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Evaluation of location estimation methods for mobile WSNs

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Abstract

This paper presents the evaluation of the energy efficient localisation method for a mobile WSN. The proposed method utilises a distance-based location estimation method together with a digital compass and a speed sensor attached to the mobile nodes. Trilateration was used to estimate the very first location of the nodes by deploying three beacon nodes. The beacon nodes sent broadcast signals to the nodes and the receiver was able to estimate its distance by the RSSI levels. Each sensor node was equipped with a digital compass which gave the angle of the movement and a speedometer was used to retrieve the speed of the node. By using the first location obtained through trilateration, the angle and speed of the movement, the next location of the node in question was then estimated. To evaluate the location estimation method, a simulation of the evaluated methods using the Network Simulator 2 (NS2). The second experiment included prototype hardware of a mobile node and implementation in an area.

1. Introduction

Location information in WSNs is an important block in the information retrieved for the deployed sensor nodes [132], [133]. The sensor node's task is to sense a specific environmental effect like humidity or pressure. The information collected from the network usually contains the information regarding the sensed event and the sensor node that initiated the sensing activity in the network [21], [39], and [134]. The location information of the sensed phenomena is of great importance to the end user because it uncovers the behaviour of the environment being monitored and how the sensed event has an effect on that environment. Location information is important also to apprehend a source of an undesirable activity [86] (e.g., fire protection systems).

Location information can be exploited to improve the operation of other layers in the network operational stack like routing protocols [135], [136], [113], and [137]. Amongst the resource constraints the WSNs share, network lifetime is an important aspect and needs to be covered in the development of WSN operation [132], [138]. Mobility in WSNs can have an effect on the power consumption of the network in general because of the rapid change of the nodes' locations. Location estimation of the mobile nodes can become a frequent process and consumes power. Therefore, a location estimation method for mobile WSNs has to be power efficient.

2. Simulation setup and scenarios

The simulation scenario contained six mobile nodes and three beacon nodes situated at places where it was possible to cover the whole deployed network (Figure 1). The area of the simulation was 400 × 400 square meters.

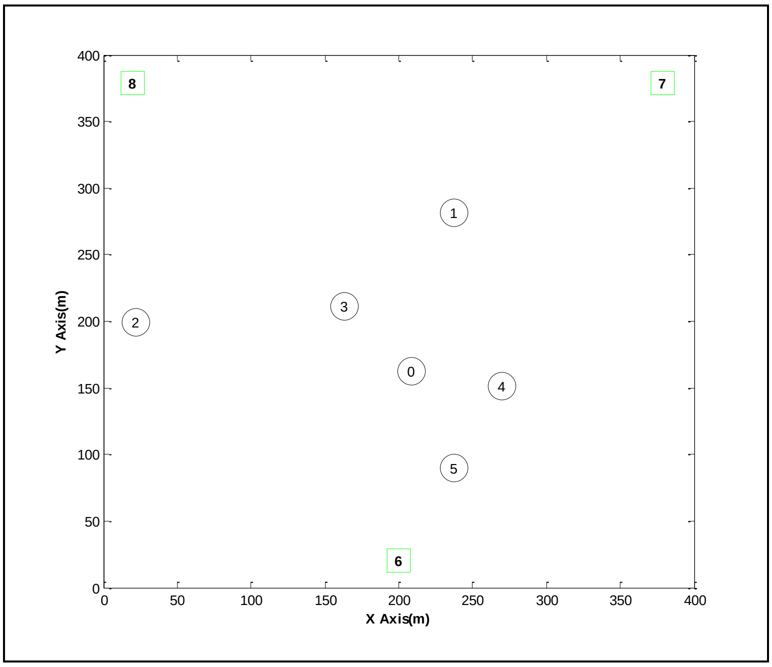

Figure 1: Simulation scenario

Two simulation experiments were implemented for the same simulation scenario with different mobility settings. In the first, the mobile nodes moved in a uniform speed of 1 m/s (the speed can be translated to about 3.6 km/h, a walking speed). The second setting involved the nodes moving at a random speed which varied from a minimum speed of 1 m/s to a maximum speed of 3 m/s. The mobile nodes were randomly deployed in the area of movement. The movement directions were random for each node. The Random-Way Point mobility model [179] was used to implement the node's mobility scenario. The compass module simulated in this experiment was HMC6352[180] manufactured by Sparkfun Co. Three configurations were implemented for each mobility scenario. The pure trilateration was the first method tested as the localisation method of the mobile nodes. The second configuration implemented the proposed method with the random compass error according to the module specifications. The third setting represented the worst case scenario where the compass was assumed to produce the orientation angle with the maximum error. Table 1 below shows the simulation settings which included the node transmission/reception power, propagation model, initial energy and the compass power consumption.

Table 1: Simulation scenario parameters

Simulation parameter	Parameter value
Simulation time	900 seconds
Node's initial energy	2 joules
Mobile node velocity	1 m/s-3m/s
Wireless propagation model	Two Ray Ground
Compass Max. Error	1 Degree
Compass resolution	0.5 Degree
Transmission power	31 mW
Reception power	35 mW
Transmission freq.	2.4 GHz
Compass power consumption	3.2 mW

3. Results and discussion

The proposed method was evaluated against one of the most widely used methods of localisation in WSNs which is trilateration. The criteria of the evaluation were the energy consumption of the system and location estimation error.

3.1 Energy consumption results and analysis

Starting with the energy consumption evaluation, during the simulations and experiments, the average power consumption of the nodes was the same for both simulation implementations. Figure 2 below shows the network average power consumption results for all of the scenario cases.

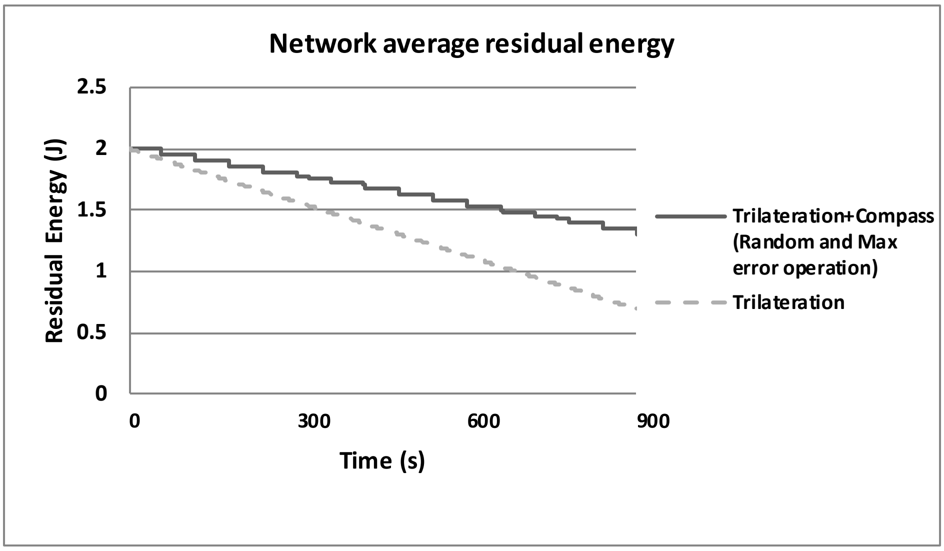

Figure 2: Average energy consumption of the network (the six nodes) for the pure trilateration and the proposed method

It is observable how the pure trilateration method consumed more power than the compass mixed operation. The trilateration method required frequent usage of the wireless interface which is the most energy consuming part of the mobile node during operation; whilst, the compass module consumed far less than the wireless interface (35 mW against only 3.2 mW). The results above were extrapolated and the results came to the conclusion that using trilateration only can make nodes survive only for 1370 seconds. The proposed method prolonged the operation of the network to about 2580 seconds (88% improvement over the trilateration method) using an initial energy of 2 joules.

3.2 Location error results and analysis

The location estimation error was the second criteria of the evaluation for the proposed method. The error of location (L_e) was calculated by the Euclidian equation:

$$L_e=\sqrt{(X_o-X_c)^2+(Y_o-Y_c)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where X_o and Y_o were the coordinates of the actual location of the node and X_c and Y_c were the estimated coordinates of the mobile node. The result was actually the straight line distance between the actual point and the estimated point of interest. The trilateration method resulted in a random error in the location estimation over the compass operation which was more of an accumulated error in operation. However, the results were promising in terms of the location estimation accuracy of the proposed method in the normal case of operation and in the worst case scenario. The location error for the proposed method also included the error of the periodic trilateration operation. The results of the error estimation were categorised into 100 bins by following the Frequency Distribution method:

1. Find the minimum and maximum estimation error value from the original data.

2. Calculate the range by subtracting the minimum from the maximum.

3. Divide the range by the number of bins to calculate the bin width.

4. The upper limit (the first bin) is calculated by adding the minimum value to the bin width. From there, the addition of the bin width (adding bin width to the bin just one level up represents the next bin) is resumed until the number of required bins is reached (the maximum error value is reached).

5. Count the frequency of occurrences of each bin according to the original data.

The resulting histograms for the location errors are shown (Figure 3) for the three methods discussed.

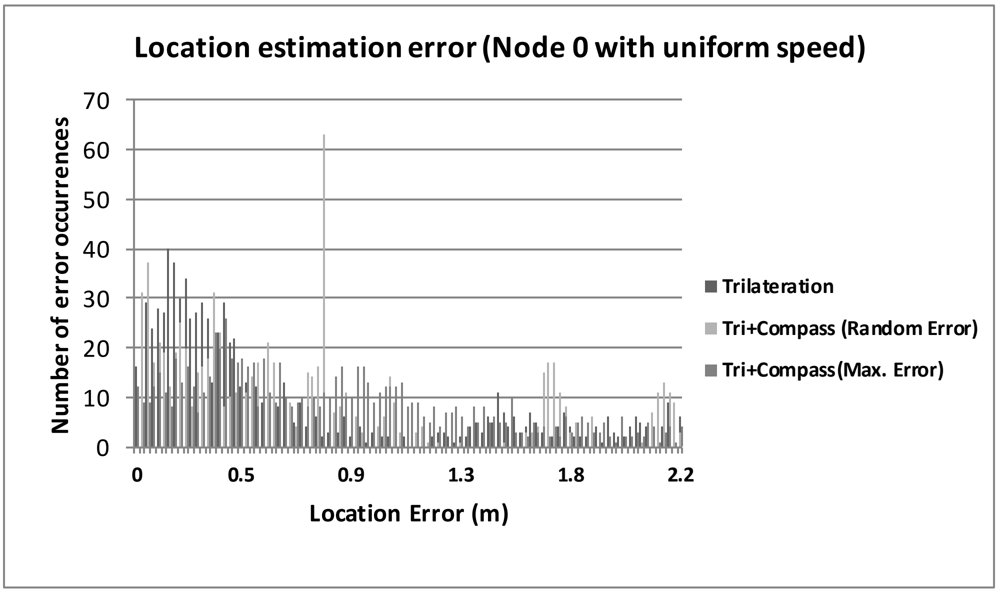

Figure 3: Node 0 location estimation error occurrences according to error categories (Actual results)

A trend-line of each method was described according to the relative error occurrence in the experiments to clearly illustrate the relative performance between the three methods. The produced trend-line for each method followed the multiple linear regression (MLR) model which was represented by equation (2):

$$Yi = \beta 0 + \beta 1X1i + \beta 2X2i + \dots\dots.. + \beta pXpi + \acute{\varepsilon} i \text{ ……………………….. } (2)$$

where $\beta 0, \beta 1, \dots., \beta p$, were defined as regression coefficients, i.e., coefficients to be derived from the data. Y_i was the estimated response for the ith element to estimate. $X_1, X_2, \dots., X_p$, were the predictors used to evaluate the fitting function representing the trend-line. The $\acute{\varepsilon}_i$ represented a normal random error of the approximated element. The model was implemented for all of the mobile nodes' output data for both simulation scenarios. Figure 4 and Figure 5 illustrate the location estimation errors for node 0 in both the uniform and the random mobility settings. The figures also show the results of the implemented localisation methods. From Figure 4, the trilateration method had the most error occurrences in the least error (bins 0-0.9 m) bins over the proposed method of localisation. The proposed method showed a rather similar performance to the trilateration method albeit the shift in the error occurrences (Figure 4: bin 0.5-0.9m). The worst case (Trilateration + Compass Max. Error) scenario trend-line showed a rather high error compared to the trilateration method and the proposed method in a normal operation (Figure 4: bin 0.5-1.8m).

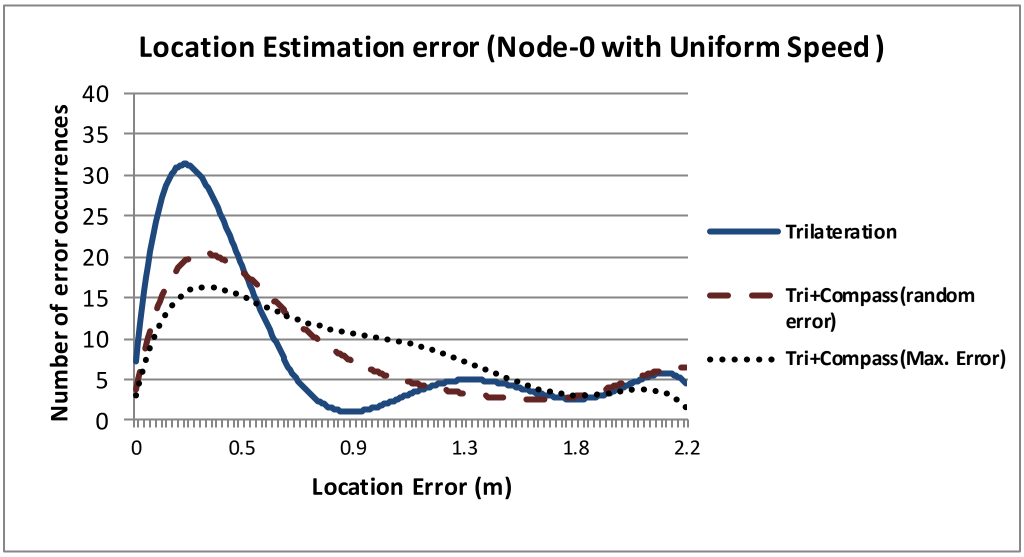

Figure 4: Node 0 location estimation error occurrences according to error categories

In Figure 5 and Figure 6, the error in location estimation increased as the speed of the node increased which was clear from the error bins (the random speed of the mobile node was between 1-3 m/s on the horizontal axis). The trilateration method and the proposed method had a rather similar trend of location estimation error. The compass operation with the maximum error resulted in a higher estimation error.

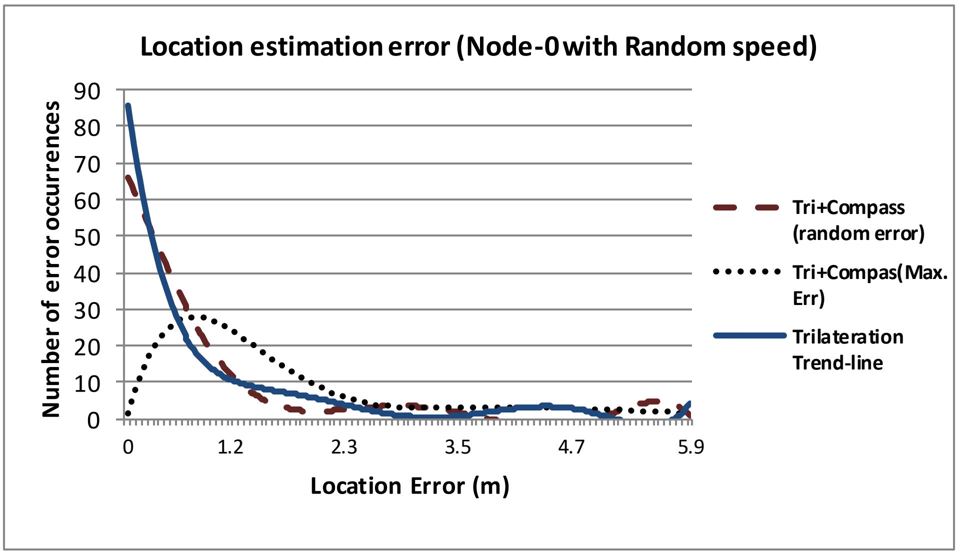

Figure 5: Node 0 location estimation error in random speed

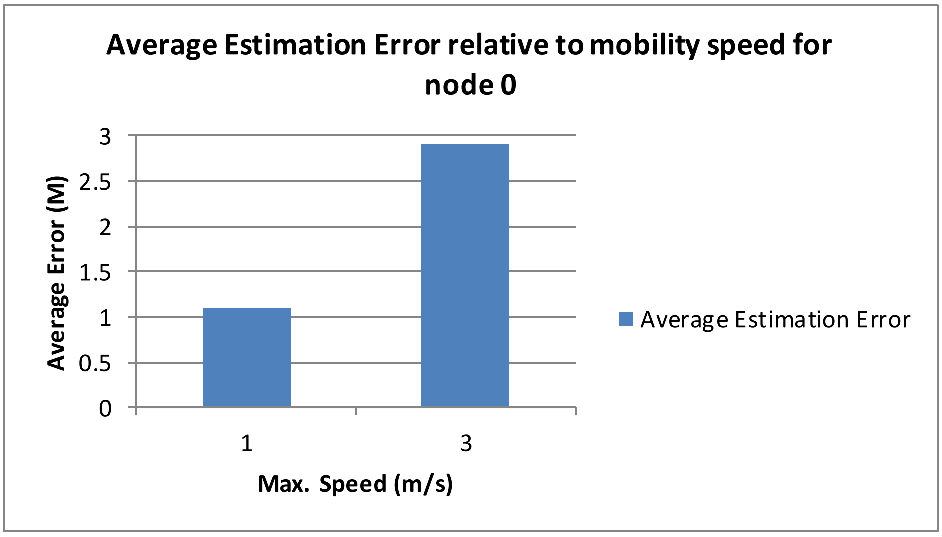

Figure 6: Average location estimation error for node 0 for both maximum mobility speeds in each simulation scenario. The average estimation error was calculated by subtracting the maximum error bin from the minimum and dividing it by 2.

Figure 7 and Figure 8 illustrate the location estimation error for node 1. The figures follow the same trends in Figure 4 and Figure 5.

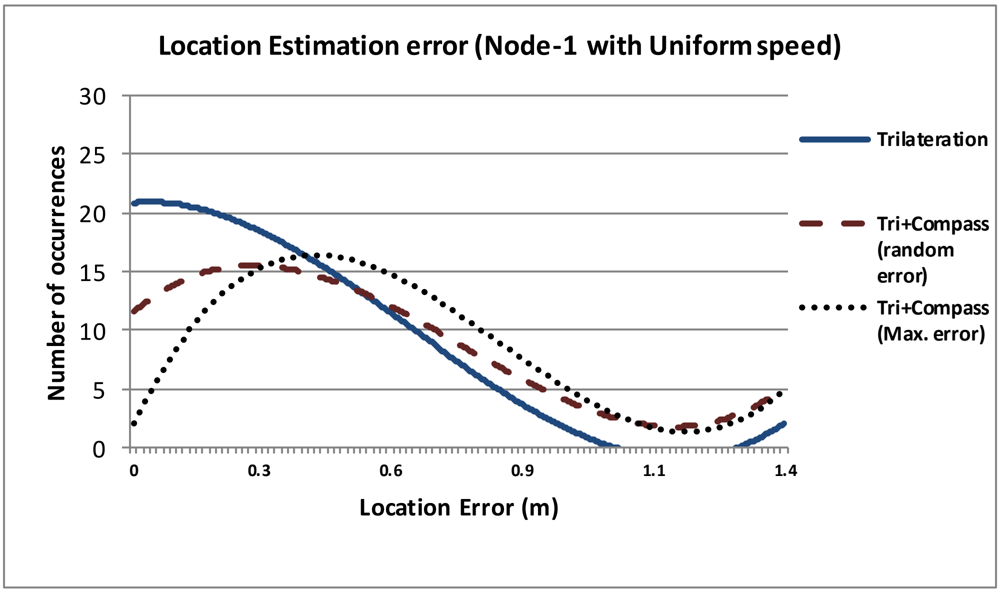

Figure 7: Location estimation error for node 1

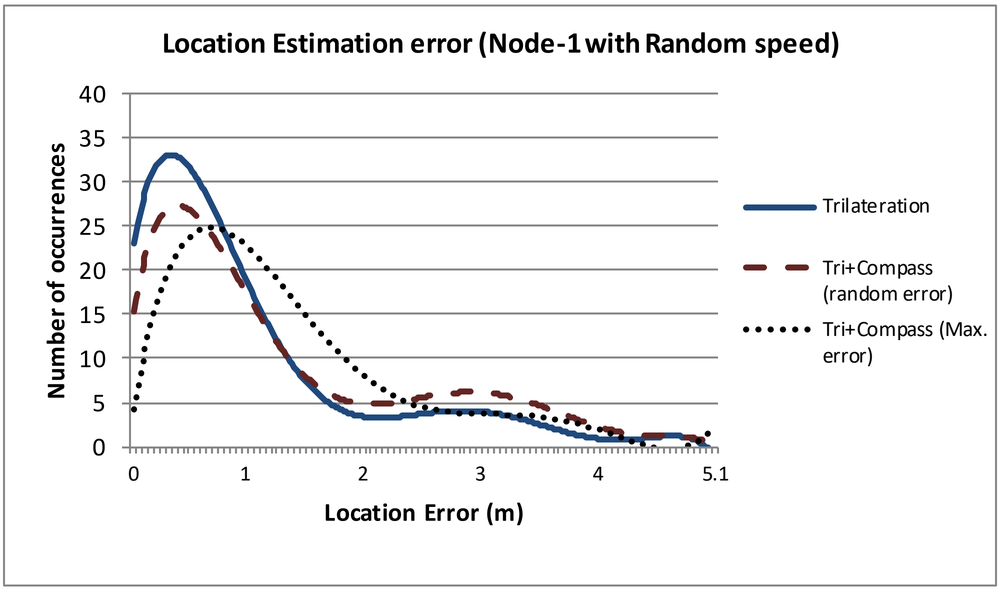

Figure 8: Node 1 location estimation error

The trilateration method and the proposed method were almost on par when it came to the location calculation error in both scenarios. The increase in the velocity of the mobility resulted in a higher location estimation error (Figure 9).

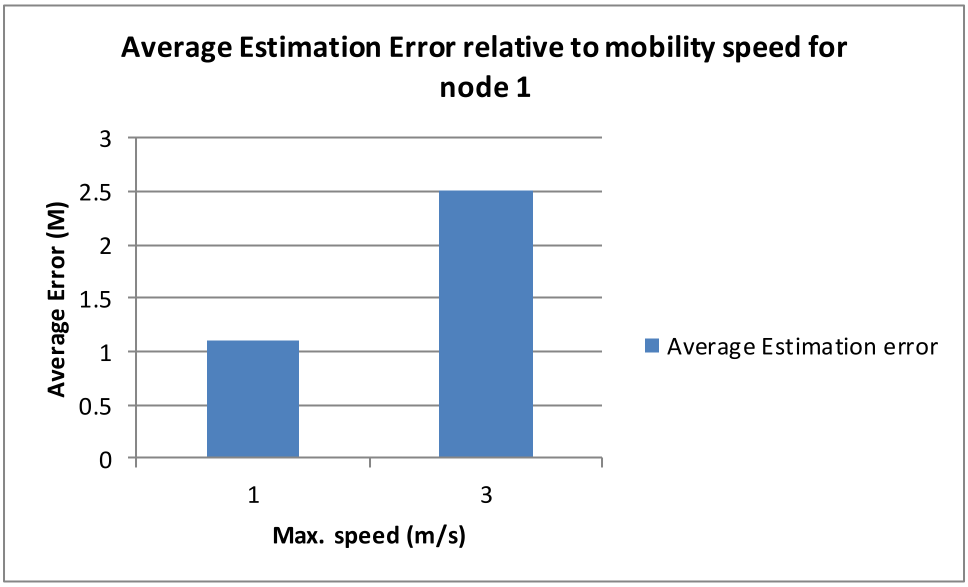

Figure 9: Average location estimation error for node 1 for both maximum mobility speeds in each simulation scenario. The average estimation error was calculated by subtracting the maximum error bin from the minimum and dividing it by 2.

The estimated location error for trilateration fell into three categories: the first estimation calculation error (in implementation, node 5 had an estimation error of 0.19 m at standstill in a random speed scenario output data), the second was the displacement of the node during the location estimation operation when receiving the signals required from the beacon nodes, and the third was the sensitivity of estimating the distance based on RSSI.

In the case of trilateration, the node purely depended on the received signal to indicate the location. However, the increment in error in the proposed method was due to utilising the digital compass as the major source of the location update plus the error resulting from the trilateration as a periodic location refreshing procedure.

Figure 10 and Figure 11 show the performance of the implemented methods in terms of location estimation accuracy for all of the mobile nodes in uniform and random speeds, consecutively.

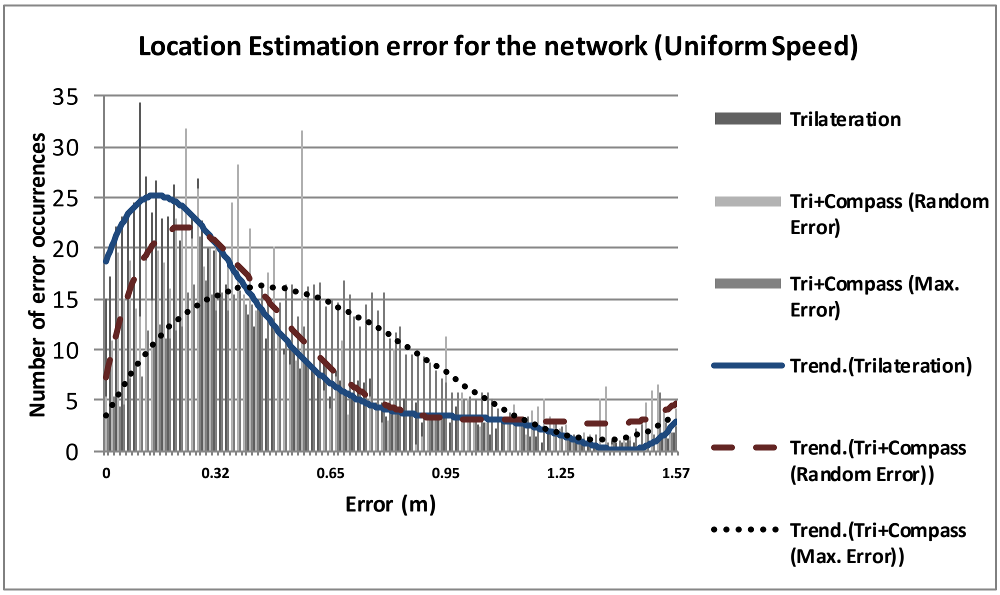

Figure 10: Location estimation error for all of the mobile nodes. The proposed method at a regular operation was close to the trilateration method in terms of location estimation.

The proposed method implementation results for a uniform speed scenario (Figure 10) are promising for overall network location estimation. The proposed method with a random compass error operation showed less location estimation error than the worst case scenario (when the compass reading included a constant 1 degree of error). The proposed method's performance was also close to the trilateration estimation method in the random speed scenario (Figure 11).

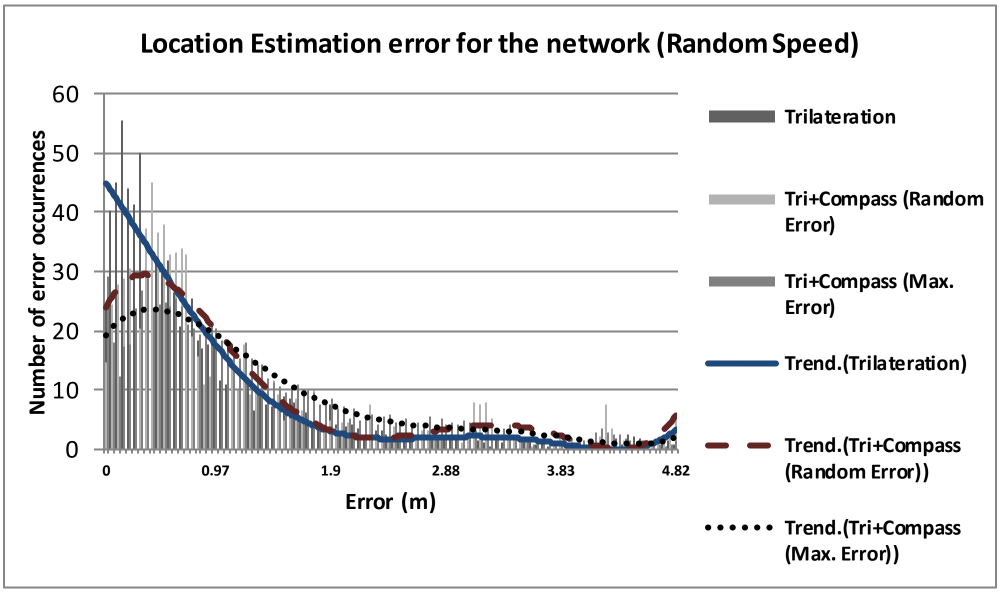

Figure 11: Location estimation for all of the mobile nodes at a random speed

The overall trend of the location estimation error of the proposed method (for normal operation and the worst case operation) was comparable to the location estimation error for the pure trilateration method for the whole of the deployed mobile nodes (Figure 10 and Figure 11). This observation supports the proposed method of location estimation to be used in mobile WSNs because the method provided a similar location estimation as compared to the trilateration method for the given simulation scenarios. The proposed method outperformed the pure trilateration method in terms of energy consumption because it combined the periodic operation of trilateration (every 60 seconds) and utilised a digital compass and a speedometer to update the mobile node location. Pure trilateration implementation requires the beacon nodes to frequently transmit localising signals to the mobile nodes which can exhaust the nodes lifetime because the wireless interface power consumption is higher than the digital compass power consumption.

3.3 Visual location estimation simulation

To show the effect of each method on the estimation of the nodes location during its mobility, a visual trace of the nodes has been made for the proposed simulation scenarios (the uniform speed situation was considered as an example). Figure 12 below shows the traces of the nodes' mobility in the field of deployment.

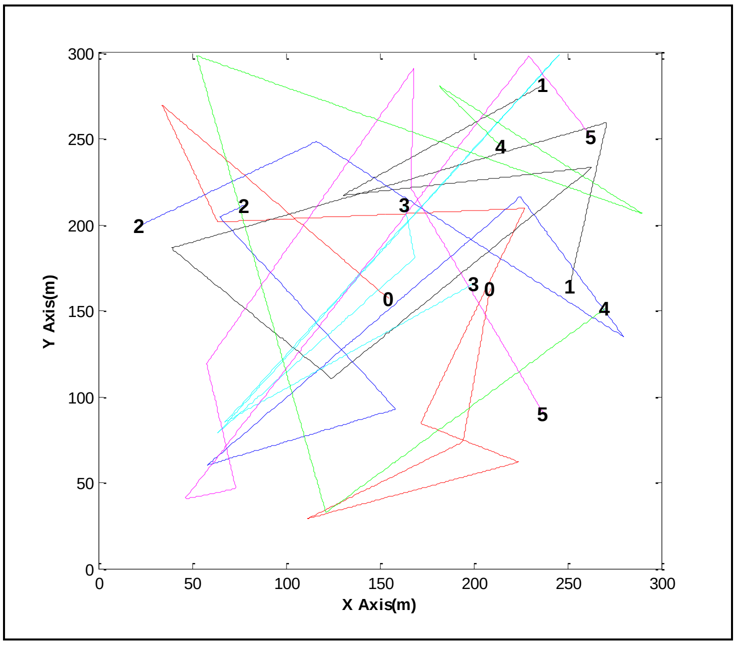

Figure 12: The deployed nodes' mobility traces in a uniform speed scenario

From the trace lines shown in Figure 12, the node 0 mobility trace line was considered as an example to show the performance of each method of location estimation (Figure 13).

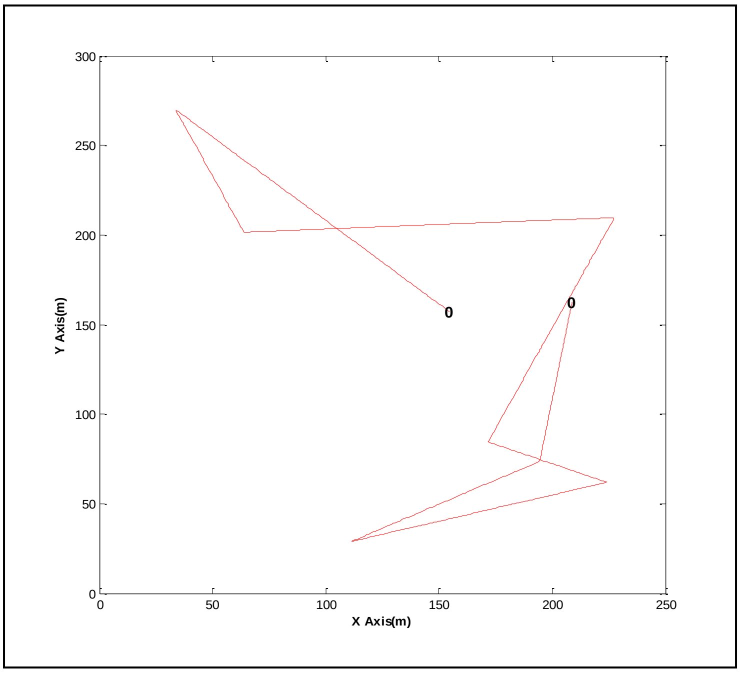

Figure 13: Node 0 mobility trace line. The trace line shown in this figure is the actual mobility trace for node 0 during simulation.

The deployed nodes were mobile throughout the period of the simulation. The location estimation methods were periodically initiated each for 1 second. That means there were 900 points of location estimation for each method (Trilateration), proposed method (random Compass error) and proposed method (worst case scenario). Aligning the points of each method with the actual trace line of node 0 (Figure 14) makes the differences impossible to appreciate (due to the fact that the area of deployment was very large as compared to the error of the estimated points from their actual points).

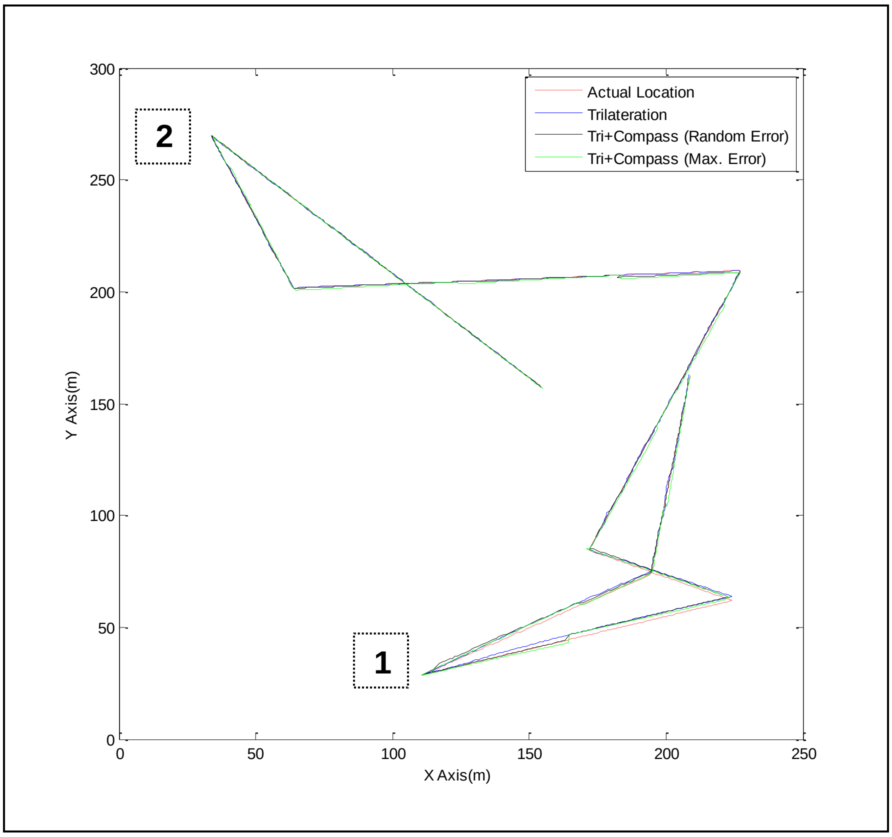

Figure 14: Node 0 mobility trace lines for each method of localisation. The trace lines are very condensed.

From the mobility trace line of node 0 (Figure 14) it is difficult to observe how each method performed in location estimation. By zooming in on the part of movement at X: 110-125m, Y: 22-40m and at X: 33-41m ,Y: 260-270m areas from Figure 15, it is possible to have a better look of how each method was estimating the node's location during movement (Figure 15 and Figure 16). It is possible to observe that the proposed method (both in the regular case and in the worst case scenario) was marginally similar to the pure trilateration method in terms of location estimation accuracy. The proposed method is aimed at mobile WSNs where the nodes change their places rapidly. The proposed method's implementation results are promising in terms of average network energy consumption and location estimation accuracy.

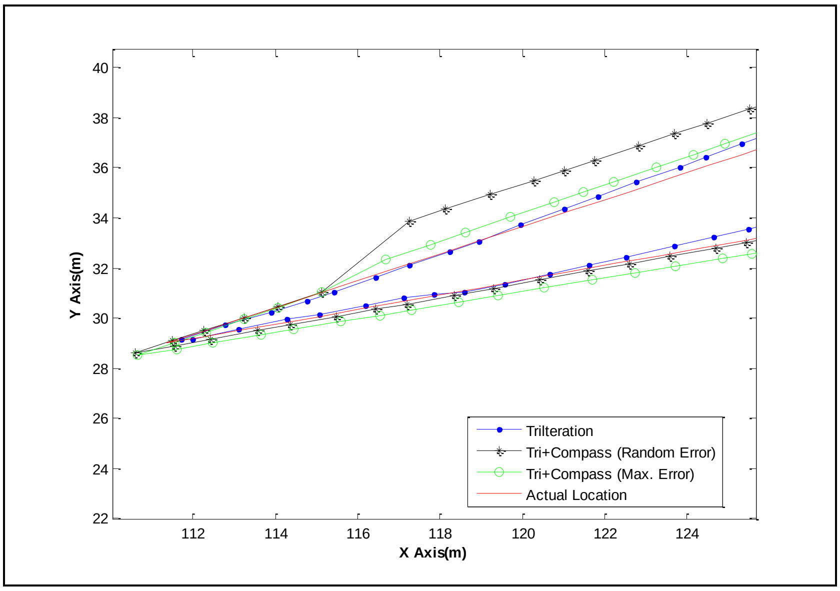

Figure 15: A closer look at the operation of each method for node 0 movement at uniform speed (Dotted-Box 1 in Figure 14)

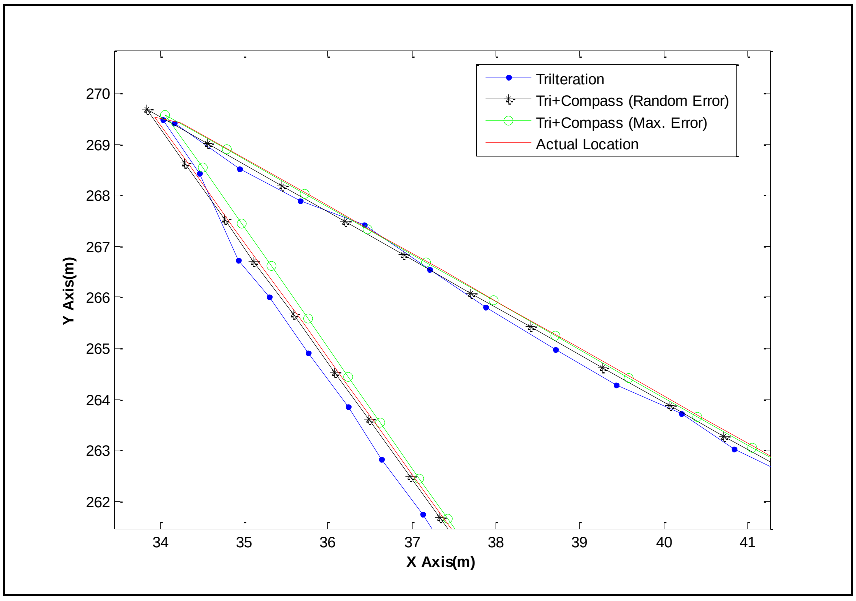

Figure 16: Closer look at the operation of each location estimation method for node 0 mobility at uniform speed (Dotted-Box 2 in Figure 14)

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