Methods of Determining the Coordinates of Nodes of Wireless Computer Networks According to the Ieee 802.15.4 Standard

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Abstract

One of the urgent tasks is to determine the location of individual network objects. An indispensable condition for the operation of any monitoring and control systems is the linking of the data collected by the entire system to geographic coordinates for displaying the collected information on the map and further analysis. In addition, such a network (unlike traditional radio networks) with a built-in subsystem for positioning individual objects can be deployed almost anywhere with minimal costs. This can be done, for example, by scattering network objects from an aircraft. In addition to linking the data received by the network in the process of work to the map of the area, information about the coordinates of objects will be necessary in the process of functioning of the network itself (building efficient routing algorithms from the point of view of energy consumption, collecting the received data). In this regard, the development of algorithms for determining the coordinates of objects in the sensor network becomes an urgent task. This article examines the problem of determining the distance between transceivers of chaotic radio pulses. the distance is calculated based on the signal propagation time in the air. The accuracy of the determination between the transceivers is evaluated, based on the signal transit time, taking into account interference. The purpose of this article is to describe a model for determining the time of receiving a signal, in order to determine the distance between sensor transceivers of chaotic radio pulses. And also estimation of measurement error. The calculation of the distance is carried out relative to the propagation time of the signal on the air, and the accuracy of the distance determination must also be evaluated.

Keywords [1]

sensor network, node, anchor, localization, zig-bee, transceiver, radio pulse, time, distance, measurement error.

1. Introduction

Today, "wireless sensor networks" ("Sensor Networks", hereinafter simply sensor networks) are attracting more and more attention all over the world. The term "Sensor network" appeared relatively recently (a few years ago), but today it is already a completely stable term (Sensor Network), which means a distributed, self-organizing, failure-resistant network consisting of a large number small-sized and cheap semiconductor devices that exchange information via a wireless communication channel are maintenance-free and do not require special installation. Each device can contain various sensors of the physical parameters of the environment (motion, light, temperature, humidity, pressure, etc.), as well as means for primary processing and storage of the received data. The number of objects in such a network is theoretically determined only by the scope of application and budget, and due to the low price of individual devices (on the order of several dollars and below), it can be very large (on the order of several thousand and above) [1-3].

Now there are various technological solutions for determining the position of objects in space or on the surface of the earth. This is due to the fact that it is impossible to implement one universal method that is suitable for all possible cases. More precisely, it is impossible to make a device whose specifications would meet the requirements of all (or even most) tasks. The task of positioning is of great interest to developers and manufacturers of equipment, which can testify to its demand. Moreover, most solutions use the radio signal as a carrier of information. Consequently, universal devices that allow simultaneously to transmit and receive

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data, as well as determine their position in space will have a consumer value. One of the standards governing the operation of wireless transmitting devices with positioning function - IEEE 802.15.4 [4-5].

This approach to network formation allows to adapt sensor networks to solve an extremely wide range of tasks. In particular, one of the main applications of sensor networks is the creation of various monitoring and control systems. It should be expected that in the near future sensor networks will occupy a much wider niche among existing telecommunication technologies that use wireless radio communication. In this connection, the analysis and search for methods for determining the coordinates of objects in the sensor network becomes an urgent task [6-9]. The general approach to determining the location of an object is based on measuring the characteristics of the radio signal emitted by the transmitter located on the object, and is taken by stationary receivers with known coordinates. According to these characteristics, the distance between the transmitter and each of the receivers is estimated [10-12].

Then, taking into account the geometric principles, the coordinates of the object are determined. In this paper, the problem of determining the distance between transceivers of chaotic radio pulses is investigated. the distance calculation is based on the propagation of the signal on the air. It is estimated the accuracy of the definition between the transceivers, based on the time of the signal passing, taking into account the obstacles. In further studies, for the possibility of obtaining alternative results, as well as a more detailed analysis of the measurement error, the laser distance measurement will be included in the sensor network. [13-15]

2. Analysis of literature and problem statement

There are positioning technologies such as GPS, which is discussed in the work of Sichitiu M. [16-17], Galileo, which is dedicated to the work of the Federation of American Scientists [18-21], Glonass, which is discussed in the joint work of Spanish scientists on environmental monitoring [22-25], use Wi-Fi [26] or ultrashort pulses, which is mentioned in the relevant standard of the Institute of Electrical and Electronics Engineers, or positioning technology of GSM cellular phones, to which the work of He T. [27-30] is dedicated, etc. All these technologies have their pros and cons. Galileo, GLONASS, GPS, for example, allow you to navigate on the surface of the earth, carrying a compact device with a set of terrain maps.

These are very useful technologies for moving around in open terrain. The accuracy of the position of such devices now reaches units of meters. However, it can worsen in large cities, in difficult terrain, or simply in a closed room. In the latter case, the use of satellite positioning is unacceptable.

3. Formulation of the problem of research distance measurement method using sensor networks

One of the urgent tasks is to determine the location of individual network objects. An indispensable condition for the operation of any monitoring and control systems is the linking of the data collected by the entire system to geographic coordinates for displaying the collected information on the map and further analysis. In addition, such a network (unlike traditional radio networks) with a built-in subsystem for positioning individual objects can be deployed almost anywhere with minimal costs. This can be done, for example, by scattering network objects from an airplane. In addition to linking the data received by the network in the process of work to the map of the area, information about the coordinates of objects will be necessary in the process of functioning of the network itself (building efficient routing algorithms from the point of view of energy consumption, collecting the received data).

The problem of positioning is of great interest to developers and manufacturers of equipment, which may indicate its demand. Moreover, most solutions use a radio signal as an information carrier. Therefore, universal devices that allow simultaneous transmission and reception of data, as well as determining one's position in space will have consumer value. One of the standards regulating the operation of wireless radio transmitting devices with a positioning function is IEEE 802.15.4.

The general approach to determining the location of an object is based on measuring the characteristics of a radio signal emitted by a transmitter located on the object and received by stationary receivers with known coordinates [6]. Based on these characteristics, the distance between the transmitter and each of the receivers is estimated. Then, taking into account geometric principles, the coordinates of the object are determined.

The following values can be used as signal characteristics:

• signal propagation time from the transmitter to the receiver;

• the difference in indicators of signal propagation time from the transmitter to different receivers;

• signal intensity;

• direction of signal arrival.

4. Description of the distance determination model

To determine the distance between two objects, the propagation time of the signal from the first object to the second plus the propagation time of the signal in the opposite direction can be used.

Consider the problem of determining the distance between the transmitter and the receiver using chaotic radio pulses. We will assume that there are 2 devices: probing (d_1) and probing (d_2). Both devices include a receiver, a transmitter and a digital part. The transmitter in (d_1) emits a pulse or a series of pulses, and the receiver in (d_2), respectively, receives a pulse or series of pulses. Due to a fixed time delay, the transmitter in (d_2) emits a single pulse or a burst of pulses, and the receiver in (d_1) receives them.

The time interval Δt between the moment of emission of the pulse by the transmitter in (d_1) and the moment of its arrival at the receiver in (d_1), after deducting the delay τ in device (d_2), divided in half and multiplied by the speed of light c, determines the distance l between the transmitter and the receiver:

$$l = \frac{\Delta t - \tau}{2} c. \quad (1)$$

We will estimate the moment of arrival of a chaotic radio pulse using a receiver that isolates the envelope of a chaotic radio pulse. The receiver is a quadratic detector and a low-pass filter connected in series. After the low-pass filter, there is a limit device that detects the moment when the signal corresponding to the pulse begins to exceed a certain threshold value. We take this moment of time as the moment of arrival of a chaotic radio pulse.

Trilateration method. Trilateration is the main and simplest method. This method calculates the position of a node by the intersection of three circles, as shown in Figure 3. To estimate its position using trilateration, a node needs to know the positions of three reference nodes and the distances to each of these nodes (Figure 1).

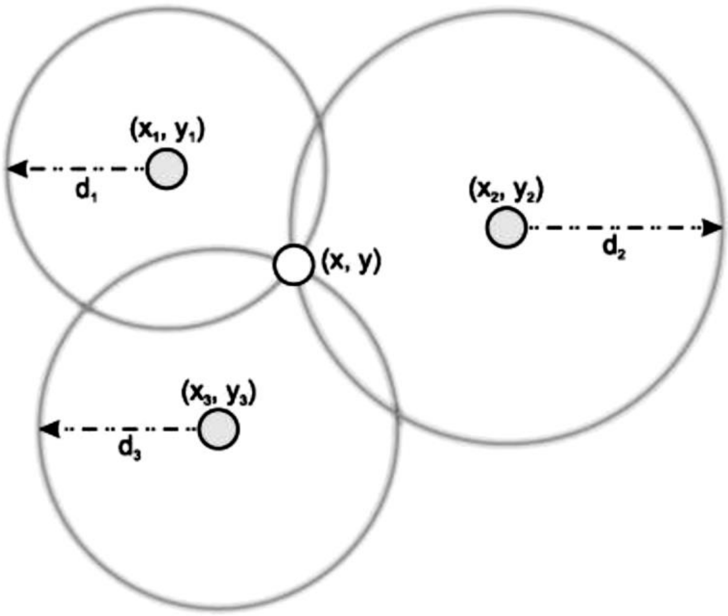

Figure 1: Theoretical model of trilateration

The circles formed by the position and distance to each point are expressed by the formula:

$$(\hat{x} - x_1)^2 + (\hat{y} - y_1)^2 = d_1^2$$
$$(\hat{x} - x_2)^2 + (\hat{y} - y_2)^2 = d_2^2$$
$$(\hat{x} - x_3)^2 + (\hat{y} - y_3)^2 = d_3^2$$

where $(\hat{x}, \hat{y})$ is the position to be found, (x_i, y_i) is the position of the anchor nodes, d_i is the distance of the anchor node to the unknown node. In this case, we have three quadratic equations with two unknowns that can be solved, theoretically.

In practical applications, it is difficult to estimate distances and accurate information about the location of reference nodes to calculate coordinates. As shown in Figure 2.a, the circles do not intersect at just one point, resulting in an infinite set of possible solutions.

The bounding square method. The Bounding Box method uses squares - instead of circles, which are used, for example, in the trilateration method - limiting the possible positions of the node. An example of this method is shown in Figure 3 [2].

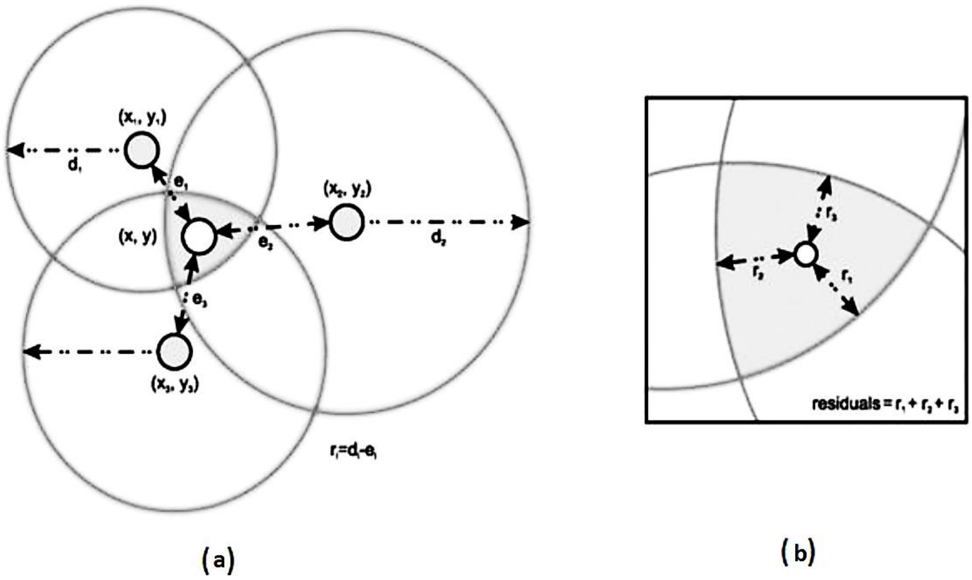

Figure 2: A practical model of trilateration: a) mismatch of positions and distances generate a system with infinite solutions; b) the residual value as the sum of the squares of the differences between the estimated and calculated distances

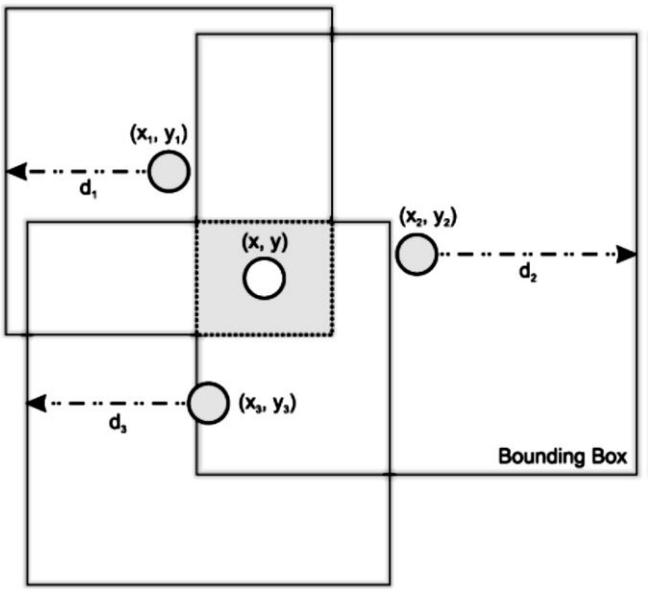

Figure 3: The Bounding Box method

Despite the error of this method when the calculation is completed, which is greater than that of the trilateration method, but it requires significantly less processor resources when calculating the intersection of squares than when calculating the intersection of circles.Under the assumption that the most likely location of a node is the center point among all reference nodes, we can calculate the position of an unknown node without the need to estimate distances or angles, but only when using the signal range-based method.

For each reference node i, the bounding square is defined as a square centered at the position of this node (x_i, y_i), with sides of size $2d_i$ (where d is the expected distance), with coordinates:

$$(x_i - d_i, y_i - d_i\ ) and\ (x_i + d_i, y_i + d_i\ ).$$

The intersection of all bounding squares can be computed without the need for floating-point calculations by taking the maximally low and minimally high coordinates of all bounding squares:

$$\left(max(x_i - d_i), max(y_i - d_i\ )\right)\ and\ \left(min(x_i + d_i), \min(y_i + d_i\ )\right).$$

We get a shaded rectangle, which can be seen in Figure 2. The position of the unknown node is then calculated as the center of intersection of all connecting squares:

$$(\hat{x},\hat{y}) = \left(\frac{max(x_i - d_i) + min(x_i + d_i)}{2}, \frac{max(y_i - d_i) + min(y_i + d_i)}{2}\right).$$

In this case, the position of the node is calculated using the following equation [8]:

$$(\hat{x},\hat{y}) = \left(\frac{\sum_{i=1}^{n} x_i}{n}, \frac{\sum_{i=1}^{n} y_i}{n}\right),$$

where n is the number of support nodes.

This method is the simplest in terms of computing resources and required information. Only floating-point operations (where n is the number of reference nodes) are required to calculate the position. On the other hand, the obtained solutions are not accurate, the main thing is that the number of support nodes is small.

Multilateration method. Also, when more than three nodes with known coordinates are available, we can use the multilateration method to calculate the node's position.

Then the uncertain system of equations, where the number of equations is greater (due to the increase in the number of anchor nodes), the number of unknowns must be solved. Figure 4 shows this case. Usually, such systems do not have a unique solution.

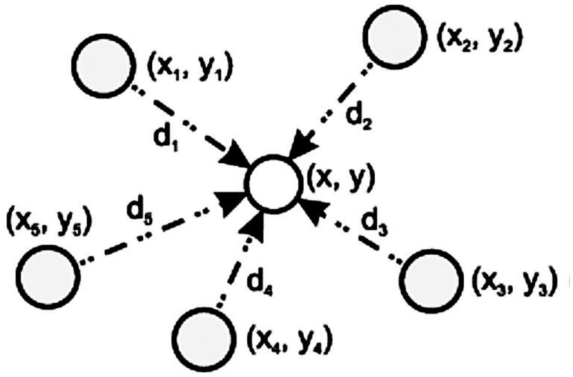

Figure 4: The multilateration model is used only when more than three anchor nodes are used

Having considered n anchor nodes and the distance estimation error, which is $d_i = \hat{d_i} - \epsilon$,the system of equations will look as follows:

$$(\hat{x} - x_1)^2 + (\hat{y} - y_1)^2 = \hat{d}_1^2 - \epsilon$$
$$\vdots$$
$$(\hat{x} - x_n)^2 + (\hat{y} - y_n)^2 = \hat{d}_n^2 - \epsilon$$

where, ∈ - is usually considered an independent normal random variable. Taking into account the last equality, the system of equations can be simplified to a linear one, $A_x \approx b$, or:

$$\begin{bmatrix} 2(x_1 - x_n) & 2(y_1 - y_n) \\ \vdots & \vdots \\ 2(x_{n-1} - x_n) & 2(y_{n-1} - y_n) \end{bmatrix} \begin{bmatrix} \hat{x} \\ \hat{y} \end{bmatrix} \approx$$

$$\approx \begin{bmatrix} x_1^2 - x_n^2 + y_1^2 - y_n^2 + d_1^2 - d_n^2 \\ \vdots \\ x_{n-1}^2 - x_n^2 + y_{n-1}^2 - y_n^2 + d_{n-1}^2 - d_n^2 \end{bmatrix}$$

This linear system can be solved using standard methods such as the least squares approach. This can be done as follows:

$$x = (A^T A)^{-1}(A^T b)$$

The main idea of this method is to minimize the sum of squares of the difference between calculations (for example, using RSSI) and calculated distances (by estimates, positions). The sum of the differences is known as the residuals, as shown in Figure 2(b). Mathematically, it is written as follows:

$$(\hat{x},\hat{y}) = \min\left(\sum_{i=1}^{n} (\sqrt{(\hat{x} - x_i)^2 + (\hat{y} - y_i)^2} - d_i)^2\right),$$

where (x_i, y_i) is the position of the reference node, d_i is the distance estimate, $\sqrt{(\hat{x}-x_i)^2+(\hat{y}-y_i)^2}-d_i$ is the distance between the calculated position and the position of the reference node, which is the calculated the distance.

It is necessary to calculate several floating-point operations depending on the method that calculates the position used to solve the system of equations. In the case of the method of least squares $(m+\frac{n}{3})n^2$, floating-point operations (where m is the number of unknowns and n is the number of equations) are necessary to determine the position.

Triangulation method. Triangulation is the process of dividing a polygonal area with a complex configuration into a set of triangles. When analyzing or synthesizing complex surfaces, they are approximated by a grid of triangles, and in the future we operate with the simplest polygonal areas, that is, with each of the triangles. The use of triangulation is explained by the following reasons:

- a triangle is the simplest polygon, the vertices of which uniquely define a face;
- any area can be guaranteed to be divided into triangles;
- for a triangle, it is easy to determine its three nearest neighbors that have common faces with it;
- the computational complexity of triangulation algorithms is significantly less than when using.

For a visual representation of the triangulation, a mathematical model of the sensor network deployed on the hill was simulated using the Delaunay function (Figure 2.2). The software product MathLAB is used for modeling. The complex polygonal region depicted in the graph was divided into a set of triangles using Delaunay triangulation. There are many positioning algorithms, mainly their approaches differ in triangulation methods, which in turn depend on the equipment used.

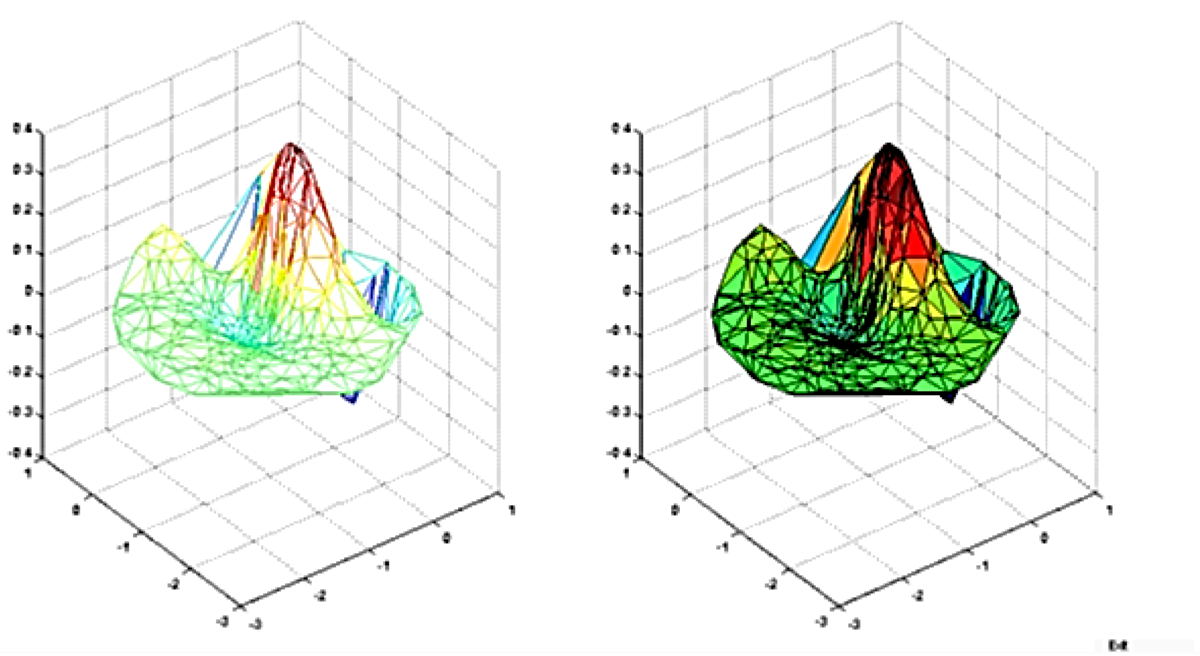

Figure 5: A sensor network deployed on a hill modeled using the Delaunay triangulation method

The complex polygonal region depicted in the graph was divided into a set of triangles using Delaunay triangulation. There are many positioning algorithms, mainly their approaches differ in triangulation methods, which in turn depend on the equipment used.

In the triangulation method, angle information is used instead of distances. The position calculation can be done remotely or by the node directly. In both cases, the position is calculated using trigonometry and the laws of sines and cosines. In the first case, remote positioning, shown in Figure 6 (a), at least two reference nodes estimate the arrival angle and remotely calculate the position of the unknown node as the place where the angle lines from each reference node intersect. This type of triangulation is mainly used in cellular communications.

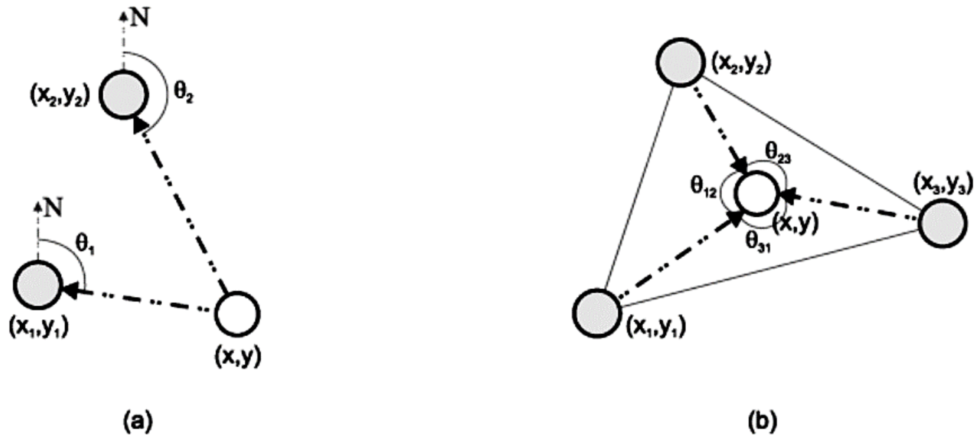

Figure 6: Triangulation: a) two anchor nodes; b) three anchor nodes

But for sensor networks, the most important thing is that the node itself calculates its own position, so for this it is necessary to have at least three nodes with known coordinates (Figure 6.b). The unknown node estimates its angle to each of the three reference nodes, based on these angles and the positions of the reference nodes (which form a triangle), calculates its own position using simple trigonometric ratios. This method is similar to the trilateration method.

5. Discussion of estimating the error of determining the coordinates of nodes of wireless computer networks taking into account obstacles

Let *n(t)* be the amplitude shift of the pulse due to noise, *A* is the amplitude of the received unnoised pulse, ΔT_R is the measurement error of the pulse arrival time, t_R is the duration of the leading edge of the pulse, τ is the duration of the pulse during transmission (Figure 2).

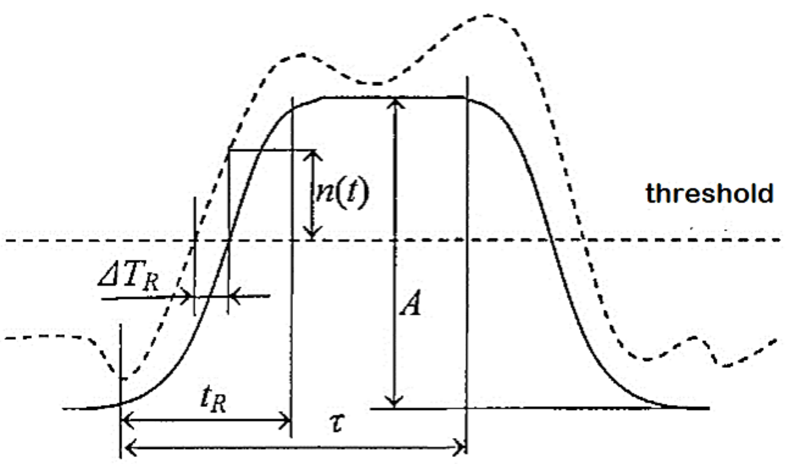

Figure 2: Determination of the arrival time of the pulse along the leading edge

Then the growth rate of the leading edge of the pulses [9] in the unnoised S_1 and noisy S_2 cases will be, respectively [10]:

$$S_1 = \frac{A}{t_R} \tag{2}$$

$$S_2 = \frac{n(t)}{\Delta T_R} \tag{3}$$

With large pulse amplitudes, these growth rates should be equal. That is, $S_1 = S_2$. Then from (2) and (3)

$$\Delta T_R = \frac{n(t)}{A/t_R}, or$$

$$\sqrt{\overline{(\Delta T_R)^2}} = \delta T_R = \frac{t_R}{\sqrt{\frac{A^2}{n^2}}} = \frac{t_R}{\sqrt{\frac{2P}{N}}} \tag{4}$$

where $\frac{A^2}{n^2}$ – the signal-to-noise ratio for the detected video pulse. Here, P is the signal power, N is the noise power in the low-pass filter band. If B is the low frequency band, then

$$t_R = \frac{1}{B}.$$

Let

$$S = \frac{E}{\tau},$$

N=N_0B, where E is the received pulse energy, N_0 is the noise power spectral density. Then

$$T_R = \frac{\tau}{\sqrt{2B\frac{E}{N_0}}}$$

$B = 5\text{x}107\ \text{Hz}, \tau\ =\ 10 - 7\ \text{s}, \frac{E}{N_0} = 20\text{dB} = 100$, then $\delta T_R \approx 3$ ns. The influence of the effect of the heterogeneity of the energy distribution in a chaotic pulse over time is similar to the influence of white Gaussian noise.

Therefore, having estimated the "signal/noise" ratio caused by this effect, you can compare it with the signal/noise ratio caused by white noise and substitute the smaller of these two ratios in the calculations.

6. Conclusions

The choice of the method for estimating the distance between nodes in the localization system is an important factor that affects the performance of the system. Typically, at least three distance estimates must be used to estimate the exact location of a node.

The choice of the position calculation method is also not a little important. Because the chosen method can also affect the final performance of the localization system. Depending on the used localization algorithm, an error in the calculation of the position can cause damage to a large or small extent to the localization system as a whole. In some algorithms, for example, nodes that were unknown when calculating their position are used to help other unknown nodes calculate their positions. In this case, an insignificant error in the calculation of the position can introduce large errors into the operation of the localization system.

The location and distance information collected by the node and available processor resources also limit the choice of method to be used. The localization algorithm is the main component of the localization system. This component defines how information provided by anchor nodes, based on distance estimates and position calculations, will be managed to allow localization information to be propagated from anchor nodes to network nodes. An analytical model for determining the distance between sensor transceivers based on the signal arrival time was built. The estimation of the signal arrival time error was carried out which is $\delta T_R \approx 3$ ns., and the main parameters affecting it were also determined: $B = 5\text{x}107\ \text{Hz}, \tau\ =\ 10 - 7\ \text{s}, \frac{E}{N_0} = 20\text{dB} = 100$.

In further research, for the possibility of obtaining alternative results, as well as a more detailed analysis of the measurement error, laser rangefinders will be included in the sensor network.

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