Relative positioning of UWB tags with deferred ranging

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Abstract. The aim of the work is to develop relative navigation systems based on ultra-wideband signals. In a relative navigation system, measurements are transmitted not to the base station, but to mobile subscribers who solve the navigation problem. The work of the network with the SDS-TWR distance measurement protocol is shown and a method for reducing the load in the network of devices is proposed, in which delayed distance measurements are used.

1. Introduction
Indoor positioning has a rapidly growing demand as a service for the navigation services provided today, especially in the context of the Internet of Things (IoT). For the most part, existing positioning technologies require two preconditions before starting work. First of all, it is necessary to pre-establish and configure fixed reference points, hereinafter called "anchors", for example, Wi-Fi range transceivers, Bluetooth devices, ultra-wide band (UWB) base stations. Then, you need to synchronize the network devices to the system timestamp. Devices carried by mobile network subscribers are also often called "subscribers" in the literature [1].

As a rule, systems based on UWB remain out of competition in terms of positioning accuracy due to the radio technical features of signals - a spectrum bandwidth from 500 MHz and a carrier frequency from 3 GHz to 7 GHz [2]. A large number of works for more than 15 years of active development of technology are devoted to the review of UWB positioning technologies [3]. Comparative characteristics of system accuracy are shown in table 1.

2.4 GHz technology implies 2 different types of operation - the use of chirp modulation (CHIRP) and phase modulation (PHASE) [4].

| System type         | Accuracy | Distance         |
|---------------------|----------|------------------|
| 2.4 GHz Chirp       | 1 m      | 100-200 m        |
| 2.4 GHz Phase       | 1 m      | 100 m            |
| UWB                 | 20 cm    | 30 m             |
| WLAN                | 15 m     | 150 m            |
| Bluetooth           | 8 m      | 75 m             |
| RFID (presence fixing) | same as distance | 10 cm-8 m |

Systems, in which there is no need for fixed anchors, relies on the relative position of network subscribers, making measurements of the distances between them. Coordinates in such a system are either only relative, or can be calculated in absolute terms, if there is information about the coordinates of the control point. The pivot point in such systems is quasi-constant. With regard to the moment in
time when one subscriber makes measurements on neighboring subscribers, it can be assumed for simplicity that the reference points are fixed. With further complication of the system, given the availability of an information channel when using UWB technologies, subscribers can transmit information about their own speed to correct measurements of distances between subscribers.

Such systems are called relative navigation systems and their features are: rapid deployment in emergency cases and at the same time high enough accuracy for indoor navigation, arbitrary connection/disconnection of new subscribers in time. Difficulties that must be taken into account when building such systems - energy saving for working in the radio, optimization of information transmission routes, optimization of the procedure for measuring distances between subscribers, regulation of subscriber broadcasting on the air, synchronization of measurements, the ability to transmit reliable binding of individual system subscribers, self-organization of the system when switched on/disconnecting subscribers to/from the network.

2. Methods

Many published works devoted to the optimization of computer networks say that optimization of the network load is possible due to the division of the subscriber network into clusters and the allocation of the head (master) of the cluster [5].

The load on the network in the relative navigation system is the volume of interaction of each subscriber with the network, i.e. with other subscribers. The less interaction of the subscriber in the network for determining the location, the less energy consumption and greater autonomy. With a large number of subscribers, a decrease in the interaction of each subscriber leads to an increase in network capacity, an increase in distance measurements to improve the accuracy of relative navigation. Thus, all the key characteristics of such systems are determined by the protocol of interaction between subscribers.

One of the most suitable network protocols for relative navigation networks is Low-Rate Wireless Networks [6]. The peculiarity of this standard is that it defines two types of nodes in the network. The first is a Full Function Device (FFD). Which works as a coordinator of personal area networks (PAN - Personal Area Network), and can serve as a common node. The device implements a general communication model that allows you to talk with other devices, it can also transmit messages further, in this case it is called a coordinator (PAN Coordinator). The second is a Reduced Function Device (RFD). These are simple-structured devices that can only communicate with fully functional devices and cannot act as coordinators.

Networks can be peer-to-peer (point-to-point) or have a star topology. Networking is designed so that there must be at least one fully functional device. Each device has a 64-bit identifier (or 16-bit) for connections within the PAN. Additional topological constraints can also be added: for example, a cluster tree is a structure in which an RFD can be associated with only one FFD at a time, thus RFDs are exclusively tree leaves, and most nodes are FFDs. It is also possible the situation of a mesh network topology, whose nodes are clustered tree networks with a local coordinator for each cluster, in addition to the global coordinator.

A more structured star topology is also supported, where the network coordinator must be the central hub. Such a network can arise when the FFD decides to create its own personal area network (PAN) and declare itself its coordinator, after which a unique identifier for the PAN is chosen. After that, other devices can join a network that is completely independent from other networks with a star topology [6].
Devices based on this standard are classified as short-range devices. This standard became the basis for such protocols as: ZigBee, MiWi, WirelessHART and Ad-hoc networks of mobile devices (MANET) [7].

A feature of the application of this standard in relative navigation systems is, firstly, the presence of distance measurement procedures that determine the moments of subscribers' work on the air, and the transmission of information about measurements made by subscribers.

The most common method for determining position in ultra-wideband positioning systems is the difference-ranging method. The method is based on the time of receiving the signal, provided that the receiver knows the time of emission of this signal, which requires high accuracy of synchronization of the time scale of mobile devices.

TWR (Two-Way Ranging) method usually involves measuring the propagation time of a signal to an object and back, with a delayed signal relay. SDS-TWR (symmetrical double-sided two-way ranging) is a method of measuring distance, which is an advanced TWR, which uses a double measurement according to the TWR method sequentially in two directions, from the first device to the second and vice versa [2]. In each cycle, the devices exchange retransmission times measured by the devices themselves. SDS-TWR method allows to achieve instrumental error of distance measurement up to 12 mm due to desynchronization of time scales, since the measurement error in one direction is mostly compensated for by the measurement error in the opposite direction and affects only the difference in response times of the devices.

3. Modelling and results
In general, SDS-TWR is generally used for communication between mobile devices and base stations, in systems with fixed anchor points, or between the anchor points themselves. After the devices interact using the SDS-TWR protocol, each of them has data on the distance to each other, which reduces the number of interactions between subscribers in the system. Below is how ad-hoc network works when using SDS-TWR.
Figure 2. Modelling the interaction of devices on the network using SDS-TWR.

Figure 2 shows how device 1 is the master (circled) and is responsible for organizing the network, in this case for simplicity, one cell. Modelling the interaction of devices on the network using SDS-TWR shows how device 2 measures the distances to neighbouring subscribers. Over the course of the system operation, each subscriber of the network makes measurements of the distances to neighbouring subscribers. Solid lines indicate distance measurements made using the SDS-TWR method. Thanks to the use of SDS-TWR, the results of each measurement appear for each subscriber with whom an interaction took place. As soon as the turn has reached the device to take measurements, the device makes a series of its own measurements to neighbouring subscribers, receiving the most relevant data about its relative location. Then it makes the solution to the navigation problem and calculates the relative coordinates.

However, with the introduction of SDS-TWR into the ad-hoc relative positioning network, it becomes possible to use the range measurement devices in the memory without waiting for the queue in the network to make a series of your own measurements. In Figure 1, the dashed lines mark the measurements that precede the current interactions of point 2. And the dotted line denotes the previously available measurements between points 4 and 5. Thus, after measuring point 2, points 4 and 5 from this moment are able to calculate their own relative positions, without the need to make measurements at points 1 and 2. At this very time, the freed network resources can be used for measurements made by other subscribers, which significantly increases the capacity of the network with relative positioning. Summary data on the accuracy of solving the navigation problem when averaged over 10 measurements are presented in table 2.

| Table 2. Summary data on the accuracy of solving the navigation problem. |
|-----------------------------|-----------------------------|-----------------------------|
| Velocity, m/s               | 0.00                        | 0.33                        |
| Measurement interval, m/s   | 90                          | 150                         |
| Positioning error, m        | 0.06                        | 0.15                        |

The proposed model takes place at a low speed of movement of subscribers, i.e. with a small equivalent frequency detuning for the measurement interval [8]:

\[ \ell = (1 + e)t \]
where: $e$ - frequency detuning, $t$ - measurement interval, $\ell$ - signal propagation time measurement error. The less frequently the measurements are updated, the less the accuracy of the solution of the navigation problem. For these purposes, a data aging threshold can be entered in the network protocol.

4. Conclusion

The proposed method for optimizing the network load allows making measurements without waiting for the appearance of a series of own measurements. If we make a new measurement, the older measurements will become obsolete. If we don't, then we use the data that remains relevant. The fewer subscribers in the network, the more often you can take measurements and improve positioning accuracy.

This conclusion is useful for relative navigation systems, the difference of which is the transmission of measurements not to the base station, but to mobile subscribers solving the navigation problem. The method reduces the time required to obtain data for solving the problem. The characteristics of such systems are fast deployment, random connection of subscribers and self-organization.

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