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ROUND TRIP DELAY TIME AS A LINEAR FUNCTION OF DISTANCE BETWEEN THE SENSOR NODES IN WIRELESS SENSOR NETWORK

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ABSTRACT

In a dense wireless sensor networks with portable sensor nodes identification of sensor node location, distance of particular sensor node from some reference node and fault detection are the great challenging issues. Round trip delay (RTD) time measurement technique is an easy way to obtain the information regarding above issues in WSN. But round trip delay measurement is affected by various parameters of wireless sensor network. As the sensor nodes are placed randomly in network, sensor node distance has more impact on this time measurement. So it is necessary to study the relationship between the round trip delay time and Sensor node distance. To prove this relationship the other parameters affecting round trip delay time like speed, data transfer rate, number of sensor nodes in RTD path and other request handled by intermediate nodes are either made constant or disabled. A wireless sensor node hardware designed for this purpose consists of microcontroller (ATMEGA 16L) and ZigBee (XBEE S2) wireless communication module. For configuring the ZigBee module of each sensor nodes in round trip delay path X-CTU software is used. After configuring the all sensor nodes the entire network is simulated in real time by using Dock light V1.9 software. The graph plotted between round trip delay time and sensor node distance proves a linear relationship between it.

KEYWORDS

Wireless Sensor Network, Round Trip Delay, Portable Sensor Node.

I. INTRODUCTION

The advances in microelectronics and sensor technology made it possible to have of small, low-cost and large number of sensor nodes placed in measuring range through the wireless communication module like ZigBee [8-11]. The purpose is to sense, collect and preprocess the information from all sensor nodes in network. In such wireless sensor network having large number of portable sensor nodes identification of sensor node, locating the distance of target sensor node with respect to reference sensor node[2] and detection of failed sensor node becomes most difficult [3-5]. In case of indoor positing system the sensor node location accuracy needed is in centimeter. Failure detection of sensor node in WSN is essential because failed or malfunctioning sensor node may produce incorrect data or no data, which will affect the overall quality of the entire WSN. Manually checking of such failed sensor node in WSN is troublesome and impossible.

Different techniques or methods like time delay estimation (TDE), Received Signal Strength (RSS) are developed to resolve above issues in WSN [2-4]. The round trip delay and confidence factor is the most powerful tools among them [1].The minimum imposed condition for RTD measurement is that at least 3 sensor node should be present in a loop. This RTD measurement is affected by various parameters of WSN. In WSN having 'N' sensor nodes if any one sensor node fails or starts producing improper data (malfunctioning) the time delays related to this sensor node will change. This will introduce errors into the RTD time estimates. A brief analysis of RTD time errors can be found in [6]. This paper is arranged into five sections including introduction. Section II gives overview of round trip delay, factors affecting it, limits of sensor nodes in it and round trip delay paths. Section III describes the experimental setup used to prove this relationship. In Section IV real time hardware simulation results are presented. Conclusion is presented in Section V.

II. ROUND TRIP DELAY

Round-trip delay (RTD), also called as round-trip time (RTT), is the time required for a signal pulse or packet to travel from a specific source node thru path consisting other nodes and back again. The round trip delay time can range from a few milliseconds (thousandths of a second) under ideal conditions between nearby spaced sensor nodes to several seconds under adverse conditions between sensor nodes separated by a large distance [2]. Let us consider the wireless sensor network having four nodes as shown in figure 1.Consider the minimum condition of having 3 sensor nodes in RTD path. Then in this WSN the maximum RTD paths present will be 4.These are as follows

1. RTD-1 (S1-S2-S3-S1)
2. RTD-2 (S1-S2-S4-S1)
3. RTD-3 (S1-S3-S4-S1)
4. RTD-4 (S2-S3-S4-S2)

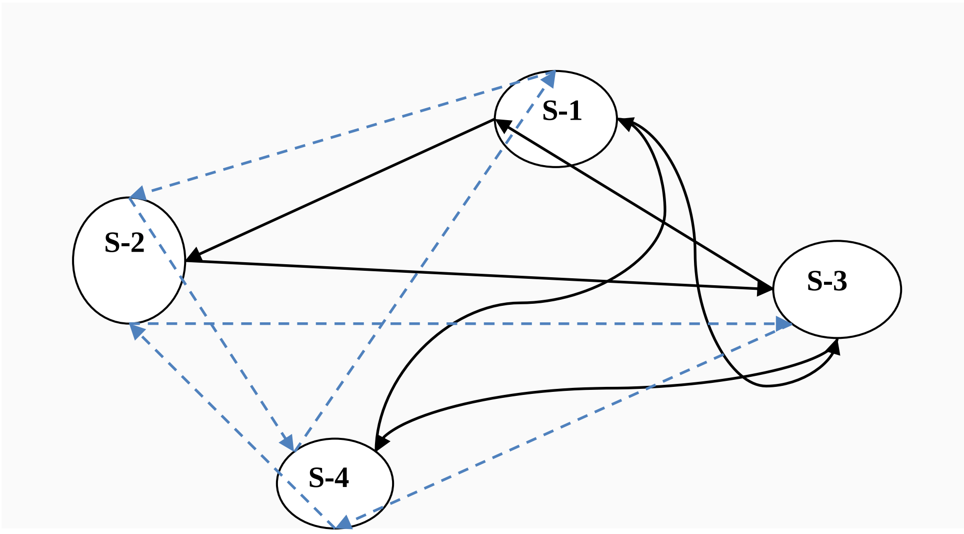

Fig 1: WSN consisting four sensor nodes with maximum four paths for RTD measurement.

The RTD time for RTD-1 path in above network is calculated by using following equation

$$T_{RTD-1} = \tau(1,2) + \tau(2,3) + \tau(3,1) \quad (1)$$

where τ(i,j) is the delay time between the sensor node i and j respectively. With the help of this equation-1 , the generalized equation for RTD time for the RTD path containing (N-1) sensor node will be written as follows

$$T_{RTD} = \tau(1,2) + \tau(2,3) + \text{------ -------- -------} + \tau((N-1),1) \quad (2)$$

The round trip delay (RTD) times, with minimum 3 sensor nodes in RTD paths, of all possible paths/orientations in WSN with 'N' sensor nodes are listed below in figure 2.

$$\begin{bmatrix} \tau_{RTD-1} \\ \tau_{RTD-2} \\ \tau_{RTD-3} \\ - \\ - \\ - \\ \tau_{RTD-(N-1)} \end{bmatrix} = \begin{bmatrix} \tau(1,2)+\tau(2,3)+\tau(3,1) \\ \tau(1,2)+\tau(2,4)+\tau(4,1) \\ \tau(1,3)+\tau(3,4)+\tau(4,1) \\ - \\ - \\ - \\ \tau(1,2)+\tau(2,(N-1))+\tau\big((N-1),1\big) \end{bmatrix}$$

Fig 2: RTD paths in WSN with 'N' sensor nodes

The $\tau(1,2)$ time delay between the sensor node 1& 2 depends upon the distance between them. Time delay is directly proportional to distance and expressed as

$$\tau(1,2) \propto d(1,2) \quad (3)$$

RTD time expressed in equation 1 depends upon the various time delays in the selected path. All these time delays are linear function of distances. Hence RTD time should be a linear function of distance between sensor nodes. Here in this paper it has been proved experimentally.

2.1. Factors affecting RTD time measurement

In a network RTD time is affected by several factors. One of them is latency, which is the time between a request for data and the complete return or display of that data. The round trip delay (RTD) time depends on various factors including:

a) Data transfer rate of the sensor node.
b) Nature of the transmission medium.
c) Physical distance between the sensor nodes.
d) Number of nodes in the RTD path.
e) Number of other requests being handled by intermediate nodes.
f) Speed with which intermediate nodes and source node functions.
g) Presence of interference in the circuit.

As stated above the round trip delay time is a function of various parameters of the wireless sensor network and can be expressed by following equation

RTD Time = ***f*** (speed, distance, medium, noise, sensor nodes in RTD path & request handled)

$$= Ts + Td + Tm + Tn + Tn_{RTD} + Toreq \quad (4)$$

A theoretical minimum is imposed on the RTD (minimum 3 sensors in path) because it can never be less than this value. Then it will not form a loop in transmission medium. As the RTD measurement depends upon various parameters [1,3,5] of Sensor Node and WSN. The WSN for various paths round trip delay (RTD) measurements has to be categorized as Symmetrical or Asymmetrical network. A WSN is briefly defined as Symmetrical network if

1) All the sensor nodes are located at equal distance from each other.
2) All sensor nodes should have same sensitivity.
3) Operating speed of all sensor nodes processing unit has to be equal.
4) Same wireless communication module is for all sensor nodes

Otherwise the WSN will be defined as Asymmetrical network.

2.2. Limitation of sensor nodes in RTD path.

As mentioned in above point'd' round trip delay time depends on the number of sensor nodes present in RTD path. There should be more than 2 sensor nodes to form a round trip in a network. The minimum number of sensor nodes required to form RTD path are 3 [2-4] and maximum sensor nodes in round trip delay paths should not be more than (N-1).This will put the limits on the sensor nodes used in round trip delay path. This limit of sensor nodes in RTD path for WSN with 'N' sensor nodes is given by

$$3 \leq m \leq (N-1) \quad (5)$$

where 'm' is the number of sensor nodes present in the respective RTD path.

2.2. Determination of number of RTD paths in WSN

The number of RTD paths in WSN depend upon the number of sensor nodes selected for RTD path. Maximum possible RTD paths in WSN having 'N' sensor nodes can be calculated by following equation

$$n_{RTD} = N\,(N- m) \qquad (6)$$

where 'n_{RTD}' is the number of RTD paths having 'm' sensor nodes in WSN consisting 'N' sensor nodes.

In the network having less number of sensor nodes, minimum criteria (m=3) for number of sensor nodes in RTD path can be used. This will results in optimum number RTD paths. But if the number of sensor nodes in WSN are large then minimum condition (m=3) for selection of sensor node should not be used because it will result in large numbers of RTD paths.

III. EXPERIMENTAL SETUP

The four microcontroller-based sensor nodes (Slave) and a master (computer) are used here for experimental purpose. Each sensor node consists of ATMEGA 16L microcontroller and XBEE S2 (Digi key) ZigBee pro wireless communication module as shown in figure 3.

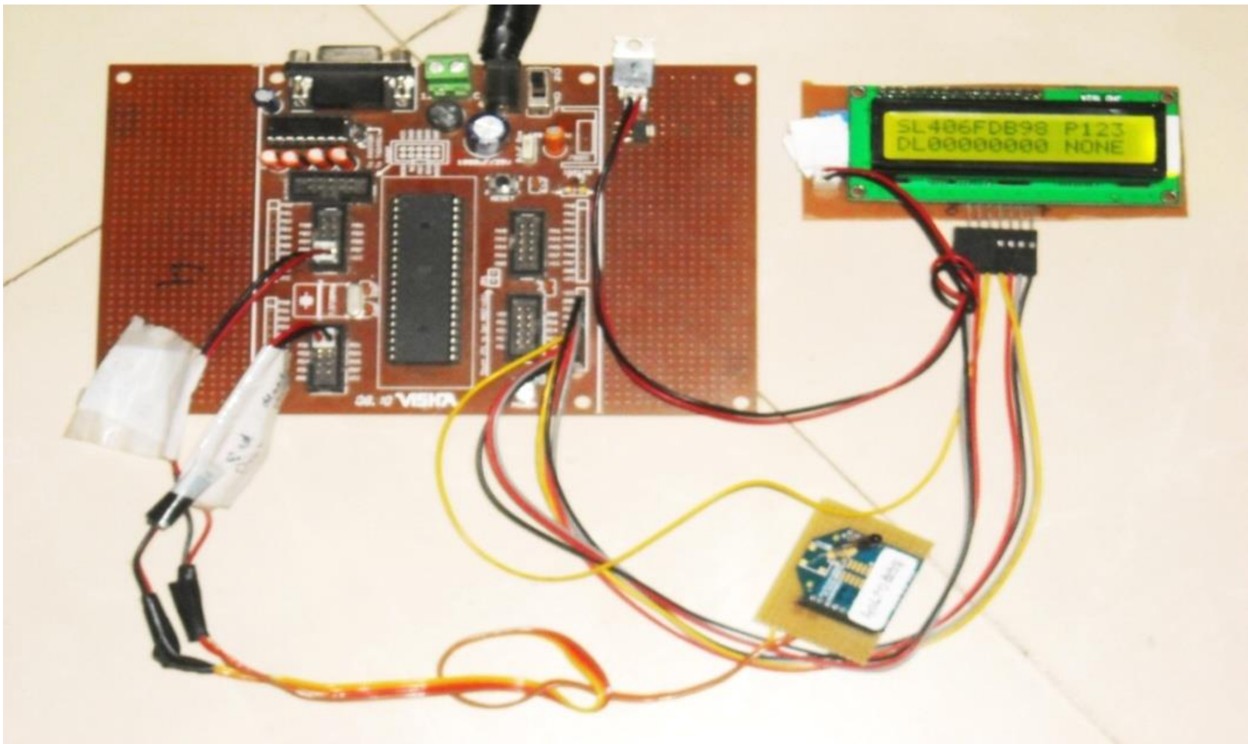

Fig 3: Microcontroller based Sensor node with ZigBee.

3.1. Hardware Selection and Configuration

Microcontroller ATMEGA 16L is selected because it is a low-power, high-performance CMOS 8-bit micro-controller with 16K bytes of In-System Programmable Flash memory. The crystal used for microcontroller is 7.3728 MHz with baud rate is set at 9600 bps.LCD display and ZigBee module are interfaced to port C and D respectively. The existence of automation device profiles and low power consumption (min.60mW) as compared to Bluetooth makes the ZigBee[9-11] an ideal wireless interface for automation devices [7].The ZigBee addresses of sensor nodes selected in the network have the id as S1 (406FDB22), S2 (406FDBD6) ,S3 (406FD976) and S4(406FDB51).

All ZigBee modules are addressed using Unicast addressing because it supports the retries. As in this application we requires one master and remaining four slaves sensor nodes, ZigBee modules used here has to be configured with NonBeacon (w/Coordinator) network technique[8]. In this network configuration technique master sensor node is configured as Coordinator and remaining slave sensor nodes are configured as End Devices. Operation mode selected here is AT Command mode, so that direct transmission will occur between the sensor nodes.

3.2. Selection of various network conditions

As the RTD measurement is affected by various parameters of the wireless sensor network mentioned in above equation 4. The various conditions have to be imposed on the selection of network before applying this method. So except distance other parameters affecting RTD measurement are kept constant. These conditions are mentioned in table 1.

Table 1. Condition Imposed on selected network.

Sr. No.	Factors Affecting RTD measurement	Condition Imposed or Chosen
1	The data transfer rate of the sensor node	Similar data rate is used for all sensor node (9600 bps)
2	The nature of the transmission medium.	Wireless
3	The physical distance between the sensor nodes	Variable with Symmetrical network
4	The number of sensor nodes in the RTD path	Minimum (m=03)
5	The number of other requests being handled by intermediate nodes	NIL
6	The speed with which intermediate nodes and source node functions	Same due identical hardware (in sec)
7	The presence of interference in the circuit	No (Laboratory Environment)

Data transfer rate and speed of communication of sensor nodes are same as ZigBee wireless communication module is used [10]. The minimum condition of sensor nodes (=3) in RTD path is selected here. If more sensor nodes are used in RTD path it will increase the RTD time [3]. This will not affect the linear relationship between the RTD time and sensor node distance.
Here we have to prove the relationship between the RTD time and Sensor Node Distance. So the distance between the sensor nodes is kept variable under symmetrical network conditions. Round trip delay path is kept fix. Sensor nodes are kept at various distances as 1,2,3,4 and 5 feet respectively and then real time results are taken.

IV. SIMULATION RESULTS

Initially the each sensor node in WSN as shown in figure 1 is defined for a selected round trip delay path by configuring them with source and destination addresses (of ZigBee module) by using the X-CTU software.RTD path selected here is RTD-1 (S1-S2-S3-S1) and the RTD path distance is 1 feet. Sensor node S1 has source address of master and destination address as 406FDBD6, sensor S2 has source address as 406FDB22 and destination address as 406FD976 and for sensor S3 source address is 406FDBD6 and has destination address as 406FDBD22.
After configuring these slave sensor nodes in WSN it is simulated in real time by using the Dock light V1.9 software. The above procedure is repeated for remaining four causes. For these cases sensor nodes are kept at distances 2 feet, 3 feet, 4 feet and 5 feet respectively. Results of simulation are mentioned in table II.

Table 2. Real Time Simulation Results of RTD Time using Dock light V1.9.

Sensor Node Distance (feet)	Transmitted Time Tx in sec	Received Time Rx in sec	Round Trip Delay Time = Tx—Rx
1	28:19.410	28:34.033	14.623 sec
2	28:56.027	29:10.651	14.624 sec
3	29:20.023	29:34.649	14.626 sec
4	29:41.124	29:55.751	14.627 sec
5	31:09.350	31:23.978	14.628 sec

The RTD time values measured for five different cases are 14.623, 14.624, 14.626, 14.627 and 14.628 sec respectively. From the readings it observed that as distances changes in 'feet' the RTD time changes in 'msec'. As the distance between sensors nodes in WSN changes, it will change the time delay between the consecutive sensor nodes, which in terms affect the RTD time measurement [2-4]. The change in RTD time against distance between sensor nodes is verified by considering five cases. The round trip delay time (msec) against sensor node distance (feet) graph is shown in figure 5. It gives us the linear relationship between the distance and round trip delay (RTD) time of sensor nodes [2].

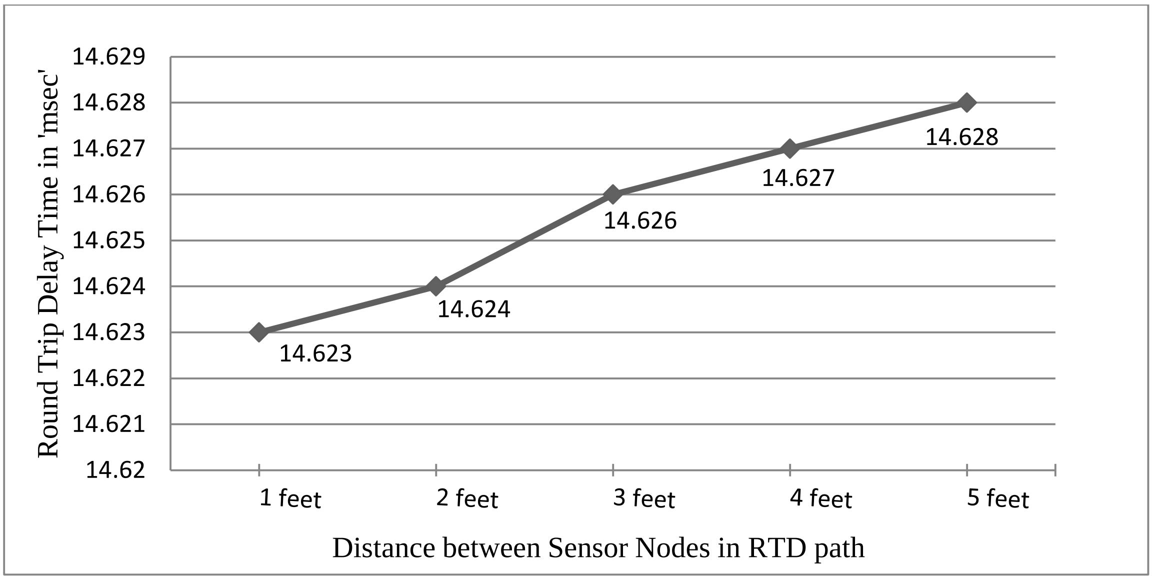

Fig 5: RTD time against Sensor Node Distance.

V. CONCLUSION

It is observed from above results that as the distance between the sensor nodes in round trip delay path increases the round trip delay (RTD) time also increases. A In above experimental case the parameters affecting RTD measurement except distance are kept identical. So the round trip delay (RTD) measurement in these cases is purely a function of distance between the Sensor nodes. Hence linear relationship exists between round trip delay time and sensor node distance in WSN.

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