Location Tracking by ZigBee

Chien-Yuan Liu and Gwo-Jeng Yu

Computer Science and Information Engineering Department, Cheng Shiu University
No.840, Chengcing Rd., Niaosong Township, Kaohsiung County 833, Taiwan, ROC
E-mail: cyliu@csu.edu.tw, gjyu@csu.edu.tw

Abstract

ZigBee is a novel open standard to be adopted in the design and implementation of wireless sensor networks. With a bunch of features about low radio emission, low power consumption, long standby duration, short distance, network enabled, great amount of nodes, flexible topology, and easy to form a network, ZigBee is rapidly becoming one of mainstream technologies for wireless digital smart life. This paper introduces the protocol stack of ZigBee and the application interfaces for the implementation of location tracking by ZigBee. Furthermore, the scheme of location tracking is explained and a pilot location tracking system is designed and demonstrated. The result shown that an observed node can be correctly positioned as expected performance.

Keywords: IEEE 802.15.4, ZigBee, Wireless Sensor Network, Location Tracking

1. INTRODUCTION

Wireless sensor network (WSN) has become one of rigorous research issues due to rapid advancement of micro sensors, micro electro-mechanical technologies, digital wireless communications, and the integration with computers. The features of WSN include low cost, low volume, low power consumption, long standby duration, short distance, network enabled, a great deal of nodes, flexible topology, easy to construct a network, and low maintenance after installation in a great scale. It is the right time for academic and industry to invest in WSN.

ZigBee technology is one of the best solutions for WSN. It is based on IEEE 802.15.4 and is extended with upper network and application layers for productive design of WSN applications. ZigBee can apply to the application domains of home care, home control, security, and location tracking. With proper integration of sensors, actuators, it is efficient to develop and build a wireless real-time monitor and control system. The work of this paper attempts to utilize ZigBee to develop a location tracking function for several applications, such as patients care assistant system, precious instrument management, and human resource dispatching.

2. DESIGN ARCHITECTURE AND THEOREM

2.1 ZigBee Architecture

The draft of ZigBee specification was initiated by Honeywell, Invensys, Mitsubishi Electric, Motorola, and Philips in 2003. The latest specification was released on December 2006. ZigBee adopts IEEE 802.15.4 as its media access control (MAC) and physical (PHY) layers. In addition, network (NWK), application support (APS), and application (APL) layers, ZigBee device object (ZDO), and security service are added over the base IEEE 802.15.4. Therefore, ZigBee has already become a complete network protocol for wireless applications. The protocol stack of ZigBee is illustrated in Figure 1.

The kernel of ZigBee Stack is NWK. NWK takes care of joining into or leaving network, finding route, and data packet transmission or reception for a ZigBee device. The major functions of APS in APL include the ZigBee network formation and binding, data transmission management, and network security. The function of APO in APL is to implement the processing logic for the ZigBee application. In the other words,
APO is the basic unit of application program. APO can communicate with a remote APO through ZigBee network to realize specific application, e.g. to turn on a remote switch for lighting.

ZDP describes the behavior and properties of a ZigBee device and is defined by the ZigBee Alliance. ZigBee application profile describes the functions and parameters for a particular application and is mandatorily defined by the ZigBee Alliance. Each ZigBee application profile has a unique Profile ID. For instance location tracking application has its own profile ID. Manufacturers should obey the ZDP and ZigBee application profile to design their ZigBee products. This is to assert the interoperability between different vendors. In ZigBee specification, each APO implements only one application profile. A unique EP ID should be allocated to an APO.

There are two types of ZigBee devices: FFD and RFD. FFD can act as a coordinator or router, can communicate with all types of devices, and can support any type of network topologies. RFD can act only end device and can communicate only other end device via a router or coordinator. There is only one coordinator in a ZigBee network, but it allows multiple routers and end devices. ZigBee network specifies two network topologies: central controlled star network and peer-to-peer mesh network.

2.2 Location Tracking Algorithm

In ZeeBee location tracking application, three types of nodes are required. Those are immovable reference node (RN), mobile blind node (BN), and dongle node (DN). At least 3 RNs should be placed with known coordinates. However, up to 16 RNs is allowed in location tracking. Multiple BNs can be tracked under the cooperation of reference nodes. DN is used for the connection of ZigBee network to a personal computer. Through DN, PC configures the RN and BN, collects the coordinates of all mobile blind nodes, and shows the locations of mobile nodes in a GUI display.

In wireless communication, signal power is decayed by the pass loss. Empirically, the receiver signal strength index (RSSI) is logarithmic proportion to the distance d between the receiver and the transmitter. The mapping function from d to RSSI can be described by the equation \( RSSI = -10N \log d + A \). Where \( A \) is the signal strength at the distance of one meter from transmitter, \( N \) is the order of path loss characteristic. Typically value of \( A \) is -40 dBm. \( RSSI \), \( d \), and \( A \) can be obtained from field measurement. Thus, \( N \) can be calculated by linear regression with least square liner fit.

Location tracking algorithm (LTA) uses all the coordinates and RSSI from at least 3 to 16 reference nodes to estimate the location of blind nodes. In addition, LTA requires a set of parameters made up of \( A, N \), and search boundary limited by all gathered coordinates. Basically, having more reference nodes would
improve the estimation precision. The results of LTA are a pair of location coordinates \((x, y)\) with resolution of 0.25 meters. The coordinate is represented by a fix-point format. The two LSBs represent the fractional part and the remaining 6 bits represent the integer part. For instance, a coordinate of \([10110011]\) indicates a value of 44.75.

\[
(x_0, y_0) \quad (x_1, y_1) \quad \ldots \quad (x_{15}, y_{15})
\]

At the beginning of location estimation, LOCENG.EN flag is set. Next, the sixteen pairs of coordinates are loaded in order into REFCOORD register when LOCENG.REFLD is set. Note that the coordinates of unused reference nodes should be set to 0 and put behind other used coordinates. After the written was done, LOCENG.REFLD is reset. Figure 2 depicts the procedure of loading coordinates. Next, when LOCENG.PARLD is set, a set of measured parameters must be loaded in order into MEASPARM register before the start of location estimation. These 22 parameters include \(A, n, x_{\text{min}}, \Delta x, y_{\text{min}}, \Delta y, \) \(\text{RSSI}_0, \text{RSSI}_1, \ldots, \text{RSSI}_{15}\), \(\Delta x = x_{\text{max}} - x_{\text{min}}\) and \(\Delta y = y_{\text{max}} - y_{\text{min}}\). Figure 3 describes the loading procedure for measured parameters. Note that, instead of \(N\), index \(n\) is used for calculation by the conversion curve in Figure 4. For example \(N=2.985\), \(N\) is adjust to nearest 3.0. Its corresponding index value is 13. Therefore, parameter \(n\) is set to 13 = [00001101]. LOCENG.PARLD is reset when written work was done. The location engine starts to compute the results when LOCENG.RUN is set. Within tens mini-second, OCENG.DONE is set and the results can be read from registers LOCX and LOCY. Finally, LOCENG.EN is reset to wait for next location estimation. Figure 5 illustrates the flowchart of location estimation.

3. EXPERIMENT AND RESULT DISCUSSION

The location tracking experiment consisted of one dongle node (DN), one mobile blind node (BN), and 3 to 12 reference nodes (RN) at designated coordinates on \(15 \times 15\) meters square area. Figure 6 showed the grid diagram of the area. A PC was connected to DN to set the coordinates of RNs, to configure the operating parameters of RNs and BNs, and to collect coordinates of BN and data from sensor on RNs or BN. DN can be put anywhere within one hop to any RN. All RNs were grouped into 4 cases. The first case \((C_A)\) utilized 3 RNs. The second case \((C_B)\) utilized 4 RNs. The third case \((C_C)\) utilized 8 RNs. The fourth case
(C_D) utilized 12 RNs. In all cases, the coordinates of RNs were given at pre-defined positions as the hollow circle in Figure 6. In Figure 6, 12 solid circle (P_1~P_12) were designated as the coordinates of RNs and were chosen as the check points for the location tracking of BN. At each designated position \([P_k=(x_k, y_k)]\), we measured 6 pairs of location estimations \((x_m, y_m)\) and compared their mean value to the designated coordinates \((x_k, y_k)\) to get the estimation deviation. The deviation is defined as \(e_k=[(\Delta x_k)^2+(\Delta y_k)^2]^{1/2}\), where \(\Delta x_k=x_m-x_k\), \(\Delta y_k=y_m-y_k\).

\[
\begin{array}{|c|c|c|c|c|}
\hline
\text{Case} & \text{Mean Deviation (meter)} \\
\hline
A & 1.4 \\
B & 2.4 \\
C & 1.3 \\
D & 0.7 \\
\hline
\end{array}
\]

The results of deviations at each check points of all cases were shown in Figure 7. In Figure 7, the value within the parentheses of each case is the averaged deviation of all measured positions. Smaller averaged deviation means better performance. Thus, C_D with 12 RNs achieved the best precision in location estimation. C_B had two singular estimation values, so it became the worst one. Excluding these two singular points, C_A would have the lowest precision because it utilized only 3 RNs.

4. CONCLUSIONS

WSN can be applied in environment inspection, control, security, and location tracking. In this research, we chose ZigBee as the WSN and developed location estimation software to track the position of a mobile blind node. The results of location tracking experiments showed that using 12 reference nodes could achieve 0.7 meters deviation. This is higher that the theoretic value 0.25. RSSI smoothing algorithm may be a way to improve estimation precision.

REFERENCES

ZigBee Alliance (2006), ZigBee Specification.