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IMPROVED LOCALISATION ALGORITHM FOR WIRELESS SENSOR NETWORKS BY USING XBEE

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Abstract

In the past few years, Wireless Sensor Networks (WSN) have garnered a lot of interest, with regards to their location and range of the nodes within or outside the WSNs. Many researchers have focused on the high costs of the low-range buildings and energy consumption, though the energy nodes were limited. Here, the researchers have proposed a novel hybrid system for determining the inside range of the WSNs based on the Received Signal Strength (RSSI) and the DV-hop inside the network. This system was tested by developing nodes based on the XBee S2. The practical experiments showed that the proposed system was reliable and accurate, consumed low energy and displayed a better network range.

Keywords: Localisation, Range-based, Range-free, RSSI, WSNs, XBee S2.

1. Introduction

A WSN includes a set of sensors that can be used for reading the chemical or physical phenomena (such as vibration, humidity, temperature, fluid pressure, etc.) and then, transmitting these values wirelessly to a sink, for research purposes. Karl and Willig [1] mentioned that WSN is a very advanced technology with many applications as follows:

- Military applications: These include the surveillance of target and detection of enemy attacks.
- Civil applications: These include traffic control, vehicle tracking and monitoring.
- Emergency operations: These include detection of floods, fire, and earthquake, along with the monitoring of air and water pollution.

The WSNs are also used in other areas such as industry, trade, medicine, irrigation and agriculture. Some researchers have developed WSNs, to measure the soil and the water levels in the reservoirs. These were seen to be very beneficial in countries with less rainfall and water scarcity.

According to the definition of the network, the various components of a sensor node include a sensing unit, memory unit, processor, transmitter and a receiver, along with an antenna and power source (Fig. 1).

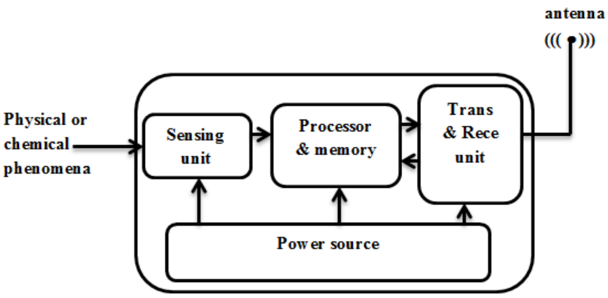


Fig. 1. Components of a sensing node.

This module is responsible for converting the transmitted or received data into the format that is compatible with the type of data that is needed for the storage and processing unit. Firstly, the data that is received from the sensor was strengthened and converted into the digital format, with the help of a data conversion tool. In the WSN, the volume and the processing unit includes a microchip with limited memory and a data processor. Along with the earlier units, the transceiver module includes an antenna, which receives the transmitter radio wave. Furthermore, concerning a power source, every sensor node includes a battery with a long life [2].

Thus, the primary components of a WSN include the sensor and router nodes, along with the data receivers, as shown in Fig. 2.

Many functions are carried out by the nodes such as the monitoring of all the physical phenomena related to the nodes, routing all the collected data, locating the nodes in the WSN and tracking the location of all the nodes. Here, the researchers have presented the various ways in which, this could be carried out. All the methods consume a node power; hence, a novel method was proposed for reducing the power consumption.

In this study, a novel range technique was proposed and experimentally tested using the XBEE S2 sensor nodes. This proposed technique was developed after integrating 2 localisation techniques, i.e., the range-based and range-free technique, i.e., the DV-hop and RSSI, respectively. A combination of these techniques would help in a better representation compared to using an individual technique. DV-hop was used for identifying the area of the mobile target node, whereas RSSI was used for determining the precise location of all these nodes [3].

This paper was structured in the following manner: Section 2 presents a review of the related works that have addressed the topic of localisation. Section 3 includes the definitions of XBEE and localisation techniques, whereas, in Section 4, the researchers have presented the novel localisation techniques. All experiments and results for the novel system were presented in Section 5. Lastly, Section 6 presented the conclusions of the study and their plans for future work.

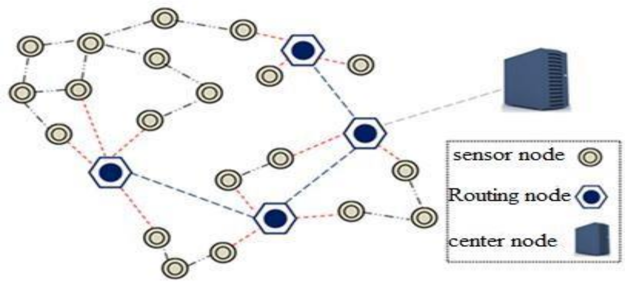


Fig. 2. Components of a wireless sensor network.

2. **Related Works**

Since it is important to determine the exact location in the WSNs, many researchers have focused on calculating the decreased energy consumption of the nodes in these networks, after applying various localisation technologies. Jie et al. [4] minimised the no. of hops in the RSSI for improving the DV-hop, thereby decreasing the hop size and estimation error. Yang et al. [5] improved the DV-hop and RSSI by auxiliary ranging the nodes with their centroid [5]. Xie et al. [6] analysed the various factors that increased the error rate in the DV-hop and RSSI techniques and selected the union nodes for decreasing the error.

3. XBEE and Localisation Techniques

The ZigBee technology was characterised by low data rate, cost and energy consumption. ZigBee was a global standard that could be used for formulating the communication protocols based on the standard IEEE 802.15.4. It was seen to be the 4^{th} in the series and displayed the minimal transmission rate. XBEE was another product was based on the ZigBee protocol. It was available in many product families, wherein every category includes devices that differ based on their speed, power consumption and connection distance. For instance, the S1 Family included many XBee circuits that communicate with one another;

however, they are not connected to the XBee circuits in the S2 Family. XBee was seen to be a small and inexpensive circuit that offered wireless connections ranging between 100 m and 70 m, based on the model. Hence, it was considered as a standard wireless connection between various electronic devices [7, 8]. On the other hand, the WSN Localisation algorithms are categorised into 2 classes, depending on the need/ no need to determine the location of the end and sink nodes for performing the localisation process.

3.1. Techniques based on the range-free system

These techniques are used for cost-effective and low-power applications; however, they cannot accurately determine the position of the nodes. They use the connection-based information for estimating the distance between the nodes, as the number of hops between the nodes. The range-free techniques include the Approximate Point-in-Triangulation (APIT), Centroid and Distance Vector-hop (DV-hop). Table 1 presents the advantages and disadvantages of range-free processes [9].

Table 1. Comparison between the various range-free techniques.

Range-free techniques	***Advantages***	**Disadvantages**
DV-hop	Unlimited number of neighbouring anchor nodes	Lower accuracy and high overhead
Centroid	Lower overhead	Lower accuracy
APIT	No radio assumption	Each node requires minimum 3 neighbouring anchor nodes
CPE	Good accuracy	Centralised, higher overhead Each node requires minimum 3 neighbouring anchor nodes

3.2. Techniques based on the range-based system

This technique helped in determining the accurate position since it was based on the ranging devices (such as angle, velocity or point-to-point distance) between the nodes. After determining the data, the sensor node position could be estimated. The range-based techniques included Angle of Arrival (AOA), Time of Arrival (TOA), Time Difference of Arrival (TDOA) and similar methods involving the RSSI. Table 2 highlights the advantages and disadvantages of range-based techniques [10].

Table 2. Comparison between various range-based techniques.

Range-based techniques	***Advantages***	**Disadvantages**
RSSI	No added hardware needed, scalable, lower overhead	Expensive memory, non-flexible
AOA	Requires a low synchronisation time, better accuracy than RSSI	Hardware limitations get affected by multipath failing and noise
TOF	Better accuracy compared to the RSSI	Ultra-high synchronisation time requires expensive hardware

4. Hybrid (RSS and DV-hop) Localisation Techniques

RSSI (Radio Signal Strength Indicator) was a simple technique, which was used for determining the range in the WSNs. However, it alone could not be used as a reliable method in the localisation algorithm. It is usually integrated with other algorithms for improving the system efficiency if the actual use of a node is unreliable. This was because of the presence of many factors such as attenuation due to barriers, interference or a node defect. Figure 3 describes the RSSI principle [11].

The DV-hop (Distance Vector-hop) algorithm requires very few anchoring or neighbouring nodes. Figure 4 presents the principle of this DV- hop algorithm.

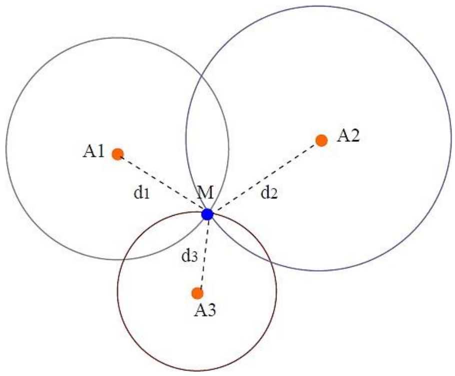


Fig. 3. Principle of RSSI technique.

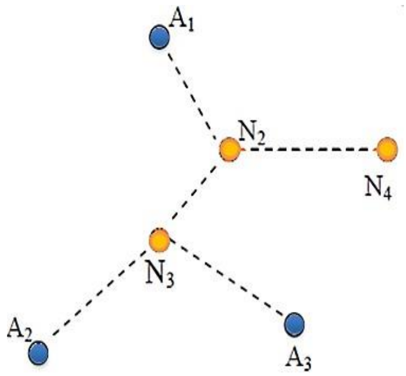


Fig. 4. Principle of DV-hop technique.

Proposed system

In this study, we have proposed a system that integrated the 2 techniques for decreasing energy consumption and improving position accuracy. The proposed algorithm was as follows:

- RSSI was used for determining the distance between the receiver (i.e., reference node) and transmitter (i.e., target node), based on its strength. This required prior knowledge of the location of a reference node and geometry deployment process used in the network. Symbols ($d1$, $d2$ and $d3$) used in Fig. 3 represent the distance between the reference and target nodes.
- DV-hop was used for determining the position of a destination node as many WSN-based applications use the nodes at a higher density, which helps in covering all the source nodes having the maximal number of reference nodes. This increased error probability [12].

This proposed system included four stages: In stage 1, the sink node sends a “hello” message to the various nodes that are located at a distance of 1 hop. In stage 2, the reference nodes, that have received this message, would transmit a location package that contained the RSSI value that was acquired from the location information and mobile target node. In stage 3, the researchers determined the position of a mobile target node using the DV-hop method. Finally, in stage 4, the location information was transmitted to a sink node. Three algorithms were used at the sink, reference and the mobile target nodes. Figure 5 presents the flow chart of this system.

Algorithm 1. Applied at sink node:

1. *R* represents reference nodes in the XBee network.
2. *T* represents a target node.
3. *SF* represents the sampling frequency rate.
4. *S* represents the sink node.
5. Every (*SF*).
6. *S* will request localisation information from *T*.
7. Appreciated *T*_((*x*, *y*)) is a matrix displayed to end-user.
8. End.

Algorithm 2. Applied at the reference node:

1. *R* represents reference nodes in the XBee network.
2. *T* represents a target node.
3. While (*T* communicates to *R* in one hop).
4. *R* sends its current location to *T* every *t_mh*.
5. End while.
6. End.

Algorithm 3. Applied at the mobile target node:

1. *MT* represents a mobile target node.
2. *R_MT* represents the reference nodes that hear *MT*.
3. *S* represents the sink node.
4. [RSSI]_((*R_i*,*MT_j*) is the value of RSSI obtained from *R_i*.
5. *R*_((*x*, *y*)) represents 2 coordinators for *R_MT*.
6. *MT*_((*x*, *y*)) represents the Appreciation location for *MT*.
7. *MT* sends a 'hello' message in a single hop communication.
8. Loop:∀R_*MT*.
9. If [RSSI]_((*R_i*,*MT_j*)≥ θ RSSI.
10. *Z*[*i*]= [RSSI]_((*R_i*,*MT_j*).
11. *I*++.
12. End if.
13. End loop.
14. *MT* Appreciated its present location using *z*[ ].
15. *MT* sends its present location to the sink node.
16. Go to 6.
17. End

$$f(1) = \left\{ \begin{matrix} 1: RSSI(Ri, MTj) \geq \theta_{RSSI} \\ 0: RSSI(Ri, MTj) < \theta_{RSSI} \\ \end{matrix} \right\} \quad (1)$$

$$RSSI_{(Ri,MT<j)} \geq \theta_{RSSI} \quad (2)$$

where $RSSI(Ri, MTj)$ refers to the signal strength acquired by the reference node, $R_{i,}$ at mobile target node $MT_{i,}$; RSS_{Θ} refers to the threshold value that is estimated using Eq. (3) as follows:

$$\theta_{RSSI} = \sum_{i}^{n} 1 \frac{Ri}{n} \tag{3}$$

Here, n was the summation of all reference nodes, present in the vicinity of MT_i. If a DV-hop method is used at the mobile target node for sending at least 1 data packet to a sink node, this process would significantly increase the energy consumption. For avoiding this issue, one must approximate the location area of the mobile target node at every T_{mh} periodically, wherein t_{mh} could be calculated using Eq. (4) as follows:

$$T_{mh} = \frac{p}{i} \tag{4}$$

where P was the mean speed of a mobile target (≈6 km/h), while i represented the no. of reference nodes in the area.

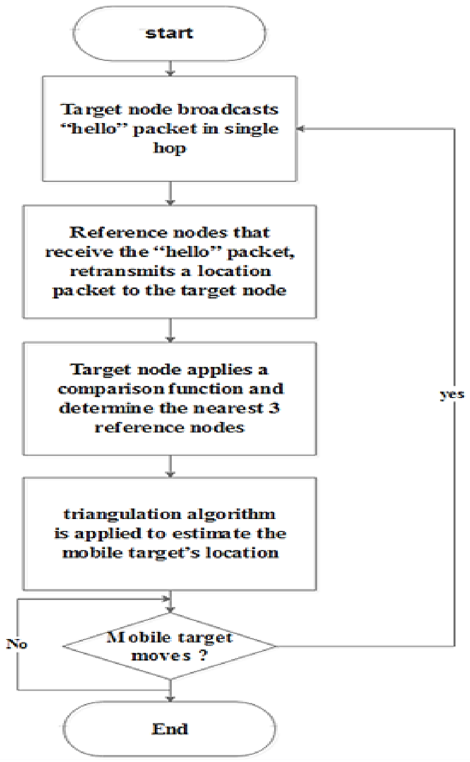


Fig. 5. Flow chart of proposed system.

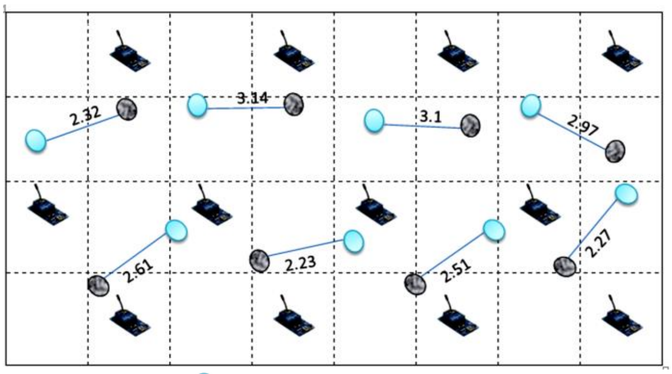
5. **Experiments and Results**

Real-time experiments were used for testing the proposed system, which included 12 nodes that were distributed at a distance of 16×4 m. One of the nodes was a mobile target node with an unknown coordinator, while the remaining were reference nodes with a predefined coordinator. Every node was developed using an XBee transmitter module and an ATTiny85 microcontroller. Table 3 presents the configuration of this experimental network.

The system was tested the accuracy of the node position and the energy consumed in the above-mentioned algorithms using 3 test scenarios. They estimated the error for the 9 reference nodes and after changing the positions of the mobile target node. Figures 6 and 7 describe the localisation error after the use of the DV-hop and RSSI techniques. Figure 8 depicts the localisation error after the use of the proposed method. They also calculated the error rate after using the 3 techniques. Results indicated that the DV-hop algorithm showed the maximal localisation error (2.67 m), followed by the RSSI (2.43), while the proposed algorithm showed the least error (1.39 m).

Table 3. Configuration of experimental network.

Parameters	Values
Number of nodes	12
Sampling rate	5 bps
Experiment time	15 min
Average number of hops	2
Communication protocol	ZigBee
Rx energy	0.47 mJ
Tx energy	0.47 mJ
Transmission range	Very low (≈7 m)



* - error location; - node position.

Fig. 6. Amount of localisation error using DV-hop technique.

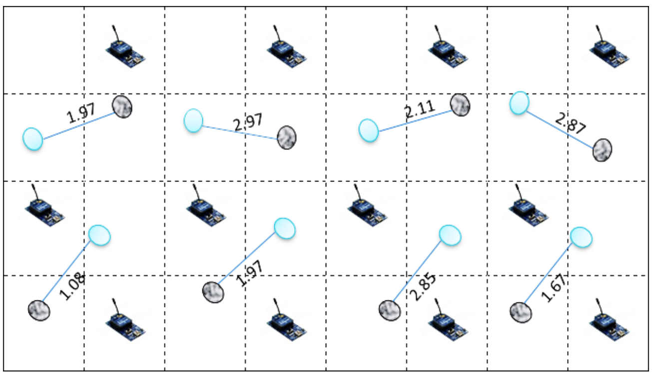


Fig. 7. Amount of localisation error using RSSI technique.

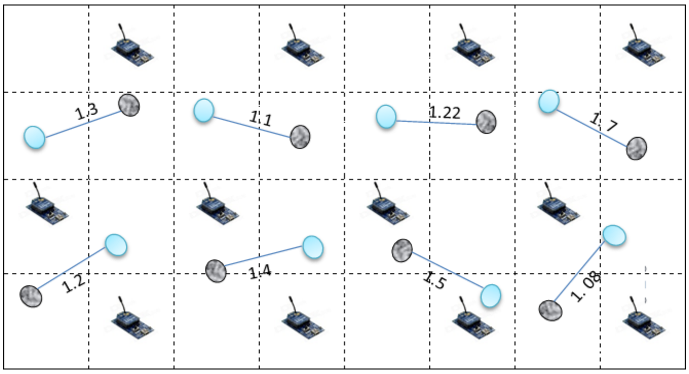


Fig. 8. Amount of localisation error using the proposed technique.

The amount of energy consumed was estimated using Eq. (5), that determined the number of data packets that were exchanged between the nodes. After determining the rate of transmission of these data packets, it was seen that the technique that transmitted more packets consumed more energy.

$$m_{pkt} = t_n \times v \times \frac{t}{f} \quad (5)$$

where t_n refers to the total number of reference nodes; whereas v represents the total number of hops occurring between the reference and the sink nodes, and f was the sampling frequency. Results indicated that the RSSI and DV-hop algorithms showed very similar data packet rates, however, RSSI consumed more energy compared to the DV-hop technique due to the nature of its algorithm. On the other hand, the proposed technique showed a minimal data exchange rate, thereby consuming low energy. These results have been presented in Figs. 9 and 10.

Table 4 presents a summary of the location error rate, data packet exchange rate and the energy consumption rate for the 3 algorithms.

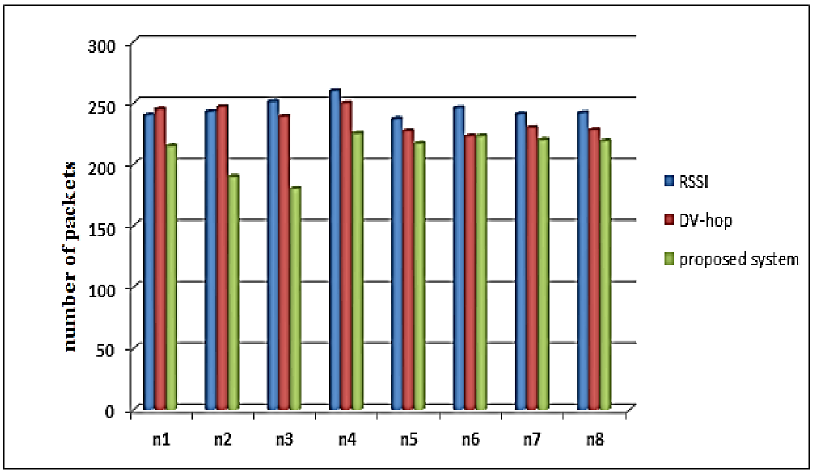


Fig. 9. Rate of exchanged data packets for 3 localisation techniques.

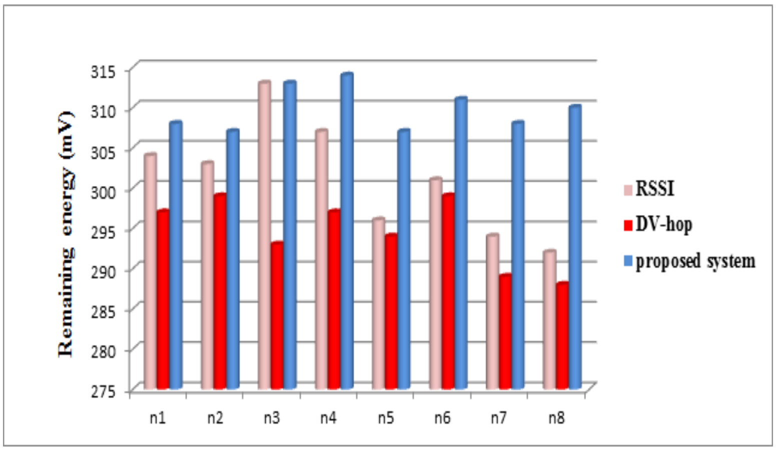


Fig. 10. Energy consumption rates for 3 localisation techniques.

Table 4. A summary of all 3 techniques.

Algorithms	Localisation error (meter)	Power consumption	No. of exchanged packets
DV-hop	2.67	1908 mA	254
RSS	2.43	1256 mA	238
Proposed	1.39	1194 mA	164

6. Conclusions

In this study, a novel technique is proposed for localising the nodes in the WSN. They combined all the characteristics of the advanced techniques, such as RSSI and DV-hop. Results indicated that the proposed technique was more efficient than the RSSI and DV-hop techniques with regards to their accuracy of localisation and energy consumption. In future, planning to develop the proposed technique in a different way for increasing its efficiency.

Nomenclatures

f	Sampling frequency
MT	Mobile Target node
P	Average speed of mobile target
R	Reference nodes
R_MT	Reference Nodes That Hear MT
S	Sink node
SF	Sampling Frequency rate
T	Target node

Greek Symbols

RSS_Θ	Threshold value

Abbreviations

AOA	Angle of Arrival Time
APIT	Approximate Point-in-Triangulation

DV-hop	Distance Vector-hop
RSSI	Received Signal Strength
TDOA	Difference of Arrival
TOA	Time of Arrival
WSN	Wireless Sensor Networks

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