Node Positioning in a Limited Resource Wireless Network

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Abstract

By using a non-standard limited resource technique in wireless networks it is possible to reach features, which are more suitable for sensor networks and personal embedded applications than using standard protocols. Using new heavily integrated controller chips and RF-modems, it is possible to implement new features, for example, low-power routing, positioning and dynamic flat topology in limited resource wireless network (LRWN). We are researching the features of light wireless networks at Seinäjoki University of Applied Sciences. The main focuses of our research projects are size minimization, low-power routing, positioning and interactive features between devices, users and environment. The aim of this paper is to introduce the positioning methods usable in LRWN.

The main problem is: how satisfactory positioning is possible in LRWN. The important feature for positioning is distance measuring between nodes. The RF-modem chip that we use gives some possibilities to measure distances. Another possible data source for distance measuring is routing tables i.e. number of multi-hops between nodes. We have simulated positioning methods and we have obtained better results than expected. The simplest method was the mean value calculation of neighbour coordinates. It gives quite acceptable results for some applications. The best results come with more complex methods while distances were measured as four multi-hops.

As a result of our simulation we have seen that very simple positioning can be acceptable. Positioning methods provide more accurate results when moving the nodes slowly and randomly. Through randomizing, the static lock configurations are released, which normally gives positioning errors. We will test simulated methods in a real wireless network later this year. In the real world the distance measurement is more random, but expected results should be near simulation values.

Introduction

The research of wireless systems is currently based on the transfer of voice and/or video data. Key words in wireless systems are 'high speed', 'multifunctional', 'standardized' and 'mass production'. All these functions need electronics with complicated architecture, large amounts of computing resources and large-scale investments. The multimedia devices are too complicated to be used by older people or children.

Wireless technology can be used in security applications for monitoring children, the elderly, those suffering from dementia or even animals. The devices must be small, have low-power, low-cost and be very easy to use. In exercise game applications, for example, we need direct interactivity functions between hand-held modules and RF-knobs located in the environment. For measuring conditions in a large cornfield via a wireless network, we need low-power, multi-hopping routing methods to collect the necessary data. In all preceding cases, the position coordinates of a single hand-held module, RF-knob or sensor is very desirable.

This paper describes the first step of the positioning research of Limited Resource Wireless Network (LRWN): The simulation methods and comparisons. The key words in LRWN are 'small', 'simple', 'embedded', 'low-cost' and 'distributed computing'. 'Small' means small size and even invisibility. 'Simple' means simple usability but intelligent functions. 'Embedded' means hidden present so the user does not need to understand its operations; only use it. 'Low-cost' means cheap standard components and simple layout. 'Distributed computing' means that wireless devices do not need the central controller or centralized configuration process.

The research of wireless sensor network (WSN) is widely the object of interest and it shows how new possibilities in wireless technology can be adapted. Most wireless networks use 2.4 GHz radiofrequency (Bluetooth, ZibBee) so the most widely used RF-modem components use the same free ISM –frequencies (Industrial, Scientific, and Medical).

The development of RFID –technology provides new hardware possibilities. Since the tags can not interact with each other, RFID –technology as such is not suitable for LRWN development. [1].

The routing protocols in WSN are widely described in literature including AD-HOC –topology, peer-to-peer communication and multi-hop routing, which allows every node to communicate with any node in a network. Mostly WSN are managed by one or more controller nodes, so the network topology is hierarchical. [2].
To identify the position of nodes (absolute or relative), we need positioning methods. The most commonly described methods need extra hardware [3], [4] or positioning uses centralized calculations. [5], [6]. Also, the methods using distributed calculations need large amounts of processing resources in nodes. [7], [8].

Related work

We have developed both hardware and software to test the basic features of LRWN. The routing protocols have been simulated and tested in real devices. This paper describes the simulation of positioning methods, which we have made using EXCEL and VB macros. Later this year we are planning to test the best positioning methods using real devices.

Distance measuring

The RF-transceiver chip nRF24L01 we use [9] has some simple features to measure the distances between the network nodes: It is possible to control the output power by the software in 4 levels: 0dBm, -6dBm, -12dBm and -18dBm. So a node can form four circles around it and it knows, which neighbours are inside which circle i.e. it can measure distances to its neighbours in four steps. If we are assuming that the range of the RF-signal is reduced as a square root of RF-power, we get the equation (1):

$$r_r = \sqrt{2^{\frac{p}{3}}}\, r \qquad (1)$$

Where
p = *output power in dB*
r_r = *reduced range*
r = *original range*

As we place the reduced output power levels -6, -12 and -18 dB to equation, we get values to reduced ranges r_r = r/2, r/4 and r/8. So, if the range is 100m at maximum power, a node in the network can measure, which neighbours are inside ranges 100m, 50m, 25m or 12.5m.

Other feature, that nRF24L01 includes, is to control the gain of the receiving amplifier (LNA, Low Noise Amplifier). The gain can be reduced 1.5 dB by software. As we place p=-1,5 in equation (1), we get r_r = 0.8 r. This measuring method is not so usable, as controlling output power.

Distance can be measured also by using multi-hop routing data. If a multi-hop route is the shortest route between two nodes, so the number of multi-hops is also the distance between these. Depending on the size of the routing table and memory capacity, distance measuring can be applied and easily used in a simple wireless networks.

Limited resource positioning

The position of nodes is necessary in order to monitor moving nodes in the specific area. If we notice limited resources in ATtiny84 –controller, the position algorithm must be simple: calculations should be done using integer values. Floating point arithmetic or trigonometric, which require a high amount of resources, are not recommend. If the node has a small capacity battery and a long life time is needed, the distance measuring using two or more output power steps including two or more transmit sequences is not recommended. It is quite often that a node knows its neighbours. Usually a very rough positioning is enough (for example in animal positioning on the field), so the method can be very simple.

The absolute positioning needs some anchor nodes, which have fixed coordinates to be as reference points to the positioning estimation. It is possible to find the positions without the anchors, but the positioning is relative and positioning area can be mirrored.

In this paper we are focused on researching the distributed positioning which is made in the nodes. It is also possible to calculate the node positions centralized in more powerful central processor and so the results should be more accurate. Our main research concern is in fully distributed systems.

Simulation principles

The positioning research in the real network should take too lot time while loading the software modifications to each node and tests should be too reduced. Therefore, we made the simulations to test different methods. There are many ways to calculate the positions of nodes depending on the distance measurement method. If a node has very little resources and a application does not need an exact positioning, it can be enough to use only the neighbourhood data. Sure, some applications need more exact positioning, so we also simulate algorithms, using output power control and 1 to 4 - step multi-hop distances measuring. In both cases, the calculation should be made without trigonometry and square root functions to fit into a reduced resource node controller.

We have fixed some values in the position simulation: The size of the area is 20 x 20 units and the four anchor nodes with fixed coordinates are located in four corners of the area. Figure 1 describes an example of the start state as simulating a network with 60 nodes. Dark blue marks are anchor nodes with fixed position. Light blue marks are the real positions of the nodes, which are located at random. Yellow marks are the estimated positions of the nodes, which are first located at random and at times moving during the position estimation process.

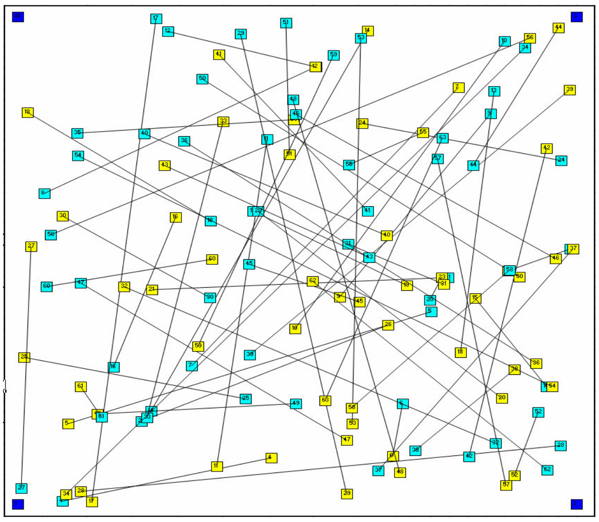

Figure 1: The start state of the simulation

We use measured distances and the algorithm types as variables in the positioning simulation. The position estimation of one node is made by scanning all neighbours and the distances to it and calculating the own estimated position according to the position data. The algorithms use different ways to calculate the estimated position: the mean values of the neighbour coordinates or incremental position estimation.

Using the measured distance data, the positioning method calculates coordinates in two ways: First: if the estimated position of a neighbour is inside the distances, no corrections are made. Figure 2 shows the state, where the neighbours are measured to be between the ranges **r1** and **r2** i.e. inside the measured area and estimated positions are shown.

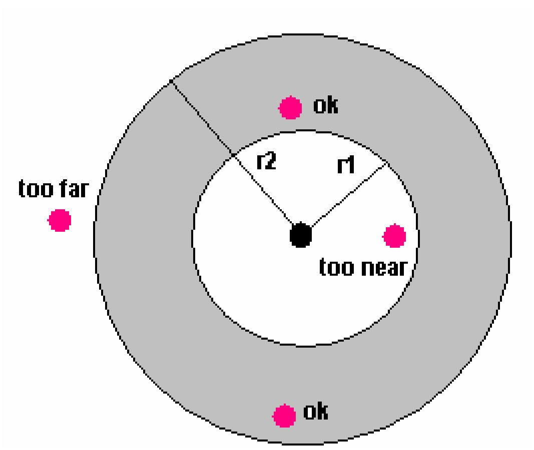

Figure 2: Neighbours according to the area

In the second method the corrections are always made except in this case the neighbour is located in the centre line of measured distance. The centre range is calculated by area: as the neighbours are located at random, there are estimated to be as many neighbours located nearer and further from the centre distance inside the measured area. So the position errors are balanced in the result. Figure 3 shows the state, where the neighbours are measured to be between distances **r1** and **r2**.

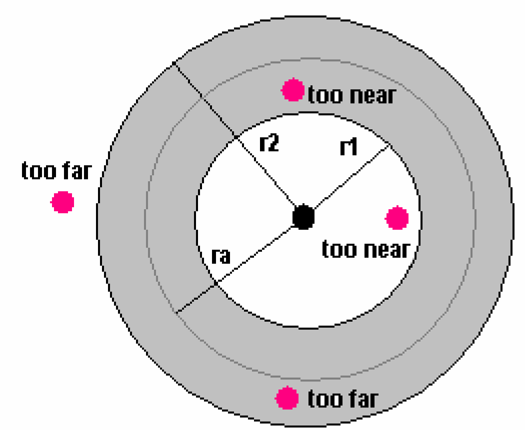

Figure 3: Neighbours according to the centre range

The neighbours are nearer or further from the centre distance **ra**. The areas on both sides of the centre line must satisfy the equation:

$$r_2^2\pi - r_a^2\pi = r_a^2\pi - r_1^2\pi$$
$$\Rightarrow r_2^2 - r_a^2 = r_a^2 - r_1^2 \qquad (2)$$

Solving **ra**, we get:

$$r_a = \sqrt{\frac{r_2^2 + r_1^2}{2}} \qquad (3)$$

In most reduced nodes the distances are not measured; only the neighbours inside the range are indicated, so we can simplify the equation:

$$r_1 = 0 \Rightarrow r_a = \frac{r_2}{\sqrt{2}} \qquad (4)$$

The resources of one node are reduced, so it is not recommended to use the square root. If the ranges are known, the centre range can be fixed as a constant variable using equation (4).
The correction of an estimated position of a node is made incrementally by pushing or pulling the position nearer or further according to the neighbour (Figure 4).

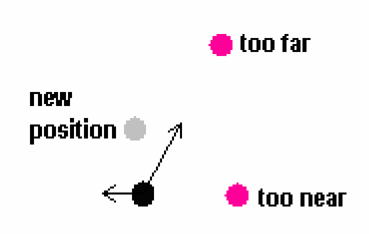

Figure 4. Push and pull corrections

We have created four positioning algorithms with variable parameters:

1. The coordinates of a single node are mean values of coordinates of the neighbours. If measuring the distances, the coordinates of near neighbours have more weight than neighbours located further.

2. Same as above, but mean values are calculated as separate in four direction sectors before the main mean value is calculated.

3. The coordinates of a node are pushing or pulling according to the measured distance of every neighbour, but only if they are outside of the measured area.

4. Same as above, but the coordinates are continuously pushing or pulling as the neighbours are not located in the centre distance.

Positioning test

We are planning to install the most promising positioning algorithms in the real network at the end of year 2007.

Results

We obtained some results while simulating positioning. To determine whether the results are acceptable or not, we must compare these to the known values and to each other. First we made evaluations to find values to compare and second we made comparisons of all results.

Evaluations the comparison values

In the positioning test the number of nodes is 60. The size of the area is 20 x 20 units. Four fixed nodes are located in corners of the area. During testing both the real and the estimated positions are at a random state at first. The results are calculated using the mean value of 10 tests. An example of a random state is given in Figure 5. Dark blue marks are the fixed nodes, light blue marks are real positions of the nodes and yellow marks are the estimated positions of the nodes. The Mean value of Square of Distance Errors (MSDE) is 126 units in this example.

What is a good position result? We must check it visually to be able to estimate. The example of positioning quality is shown in Figure 6, where MSDE is 22. It is hardly sufficient in some applications. In the example in Figure 7 MSDE is 4 and it is acceptable in most applications described in this paper. The example in Figure 8 is good, as MSDE is under 3 units.

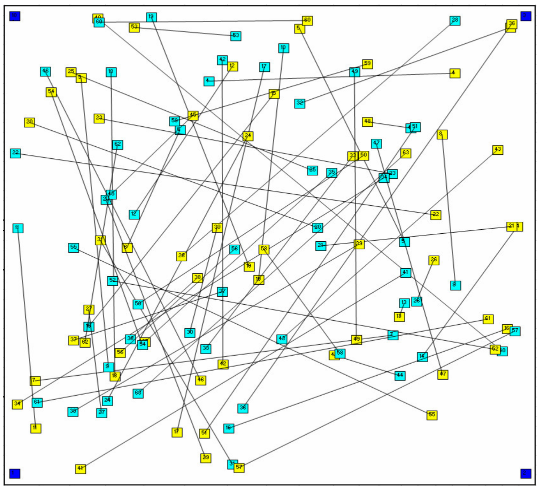

Figure 5. Start situation, MSDE = 126

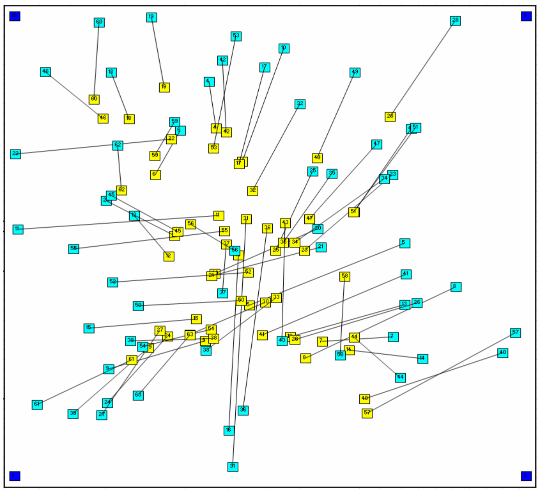

Figure 6. The result example as MSDE = 22

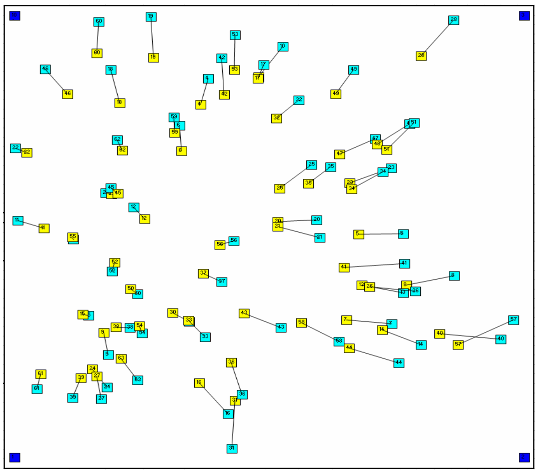

Figure 7. The result example as MSDE = 4.0

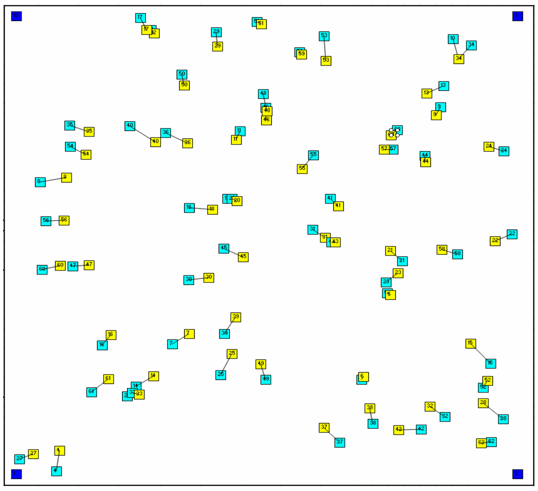

Figure 8. The result example as MSDE = 2,6

Simulation results

The range distance is very critical for testing the methods. It is the main variable for comparing methods; other parameters are fixed.

As comparing the positioning methods in different ranges we used 1 to 4 measuring steps. Except the maximum range, we also simulated with rages 1/2, 1/4 and 1/8 of the maximum. The measuring steps can be realized by controlling the output RF-power of the modem or by the multi-hop numbers in the routing table.

In our results we mostly show only the tests in which MSDE reached a value under 20 units. All other results are assumed to be unusable. In curves there can be seen the positioning using both fixed and mobile nodes. The data for the curves have been generated from the mean values of 20 position cases. In every case the start positions and movements are made randomly.

Using range 5 every node has on average 6 neighbours. The results are not satisfactory; only methods using the mean calculating provides some sufficient results using 2 to 4 steps in distance measuring as shown in Figure 9. The curves have been named using method number and the number of distance measuring steps. For example "Fix1.2" represents fixed node simulation of method 1 using 2 distance measuring steps.

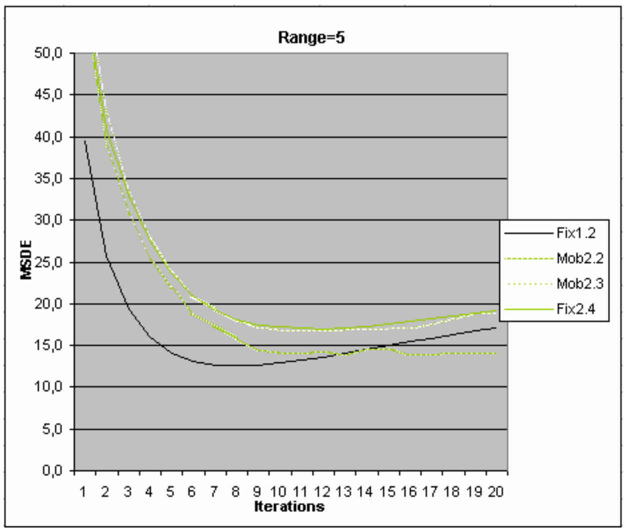

Figure 9. Positioning using range 5

Using range 8 the nodes have on average 14 neighbours and the results are better: Furthermore, variations of method 4 functions are very acceptable (Figure 10). Here we can see that the mean calculation methods 1 and 2 are much faster than others but the results of these are not better.

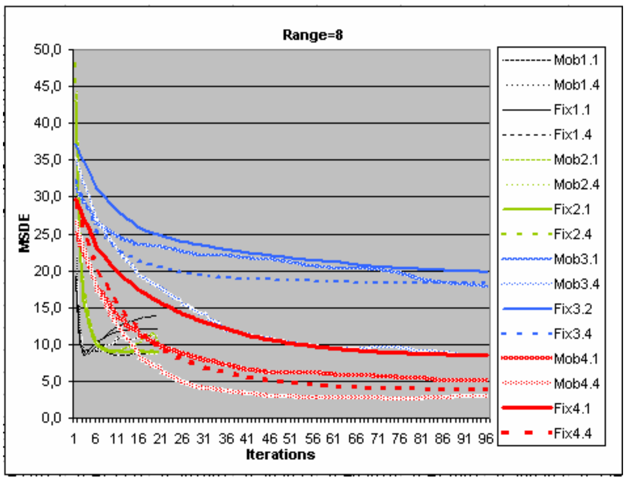

Figure 10. Positioning using range 8

Using range 11, every node has on the average 22 neighbours, method 3 also functions better (Figure 11).

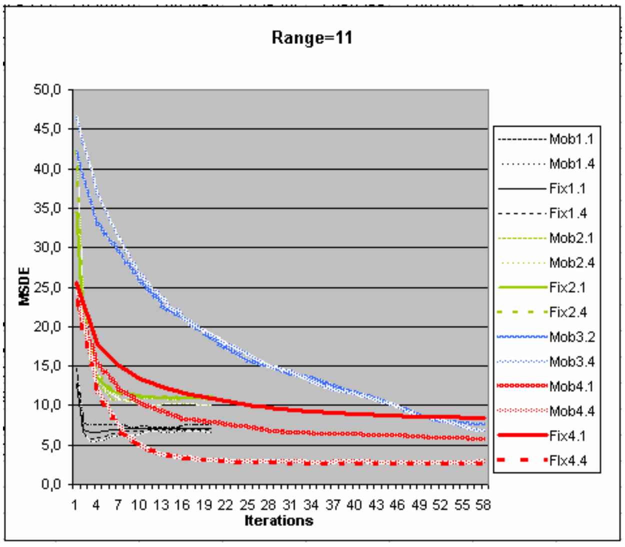

Figure 11. Positioning using range 11

Using range 14 every node has on average 29 neighbours. The results are good, but not as good as using range 11 (Figure 12). Here we can see that distance measuring in several steps is needed in dense networks.

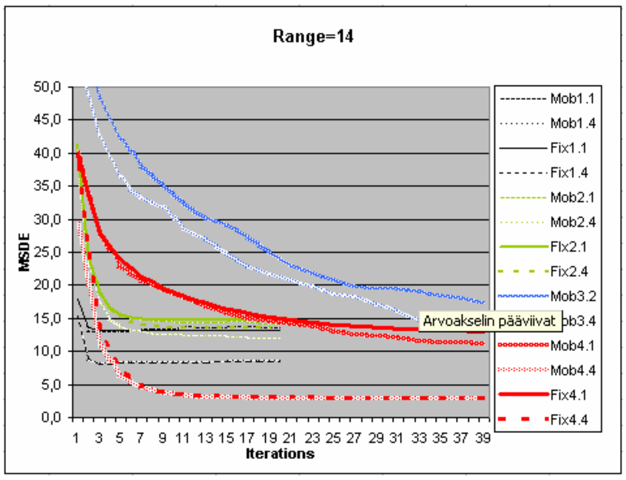

Figure 12. Positioning using range 14

Next we were comparing the methods in different node density (i.e. ranges). As a variable is the number of neighbours compared to MSDE value in every method (Figure 13). In this comparison we use the last iterated MSDE value in every positioning method.

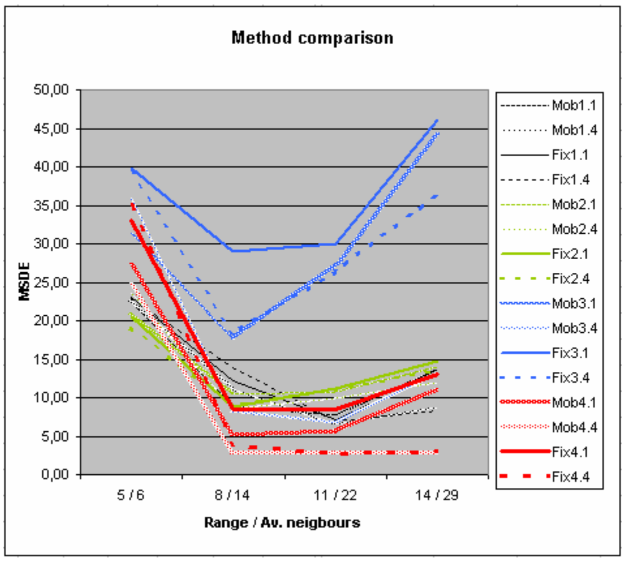

Figure 13. Comparing methods

As a result of our tests we discovered that in the coarse wireless networks calculating the mean value (Methods 1 and 2) is acceptable in some applications and a very fast way to position the nodes. Also, in denser networks it is a usable method but method 4, which is a more complicated and slower method provides more accurate results. In dense networks more accurate positioning with some kind of distance measuring is needed to separate nodes from each others.

Conclusion

After these simulations we can estimate the usability of LRWN in some typical applications. The simpler and faster positioning methods can for example be applied to monitor children in a nursery. If children are constantly moving at different speeds there is the possibility to track the children and make sure that they are all inside the allowed area. Furthermore, the nursery worker will be able to find a specific child. The simple method is also suitable to monitor an animal herd in the field. In more technical applications like sensor networks in agriculture or in geography, method 4 with distance measuring is needed to give suitable position data.

Moving nodes give better results than fixed ones in all acceptable positioning methods. During simulations we have noticed that fixed nodes can remain in static error positions, in which the position corrections are compensated for each other. If nodes are moving, locks are released and results are better.

Reliability of results

The results of positioning are made using very specific attributes. Using the other size networks and areas the results may not be the same. To acquire better conception it is necessary to research more application based structures and methods. Although these results are indicative of which possibilities we have in a very limited and light although intelligent wireless networks structure.

All start positions and node movement are random, so it is possible, that the results also include random data. To obtain more reliable results, it is necessary to reconstitute application specific network and to make longer simulations series.

Future

Very light wireless networks are suitable for many new applications. Using new electronic components we have planned the layout of one single node which is as a small round 13 mm diameter button including a controller, a radio modem, an antenna and a rechargeable battery. The power usage of a button can be 10 μA, so it can be driven by a small solar cell placed inside. If we evaluate the network usage consisting of small radio buttons, the application possibilities are very large. We can build smart clothing, passage control of people and objects, security monitoring and building automation using LRWN. Outside games can be controlled by radio buttons. Adding sensors into radio buttons they can monitor arm positions of the excavator or behaviour of animals. The conditions of a cornfield can be monitored by scattering radio buttons on the field. Widely distributed intelligence is the future layout in new control systems.

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