SOURCE SIGNAL STRENGTH INDEPENDENT LOCALIZATION

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ABSTRACT

A problem with RSSI localization methods has been dependence on assumptions about the source signal strength or dependence on knowledge of its value at the source. This paper presents a solution to WSN localization for planar WSNs which averts this problem. It is a small, fine grained, range-based, beaconless, GPS-free, low cost RSSI technique which requires an irregular arrangement of four omnidirectional antennas for accurate positioning of the source and also for the determination of the source signal strength at the source. A spiral arrangement of antennas is described and software simulation of the localization process is presented that demonstrates its accuracy. Five omnidirectional antennas are fully sufficient to enable the avoidance of blind spots.

KEYWORDS

WSN (Wireless Sensor Network), sensor node, RSSI, localization.

1. INTRODUCTION

The problem of determining the position of radio sources relative to a given detector location with small low cost antennas is a continuing problem for useful data collection in mobile ad hoc networks (MANETs) and WSNs [1, 2, 3, 4]. If the distances between all nodes in the network can be measured by one of these techniques then a distance matrix can be formed and using the Map Maker algorithm [6] the coordinates of all the nodes are known up to a system translation, rotation or inversion. The hardware of the location detector needs to be small, portable, low cost and unobtrusive and yet also sufficiently accurate in determining positions [3]. It also needs to be low in the consumption of battery energy [12]. Directional antennas [7 to 11] do not match these requirements and do not allow for the free placement of nodes or moving nodes. Omnidirectional antennas are selected in this work for their low cost, simplicity as well as meeting the other criteria: a monopole antenna is more compact being half the size of a dipole antenna tuned to the same frequency. Omnidirectional antennas give us RSSI readings and therefore node to node distance measurements based on assumptions about ψ_0. Distance measurements can be obtained from RSSI measurements using the inverse square law which in suitable intensity and distance units is [5]

$$\psi(r) = \frac{\psi_0}{r^2} \tag{1}$$

Recently a multi-antenna technique [5] was published which only required the use of three omnidirectional antennas and the solution of two simultaneous linear inhomogeneous equations in two unknowns for the determination of relative coordinates. However these RSSI techniques require assumptions about the signal source intensity ψ_0 such as all nodes in the network having the same value of ψ_0 or else the ψ_0 values of all nodes are locally detected and broadcast to all nodes. The latter assumes that all nodes have RSSI detectors but this is not a low cost solution. Alternatively a node might know its own ψ_0 based on its own battery level and transmit this.

However it was also shown in [5] that measuring battery levels is also not a cost effective solution. A different approach is presented in this paper enabling any node with the localizator described in this paper to determine the relative positions of all other nodes, their distances and their local signal intensities ψ_0. In section 5 we discuss the application of the spiral array localizator to a 2 level balanced WSN [12].

2. Distance Measurement With An Omnidirectional Antenna Array

When a wireless node is transmitting data its antenna produces a signal strength of EMR (Electro-Magnetic Radiation) which drops off according to the inverse square law given above (1). For the localization process we require that only one node of the network is transmitting at a time. A node located at point A in a WSN with an array of n simple omnidirectional antennas located at points A_i for i = 1 to n within radius R of A can measure RSSI signal strengths of a single radio source located at point S to obtain the n readings ψ_i for i = 1 to n. This leads to n simultaneous quadratic equations for the relative coordinates (x_S, y_S) of the source node S:

$$\left(x_S - A_{ix}\right)^2 + \left(y_S - A_{iy}\right)^2 = \frac{\psi_0}{\psi_i}$$

where ψ_0 is the RSSI of the source at unit distance from S. It will be assumed that $R^2 << \psi_0 / \psi_i$ for all i. Since ψ_0 is not necessarily precisely known, we eliminate ψ_0 by dividing the i'th quadratic equation by the first quadratic equation for i = 2 to n thereby reducing the system to n-1 quadratic equations. Further eliminating the quadratic quantity

$$r_S{}^2 = x_S{}^2 + y_S{}^2$$

reduces the system of equations to n-2 simultaneous linear homogeneous equations for x_S and y_S which are then easily solved. Since we only need 2 such equations it follows that n = 4 omnidirectional antennas are needed to construct this localizator. This results in the following equations

$$\begin{aligned} a_1 x_S + b_1 y_S &= c_1 \\ a_2 x_S + b_2 y_S &= c_2 \end{aligned} \tag{2}$$

where

$$\begin{aligned} a_1 &= \left\{ \frac{(A_{3x} - \alpha_3 A_{1x})}{(1-\alpha_3)} - \frac{(A_{2x} - \alpha_2 A_{1x})}{(1-\alpha_2)} \right\} \\ a_2 &= \left\{ \frac{(A_{4x} - \alpha_4 A_{1x})}{(1-\alpha_4)} - \frac{(A_{2x} - \alpha_2 A_{1x})}{(1-\alpha_2)} \right\} \end{aligned} \tag{3a}$$

$$\begin{aligned} b_1 &= \left\{ \frac{(A_{3y} - \alpha_3 A_{1y})}{(1-\alpha_3)} - \frac{(A_{2y} - \alpha_2 A_{1y})}{(1-\alpha_2)} \right\} \\ b_2 &= \left\{ \frac{(A_{4y} - \alpha_4 A_{1y})}{(1-\alpha_4)} - \frac{(A_{2y} - \alpha_2 A_{1y})}{(1-\alpha_2)} \right\} \end{aligned} \tag{3b}$$

$$c_1 = \frac{\beta_2}{2(1-\alpha_2)} - \frac{\beta_3}{2(1-\alpha_3)}$$
$$c_2 = \frac{\beta_2}{2(1-\alpha_2)} - \frac{\beta_4}{2(1-\alpha_4)} \quad (3c)$$

$$\alpha_1 = 1$$
$$\alpha_2 = \frac{r_2^{\ 2}}{r_1^{\ 2}} = \alpha_1 \frac{\psi_1}{\psi_2}$$
$$\alpha_3 = \frac{r_3^{\ 2}}{r_1^{\ 2}} = \alpha_1 \frac{\psi_1}{\psi_3} \quad (4)$$
$$\alpha_4 = \frac{r_4^{\ 2}}{r_1^{\ 2}} = \alpha_1 \frac{\psi_1}{\psi_4}$$

$$\beta_2 = \alpha_2 A_{1x}^{\ 2} - A_{2x}^{\ 2} + \alpha_2 A_{1y}^{\ 2} - A_{2y}^{\ 2}$$
$$\beta_3 = \alpha_3 A_{1x}^{\ 2} - A_{3x}^{\ 2} + \alpha_3 A_{1y}^{\ 2} - A_{3y}^{\ 2} \quad (5)$$
$$\beta_4 = \alpha_4 A_{1x}^{\ 2} - A_{4x}^{\ 2} + \alpha_4 A_{1y}^{\ 2} - A_{4y}^{\ 2}$$

So the solution is:

$$x_S = \frac{b_2 c_1 - b_1 c_2}{a_1 b_2 - a_2 b_1} \equiv \frac{detx}{det}$$
$$y_S = \frac{a_1 c_2 - a_2 c_1}{a_1 b_2 - a_2 b_1} \equiv \frac{dety}{det} \quad (6)$$

Having found the position (x_S,y_S) of the radio source by equations (2), (3), (4), (5) and (6), its strength at the source is found by:

$$\psi_0 = \psi_1 r_1^{\ 2} \quad (7)$$

where

$$r_1^{\ 2} = x_S^{\ 2} - 2A_{1x}x_S + A_{1x}^{\ 2} + y_S^{\ 2} - 2A_{1y}y_S + A_{1y}^{\ 2} \quad (8)$$

If the antennas are placed symmetrically about the node A we would have:

$$A_{1x} = b, A_{1y} = 0$$
$$A_{2x} = 0, A_{2y} = b$$
$$A_{3x} = -b, A_{3y} = 0$$
$$A_{4x} = 0, A_{4y} = -b$$

where b is a manufacture set value such that the radius of the localizator R = b is less than the minimum node separation of the WSN. When substituted into equation (5) we get

$\beta_2 = (\alpha_2 - 1)b^2$

$\beta_3 = (\alpha_3 - 1)b^2$

$\beta_4 = (\alpha_4 - 1)b^2$

When substituted into equation (3) we get

$$a_1 = \left\{ \frac{\alpha_2}{(1-\alpha_2)} - \frac{(1+\alpha_3)}{(1-\alpha_3)} \right\} b$$

$$b_1 = -\frac{b}{(1-\alpha_2)}$$

$$a_2 = \left\{ \frac{\alpha_2}{(1-\alpha_2)} - \frac{\alpha_4}{(1-\alpha_4)} \right\} b$$

$$b_2 = -\left\{ \frac{1}{(1-\alpha_4)} + \frac{1}{(1-\alpha_2)} \right\} b$$

$$c_1 = 0$$

$$c_2 = 0$$

This results in detx = dety = det = 0 so that the equations (6) become indeterminate. To avoid this situation the antennas can be placed non-symmetrically about the node at A and a suitable antenna array for this is to use the arithmetic spiral so that

$A_{1x} = b, A_{1y} = 0$

$A_{2x} = 0, A_{2y} = 2b$

$A_{3x} = -3b, A_{3y} = 0$

$A_{4x} = 0, A_{4y} = -4b$

A graphics program was written to test and demonstrate this spiral 4 antenna localizator method. The result of testing was that the spiral array of 4 antennas accurately localizes the source S. Typical results are shown in Figure 1 below. The black dashed lines show the signals travelling from S to each of the 4 antennas of the localizator. The black + sign shows where the radio source S was located on the grid by mouse click and the black circle shows the grid point where equations (2) to (6) above determined that the point S is on the grid. It is clear from the program that the equations (2) to (6) give a very accurate estimate of the source position. The result of applying equations (7) and (8) to compute the local radio source signal strength ψ_0 is also shown below the main menu on the program window: the display on the window "psi0 = …" shows the accuracy of the computed ψ_0 compared with the actual ψ_0 where in the program the actual value of ψ_0 was set as exactly 100. It is clear from the program screen shot of Figure 1 that equation (7) gives ψ_0 accurately to 11 decimal places in these experiments and the program therefore shows that the equations above return a very accurate estimate of ψ_0.

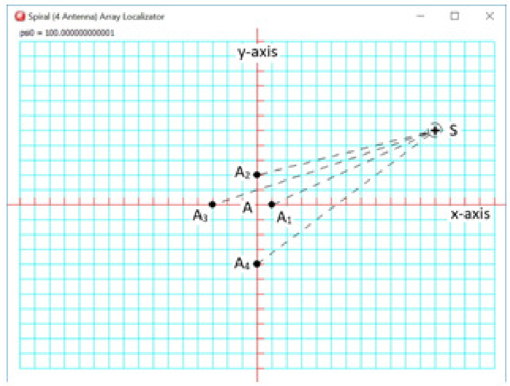

Figure 1. The spiral localizator consists of 4 antennas A_1, A_2, A_3 and A_4 positioned around a node A. It can measure the position of radio source at S.

3. BLIND SPOTS

The question that next arises is: Are there any source positions S for which the above calculations fail? Firstly a_1, b_1 and c_1 cannot be calculated if α_2 or α_3 equals 1. This occurs when either $r_2 = r_1$ or $r_3 = r_1$. Secondly a_2, b_2 and c_2 cannot be calculated if α_2 or α_4 equals 1. This occurs when either $r_2 = r_1$ or $r_4 = r_1$. Thirdly x_S and y_S cannot be computed if $a_1b_2 = a_2b_1$.

$$a_1b_2 - a_2b_1 = \left\{ \frac{(A_{3x} - \alpha_3 A_{1x})}{(1-\alpha_3)} - \frac{(A_{2x} - \alpha_2 A_{1x})}{(1-\alpha_2)} \right\} \left\{ \frac{(A_{4y} - \alpha_4 A_{1y})}{(1-\alpha_4)} - \frac{(A_{2y} - \alpha_2 A_{1y})}{(1-\alpha_2)} \right\}$$
$$- \left\{ \frac{(A_{4x} - \alpha_4 A_{1x})}{(1-\alpha_4)} - \frac{(A_{2x} - \alpha_2 A_{1x})}{(1-\alpha_2)} \right\} \left\{ \frac{(A_{3y} - \alpha_3 A_{1y})}{(1-\alpha_3)} - \frac{(A_{2y} - \alpha_2 A_{1y})}{(1-\alpha_2)} \right\}$$

This is the third component of the cross product of vectors $\underline{a} = (a_1, a_2, 0)$ and $\underline{b} = (b_1, b_2, 0)$. The 2D vector $(A_{3x} - \alpha_3 A_{1x}, A_{3y} - \alpha_3 A_{1y})$ is a vector from point A to a point P on the line A_1A_3 but not at point A_1 or point A_3. The vector $\underline{a}$ is a vector proportional to the vector $\underline{AP}$. Likewise the 2D vector $(A_{4x} - \alpha_4 A_{1x}, A_{4y} - \alpha_4 A_{1y})$ is a vector from point A to a point Q on the line A_1A_4 but not at point A_1 or point A_4. The vector $\underline{b}$ is a vector proportional to the vector $\underline{AQ}$. The line AQ is the vertical y-axis and line AP is non-parallel to AQ. Therefore the cross product of $\underline{a}$ and $\underline{b}$ is never zero and so this third case never arises.

A way to eliminate the blind spots is to add three more antennas A_2', A_3' and A_4'. These extra antennas could conveniently be placed on the arithmetic spiral of points A_1, A_2, A_3, A_4 such that A_2' is midway between A_1 and A_2, A_3' is midway between A_2 and A_3 and A_4' is midway between A_3 and A_4. The purpose of these extra antennas is to supply up to 3 extra signal strength readings $\psi_2', \psi_3', \psi_4'$. So if we have readings where $\psi_2 \approx \psi_1$ then we can replace ψ_2 with ψ_2' or if we have readings where $\psi_3 \approx \psi_1$ then we can replace ψ_3 with ψ_3' or if we have readings where $\psi_4 \approx \psi_1$ then we can replace ψ_4 with ψ_4' so that we will have equations without the detected blind spot. This placement of the extra antennas means that the localizator is still compact. While we could have any number of antennas on the localizator and they could be arranged on an arithmetic spiral of many turns the result could be a localizator which is too big, bulky and intrusive in the network especially when many nodes need such localizators. The maximum radius enclosing a localizator, R, should be significantly less than the distance to the nearest other node of the WSN and for dense WSNs we therefore need compact localizators. An advantage of the spiral array of antennas is that the normals to the spiral curve always intersect closer to the centre of the spirals than the points on the spiral where the normal is taken. The same occurs for the perpendicular bisectors of chords of the spiral. By having the maximum radius enclosing a localizator R far less than the distance between the minimum node separation we therefore cannot have double blind spots or triple blind spots occurring. This means that blind spots are caused by only one pair of antennas and not more. Figure 2 below shows the blind spots for antennas at A_1, A_2, A_3 and A_4 as any points on the green lines. Since blind spots can only be single, the extra antennas A_2', A_3' and A_4' can be cut back to a single antenna at A_5 positioned at (2b,0). Figure 2 also shows the blind spots for the antennas A_5, A_2, A_3 and A_4 as purple lines. The purple lines do not intersect the green lines outside a distance of the maximum radius R enclosing the localizator at A and therefore a source location S cannot simultaneously be a blind spot for the antenna array A_1, A_2, A_3, A_4 and also the antenna array A_5, A_2, A_3, A_4. Therefore if the raw measurements ψ_2, ψ_3, ψ_4 have any one equal with ψ_1 indicating the presence of a blind spot then ψ_5 will be used in place of ψ_1 and we are assured by the above reasoning that no equal with ψ_5 will occur, i.e. that no blind spot will now occur. This also causes minimal changes to the equations to be computed since only A_{1x} is changed to A_{5x} and α_1 should be changed from $\alpha_1 = 1$ to $\alpha_1 = \frac{\psi_5}{\psi_1}$ and no other terms in the equations above change. This leads to the following algorithm for the localizator.

4. SPIRAL LOCALIZATOR ALGORITHM

A spiral localizator at a node at position A consists of 5 antennas irregularly but accurately placed around the node at positions A_1, A_2, A_3, A_4 and A_5. To accurately determine the position of a radio source S all other radio sources (at the given frequency) must be turned off and then the strength of the radio signal from S is measured at the 5 antennas as $\psi_1, \psi_2, \psi_3, \psi_4, \psi_5$. From these 5 raw measured values the planar position of a radio source (x_S, y_S) and its local signal strength ψ_0 are determined by the following spiral localizator algorithm. The spiral localizator has the following given constants:

$$\begin{aligned}
&A_{1x} = b, A_{1y} = 0 \\
&A_{2x} = 0, A_{2y} = 2b \\
&A_{3x} = -3b, A_{3y} = 0 \\
&A_{4x} = 0, A_{4y} = -4b \\
&A_{5x} = 2b, A_{5y} = 0
\end{aligned} \tag{9}$$

where b is a characteristic size constant of the localizator antenna array.

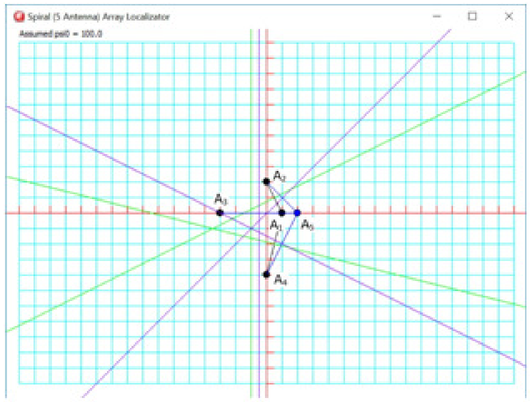

Figure 2. Blind spots are shown as green lines for antennas A_1, A_2, A_3 and A_4 and as purple lines for antennas A_5, A_2, A_3 and A_4.

Obtain the raw data $\psi_1, \psi_2, \psi_3, \psi_4, \psi_5$ from each of the 5 antennas. If ψ_1 is different from ψ_2 and from ψ_3 and from ψ_4 then compute $\alpha_2, \alpha_3, \alpha_4$ from equations (4). Next compute $\beta_2, \beta_3, \beta_4$ from equations (9) and (8). Next compute $a_1, a_2, b_1, b_2, c_1, c_2$ from equations (3) and then x_S and y_S from equation (6). Then compute r_1 from equation (8) and finally ψ_0 from equation (7).
However if ψ_1 is equal to either ψ_2 or ψ_3 or ψ_4 then use

$$\begin{aligned} A_{1x} &= 2b, A_{1y} = 0 \\ A_{2x} &= 0, A_{2y} = 2b \\ A_{3x} &= -3b, A_{3y} = 0 \\ A_{4x} &= 0, A_{4y} = -4b \end{aligned} \tag{10}$$

and replace $\alpha_1 = 1$ with $\alpha_1 = \dfrac{\psi_5}{\psi_1}$ to compute $\alpha_2, \alpha_3, \alpha_4$ from (4) or simply use

$$\alpha_2 = \frac{\psi_5}{\psi_2}$$

$$\alpha_3 = \frac{\psi_5}{\psi_3}$$

$$\alpha_4 = \frac{\psi_5}{\psi_4}$$

Next compute $\beta_2, \beta_3, \beta_4$ from equations (9) and (8). Next compute $a_1, a_2, b_1, b_2, c_1, c_2$ from equations (3) and then x_S and y_S from equation (6). Then compute r_1 from equation (8) and finally ψ_0 from equation (7).

Then the radio source is located at S = (x_S, y_S) with signal intensity ψ_0. A graphics program was written to implement this algorithm and results showing the two paths of the algorithm are shown in Figures 3 and 4 below. It was observed that in all cases the algorithm correctly avoided blind spots and accurately returned x_S, y_S and ψ_0.

It is clear that the spiral localizator algorithm can be coded in software that runs on every node that has a localizator, or else to save computational time and battery consumption the algorithm can be cheaply encoded in combinational hardware chips in the localizator itself with the output readable to the local node which has the localizator. A third possibility is to send the raw data $\{\psi_1, \psi_2, \psi_3, \psi_4, \psi_5\}$ up the line to the next level for computation in software assuming that the next level has greater power and computation capability. Indeed the raw data can be relayed up the line all the way to the mains powered base station which also has more capability than the nodes of the WSN.

5. DISCUSSION

A graphics program was written to test the accuracy of the 4 antenna spiral localizator. The output is seen in Figure 1. No matter where the source node S is selected on the grid shown, the coordinates (x_S, y_S) are accurately computed and shown graphically. However we can also notice that no grid positions occur on the green lines which are where the blind spots lie. A second program therefore was developed to allow any point off the grid to be selected as the source S and this program uses the algorithm of section 4 above to avoid blind spots – see Figure 3. When A_5 is not used in the algorithm, the black dot for A_1 is shown and the blue dot for A_5 is not shown in the graphical display. When A_5 is used in the algorithm the blue dot for A_5 is shown and the black dot for A_1 is not shown in the graphical display. The results showed that the algorithm correctly changed the input raw data from $\{\psi_1, \psi_2, \psi_3, \psi_4\}$ to $\{\psi_5, \psi_2, \psi_3, \psi_4\}$ in order to avoid blind spots. It also shows high accuracy in computing the source position and the source signal strength ψ_0.

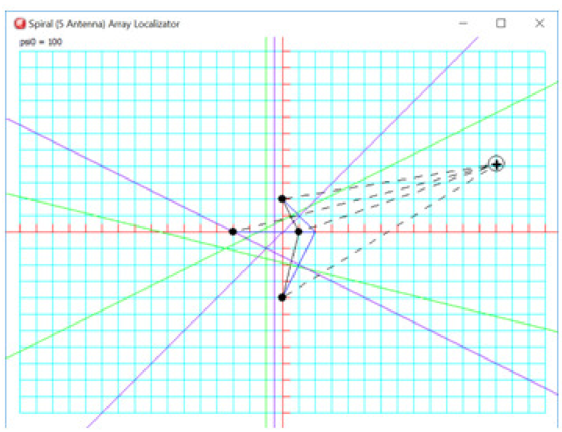

Figure 3 showing the Spiral Localizator algorithm using raw data $\{\psi_1, \psi_2, \psi_3, \psi_4\}$.

We now discuss the application of the localizator described in this paper to the general 2-level balanced WSN [12]. In this type of WSN we have data collected by N_1 clusters each of N_2 sensor nodes. The sensor nodes transmit their data to their respective cluster heads called aggregator nodes, and the N_1 aggregator nodes relay this data on to the base station. In the WSN there are therefore $1 + N_1N_2$ nodes in total but not all nodes need localizators. As discussed in [5], only the base station and aggregators are provided with localizators. Each 5 antenna spiral localizator defines the x and y axial directions since it has antennas 1, 3 and 5 along the local x-axis and antennas 2 and 4 along the local y-axis. All the localizators in a WSN can be aligned when their corresponding nodes are placed by turning them in the horizontal plane so that the line of antennas 1, 3 and 5 points to a given distant landmark by line of sight indicating the direction of the x-axis and this is then checked with antennas 2 and 4 pointing to a different distant landmark by line of sight indicating the direction of the y-axis. As explained in [5] it is not necessary for the local axes of each localizator to be aligned since when all the localization data is transmitted up to the base station, the base station makes the computations to determine the relative orientations of the x and y-axes of every aggregator localizator with respect to the orientation of the base station localizator.

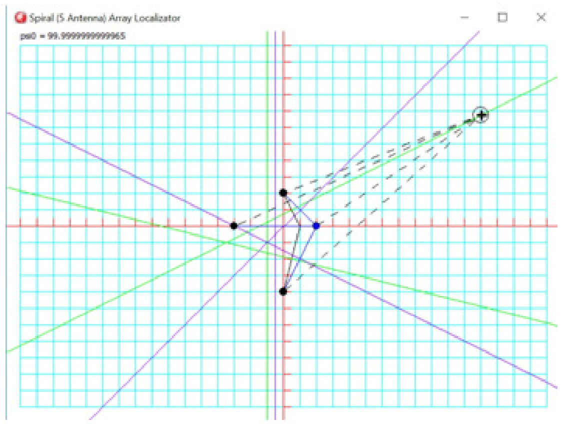

Figure 4 showing the Spiral Localizator algorithm using raw data $\{\psi_5, \psi_2, \psi_3, \psi_4\}$ to remove a blind spot.

The localization process for WSNs requires that the normal data collection operations of all nodes cease until the localization process of the whole WSN is completed to avoid radio interference in the measurement process though it would be possible for non-radio overlapping clusters to localize separately and in parallel. During the localization process only one sensor node may transmit a test pattern at a time for the duration required for the localizator of its aggregator node to capture the required raw data $\{\psi_1, \psi_2, \psi_3, \psi_4, \psi_5\}$ of that source. Likewise when the base station uses its localizator to localize an aggregator node all other aggregator nodes (as well as all sensor nodes) must remain off. For a dense 2-level balanced WSN, radio silence must be observed by all nodes of the WSN. In [5] a dense WSN was defined as one where full connectivity is initially possible. This means that the maximum separation of any two nodes in the WSN is less than the initial radius of radio reach of each node of say $\rho = 10$m. If all nodes of the WSN are within radio reach of the base station, then only the base station needs a localizator and aggregator and sensor nodes can be identical so that each has the same battery capacity. With no energy draining ADC chips in any node (including no battery level measuring hardware) and no localizators at any node, node lifetimes are maximized and node costs are minimized. With the only localizator located at the mains powered base station all localization computations are done at the base station and no localization computations are made at the nodes. In this case there is only one local coordinate system so no alignment of localizators is required and no computations compensating for non-aligned localizators is necessary. How long this ideal arrangement of radio coverage would last depends on the density of the WSN since all battery operated signals will eventually attenuate and it could be that having localizators at every aggregator node may result in a WSN with longer lifetime. There is therefore a trade-off between the operational longevity of the WSN and its cost in terms of the number of localizators installed.

6. CONCLUSIONS

Whereas other localizators have assumed a value for the signal intensity at a radio source in order to compute its position, an array of antennas and corresponding algorithm has now been found that computes the location of a radio source S and also calculates the signal intensity at S. This new localizator uses a compact arrangement of no more than 5 omnidirectional antennas. It provides a cheaper means of WSN localization than using directional antennas to determine angles and distances. The cheaper and simpler omnidirectional antennas can be used for network localization provided each localizator has at least 5 omnidirectional antennas in manufacturer fixed positions relative to the node. The equations for the position (x_S,y_S) of a radio source are linear and therefore quick to compute. The formulas for computing (x_S,y_S) can also be put into the hardware circuitry for the localizator to speed up the localization process and reduce the computational burden and energy consumption of a battery-based node. Alternatively the aggregators can send their raw data $\{\psi_1,\psi_2,\psi_3,\psi_4\}$ or $\{\psi_5,\psi_2,\psi_3,\psi_4\}$ to the base station and the calculation of (x_S,y_S), the coordinates of a node relative to an aggregator and the calculation of (x'_S,y'_S), the coordinates of that same node relative to the base station, as well as the calculation of ψ_0 the signal strength at S, are then all done on the more powerful base station PC. Note that not all nodes in the WSN need a localizator: only the base station and aggregator nodes require a localizator thereby reducing equipment costs. This method works even if nodes in the WSN can move freely as in ad hoc networks, or if node radio signals are subject to considerable attenuation as the battery discharges, so that not all nodes have to have localizators. This cuts down the cost of the WSN. Furthermore the ADCs for battery level readings should be disabled or removed from the nodes to further reduce the cost of the WSN. If the nodes are static then the localization process is only required once. If nodes are slowly moving then savings in the battery life of the aggregators can also be achieved by not executing the localization process too frequently. Further battery savings can be obtained by keeping ψ_0 for all sensor nodes just above the level necessary for error free detection by the aggregators.

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