in positioning. The implementation of overlapping groups will eliminate this problem, since it will eliminate the very possibility of the boundary condition. For example, in the situation presented in Fig. 3, this error in positioning will not occur. An additional group "3" appears on the diagram (the designation "3" is marked next to the stations belonging to this group). This group includes the boundary stations from the other three groups, thus eliminating the ambiguity of determining the stations with which there is direct visibility.

It can thus be stated that the condition of station groups located in areas without obstacles within their boundaries is ensured by mutual direct visibility of the said stations. Also, in order for each group to be able to provide positioning of the object independently, it must have at least three stations (for the case of two-dimensional positioning). Two stations in direct line of sight cannot be considered as a group, since it is not always possible to determine the object location unambiguously from the signals from two stations.

With regard to creating conditions for the formation of overlapping groups by the designed algorithm, it was experimentally established that, if a restriction on the

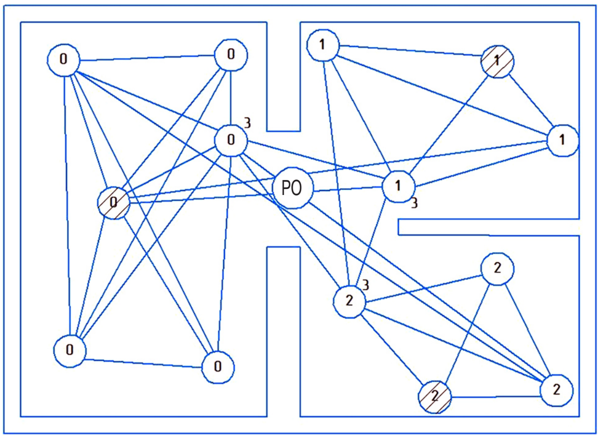

Fig. 3. Case of resolving ambiguity in line-of-sight determination with stations

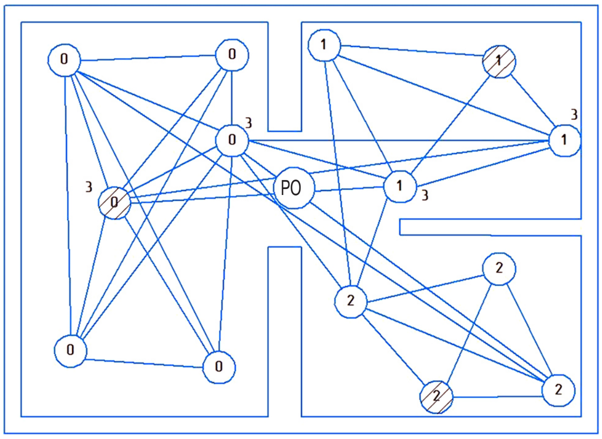

Fig. 4. Group 3 is a case of a possible overextended group

maximum distance of the stations included in the groups from each other is included in the algorithm, then, by varying this restriction, it is possible to find its optimal value. This value will correspond to the conditions for the autogrouping of stations with the creation of overlapping groups. Such a constraint will ensure that there are no conditions for the formation of excessively long groups, for example, as in Fig. 4. Group 3 in this case has a large extent, increasing the risk of incorrectly determining the range of stations in line of sight from the positioning object.

Thus, we can distinguish three principles, which should be incorporated into the algorithm of automatic station grouping:

1) mutual direct visibility of all stations belonging to the group;
2) the group cannot contain less than three stations;
3) stations in a group shall not be located at a distance from each other exceeding the specified maximum range.

ALGORITHM OF STATION AUTOGROUPING ACCORDING TO THE PROPOSED PRINCIPLES

Based on the proposed principles, an algorithm for autogrouping base stations of the indoor positioning system into overlapping groups was developed. The algorithm thus developed forms a set of groups of stations and allocates a reference station in each group. It should be separately noted that this algorithm assumes the availability of cartographic information about the location of obstacles in the potential working area of positioning.

The algorithm of station autogrouping is divided into the following steps:

1. Calculation of the table of presence and absence of line of sight between stations;
2. Formation of a two-dimensional array, each row of which is a list ranked by distance from the stations with the identifier corresponding to the column number to the station whose identifier corresponds to the row number of the two-dimensional array;
3. Exclusion from each line of the two-dimensional array of stations with no line of sight to the station whose identifier is equal to the line number;
4. Exclusion from each row of the two-dimensional array of stations with a distance exceeding the developer's distance limit to the station, and the identifier of which is equal to the row number;
5. Exclusion of lines containing less than three stations;
6. Exclusion of repeated lines;
7. Determining the matches between lines, deleting lines with station sets present in the line-ups of other lines and forming groups.

In order to illustrate the algorithm, a map of a 5 m × 5 m room with two additional room-dividing partitions was taken. The map with arranged stations and marked station identifiers is shown in Fig. 5.

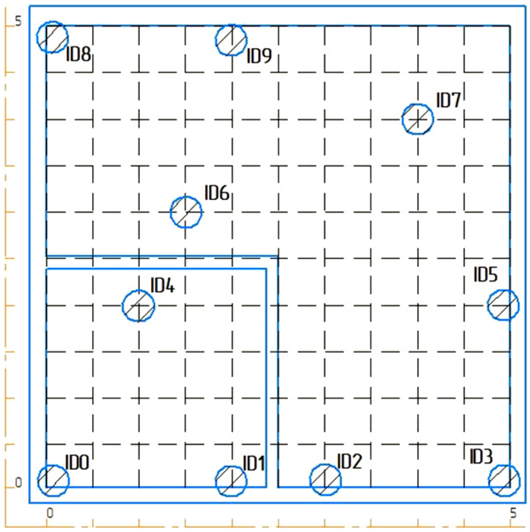

Fig. 5. Map of the working area for illustrating the principles of the program operation

Automatic grouping was provided by a program which implements the proposed algorithm. Figure 6 shows the map of the working area. The marks on the stations show which group they belong to, as a result of the algorithm. In addition, a reference station was identified in each group (in Fig. 6, such stations are marked with a black dot).

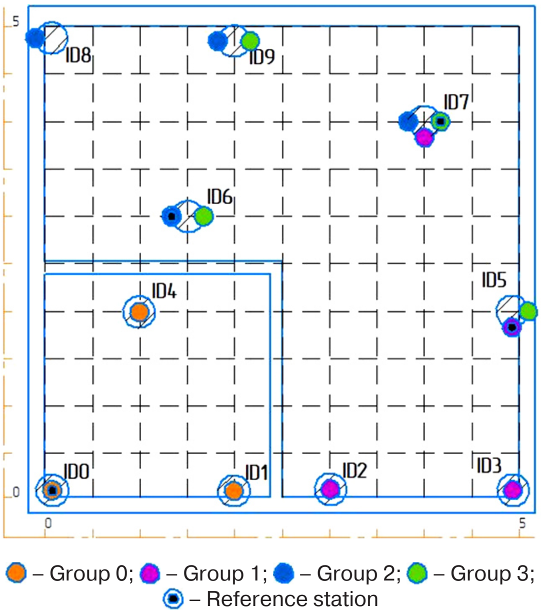

Fig. 6. Map of the working area with the results of the grouping performed

As can be seen, in Fig. 6, the possibility of ambiguity of line-of-sight station identification at the boundary of groups 1 and 2 is eliminated due to the intersection of groups, as well as due to the creation of an intermediate group 3.

Thus, the algorithm of automatic station grouping in the conditions of the working area with obstacles, logically complements and improves the algorithm given in [19].

CONCLUSIONS

The article proposes the principles of station autogrouping, and a universal algorithm for partitioning stations into groups. As a result, it is possible to prepare in automated mode the minimum necessary initial data for the operation of the program given in the article, in order to implement the positioning algorithm in the zone of inhomogeneous radio transparency. During the development of the autogrouping program, the method of mutual overlapping of groups by stations was introduced, in order to supplement the previously proposed algorithm. This enabled us to resolve the problem of ambiguous determination of line of sight between stations at the boundaries of groups. In further works, it is planned to supplement this set of software solutions with an intelligent algorithm for the optimal arrangement of stations of the indoor positioning system in premises. This will allow a complete program complex to be created, which will enable us to perform the preliminary arrangement and grouping of stations in the designed indoor positioning system.

Authors' contribution

All the authors have equally contributed to the research.

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Translated from Russian into English by Lyudmila O. Bychkova
Edited for English language and spelling by Dr. David Mossop