Proposal and Implementation of Coordinate Integrations for Heterogeneous Network Protocols

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Abstract - Location estimation is important for ad-hoc and sensor networks. Existing localization techniques assume to be operated in a single network protocols. We propose coordinate integrations for heterogeneous network protocols. The fundamental concept underlying coordinate integrations is that sets of coordinates is iteratively integrated by using at least three shared nodes in two-dimensional space so that coordinates generated in different network protocols become compatible across the networks. We used a simulation to demonstrate the proposed coordinate integration. We also present details of implementations on sensor nodes and experimental results for RSSI measurements inside a university building.

Keywords: Localization, location estimation, sensor networks, heterogeneous networks, ad-hoc networking

1 Introduction

Ad-hoc networking enables a wireless network to be constructed without an infrastructured base station. Ad-hoc networking also enables nodes to relay a data using multi-hopping. Emerging products of sensor networks such as Zigbee use ad-hoc networking capabilities over IEEE 802.15.4 [6]. Other wireless networking technologies such as wireless local area Networks (WLANs) and bluetooth support ad-hoc networking over IEEE 802.11 [4] and 802.15.1 [5].

Localization is an attractive functionality of using ad-hoc networking capabilities, which enables nodes to estimate their positions. The motivation for developing a localization technique is to inform an observer of the many deployed node positions with a small number of anchor nodes whose positions are known in advance. Location information is not only used for bundling sensing events with their locations, but also for improving network performance.

Anchor-free localization was proposed in [11], and it has received much attention. The advantage of the anchor-free localization is that it enables nodes to estimate their positions without using anchor nodes. The set of node coordinates is relatively determined, and hence it assigns an arbitrary relative coordinate system in each network protocol.

Assume that the nodes are deployed over a field and that they have incompatible network protocol. When anchor-free localizations are applied to heterogeneous network protocols that have different network protocols coexisting, one coordinate system is incompatible with other coordinate systems. This is because the set of node coordinates is relatively determined. Therefore, nodes cannot use location information obtained using anchor-free localizations across other network protocols.

In this paper, we propose coordinate integrations for heterogeneous network protocols. Sets of estimated coordinates in heterogeneous network protocols are iteratively integrated using nodes that physically share same coordinates on different network protocols. The coordinates are then compatible for heterogeneous network protocols. We first conducted simulation evaluation to verify the proposed coordinate integration. We are currently implementing functionalities of proposed coordinate integration on sensor nodes, and present details of the implementation.

This paper is organized as follows. Related work and localization issue in heterogeneous network protocols are described in Section 2. Proposed coordinate integration is presented in Section 3. An evaluation of coordinate integration using simulation is presented in Section 4. A detail of our implementations of coordinate integration is presented in Section 5. Results for RSSI experiments are reported in Section 6. Section 7 concludes the paper and mentions future work.

2 Related work and issue

2.1 Related work

Localization techniques have been discussed for wireless multi-hop networks such as sensor and ad-hoc networks. The motivation behind developing multi-hop localization is wanting to know where the node position is in wireless multi-hop networks by using a small fraction of the anchor nodes. An anchor node is one whose position is known in advance through means such as global positioning system (GPS). A simple solution to obtaining location information is to equip each node with a GPS receiver. However, a GPS receiver cannot always receive signals from GPS satellites when it is located in a building, and it enforces equipment costs for nodes. Much research has been conducted on how to estimate node positions in wireless multi-hop networks. Most localization techniques can be categorized into two types. The first is localization by using extra ranging devices, such as ultra sound devices, and the second is localization without using extra ranging devices.

AHLoS [10] is the distance-measurement localization approach using ultra-sound ranging devices. In AHLoS, at least three anchor nodes iteratively conduct multilateration to estimate unknown node positions. Once the positions for unknown nodes are estimated by anchor nodes, the nodes are

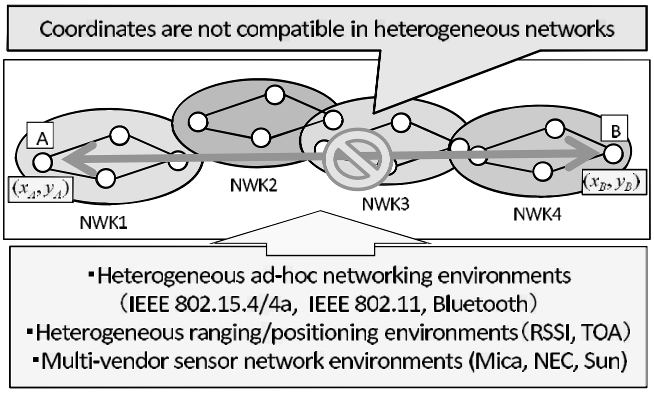


Figure 1: Localization issue in heterogeneous network environments.

configured as pseudo-anchor nodes and estimate unknown nodes that remain in the network. In sweeps [13], algorithms to identify global rigidity were employed to estimate the node positions without flipping for sparse node networks. The distance-measurement approach normally achieves precise positioning accuracy. However it requires extra ranging devices, increasing the cost for all nodes.

The localization scheme without using extra ranging devices has been developed for large-scale sensor networks, and it exploits connectivity information of multi-hop networks. In DV-Hop [9], the positions for unknown nodes in a network are estimated by using trilateration using average hop-count distances from at least three anchor nodes. In anchor-free localization (AFL) [11], the positions of unknown nodes are estimated without using anchor nodes. The basic idea behind AFL is to select reference nodes that represents the relative axis in a network and they determine relative node positions based on the hop-counts from their reference positions..

Some research proposed to use multidimensional scaling (MDS) [12, 14] to estimate node positions. MDS is the statistical technique to obtain geographical representations of data from data proximity. Since distance information can be used as data proximity, MDS can plot the relative coordinates of nodes in a network. Basic idea to apply MDS to localization technique is that node collects distance information such as hop-count and TOA measurement and calculates relative node positions by using MDS.

The localization scheme without using ranging devices enables nodes to estimate node positions while only using the radio capabilities of a sensor node. Hence, it has great flexibility to enable nodes to be applied to localization in the network. However, existing localization techniques are assumed to be operated in single network protocols.

2.2 Localization issue in heterogeneous network environments

Figure 1 presents a localization issue in heterogeneous network environments. Some localization techniques require anchor nodes that have the unique original point of the coordinate system. For example, GPS has the original point that is centroid of earth in the coordinate system. The coordinate system has the original points in its own network, however these coordinate system can be arbitrary determined in the network. In addition, in anchor-free localization, the estimated coordinates are relatively determined and original points are arbitrary determined. Therefore, coordinate systems that are generated by using localization techniques in different network protocols are not compatible with each other. Especially, localization technique using ad-hoc networking capability can be more general technique for position estimations since anchor-free localization only requires ad-hoc networking capability to estimate node positions. Currently, several IEEE standardized networking protocols such as IEEE 802.11 [4], IEEE 802.15.4 [6], IEEE 802.15.1 [5] (bluetooth) supports ad-hoc networking capability. However these networking protocols are not able to communicate with different network protocols. In the sensor networks, networking protocols such as Zigbee [1] have been standardized. Several vendors such as MICA and NEC have released sensor nodes in market. However, one vendor's sensor node cannot communicate with another vendor's sensor node. In heterogeneous network protocol environments, we encounter an issue that one set of coordinates generated by a network cannot be used in another network as shown in Fig. 1. Hence, a mechanism that converts coordinates generated in heterogeneous network into one set of coordinates that is compatible across the networks is required.

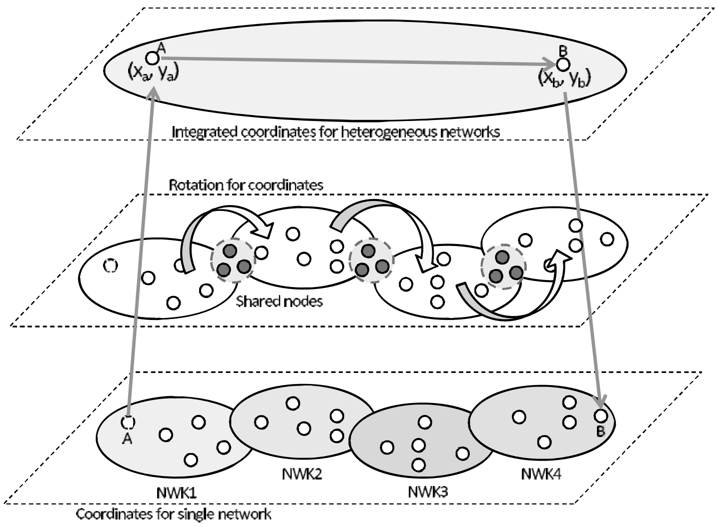


Figure 2: Conceptual illustration of proposed coordinate integrations.

3 Coordinate integrations for heterogeneous network protocols

3.1 Overview

Figure 2 shows a conceptual illustration of proposed coordinate integrations. We consider that heterogeneous network protocols are coexisted in a field as shown in bottom of Fig. 2. Each network protocol conducts localization techniques by using ad-hoc networking capability. In the coordinate integration, coordinates estimated by each localization protocols are integrated by using at least three shared nodes as shown in middle of Fig. 2. The shared node is the node that physically

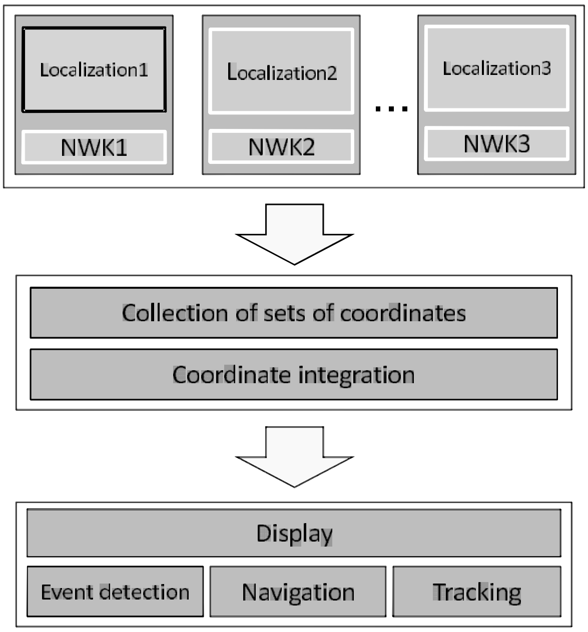


Figure 3: Logical organization for proposed coordinate integration.

shares same coordinates in different network protocols. Some nodes in different network protocols are set as shared nodes for the coordinate integration. The integrated coordinates are compatible with different network protocols and they can be accessed by users as shown in top of Fig. 2.

Coordinate integrations for heterogeneous network protocols are conducted as follows.

1. **Coordinate assignments:** Each node in the heterogeneous network protocols estimates its relative or absolute node coordinates within its network protocol. Developing the precise localization algorithm is not our focus for this paper. Reader may refer to the literature [11].

2. **Coordinate conversions:** The orientations of two sets of coordinates are adjusted into one set of coordinates by using three or more shared nodes. The coordinate conversion requires rotation, flipping and translation operations. Here, we used procrustes analysis [16] for the coordinate conversions.

3. **Coordinate integrations:** Two sets of coordinates in different network protocols are integrated into one set of coordinates. The other sets of coordinates are iteratively converted and integrated into one set of coordinates. The coordinate system is then compatible for heterogeneous network protocols.

Figure 3 presents the logical organization of proposed coordinate integration. When nodes in heterogeneous network conduct a localization technique, one set of coordinates of network that is incompatible is generated (top of Fig. 3). One localization server collects all sets of coordinates of networks, and conduct coordinate integration to be compatible with each other (middle of Fig. 3). The coordinates that is compatible with heterogeneous network protocols are available for application such as event detection, tracking and navigation regardless of the network protocols (bottom of Fig. 3).

3.2 Algorithm

The objective of proposed coordinate integration is to convert sets of coordinates that are incompatible with other coordinates of networks into a set of coordinates that is compatible with other coordinates of networks. Therefore, localization technique to obtain estimated coordinates is not our main focus of the proposed coordinate integration. In this work, we assumed to use MDS that can obtain the relative coordinates of networks from distance measurements such as RSSI.

MDS [16] is statistical technique used to analyze proximity data in multidimensional space. The proximity data for MDS can be represented by geographical expression. Therefore proximity matrix that is constructed by using node distances can be transformed to the relative coordinate system by using MD.

MDS to obtain relative coordinates from node distance is operated as follows. First a node constructs the squared distance matrix,

$$\mathbf{D}^{(2)} = \{\hat{d}^2_{\{k,l\}}\}, \tag{1}$$

where the number of nodes is n and the node distance between (i, j) is denoted by d_{ij}. Multi-hop distances are approximated by using hop-couting. The scalar product matrix, $\mathbf{B}$ is constructed by applying double centering as

$$\mathbf{B} = -\frac{1}{2}\mathbf{J}\mathbf{D}^{(2)}\mathbf{J}, \tag{2}$$

where $\mathbf{J} = \mathbf{I}_n - \frac{1}{n}\underline{1}\underline{1}^T$ and $\underline{1}$ is an n by 1 vector of ones and n is the length of $\mathbf{D}_i$. A singular value decomposition is conducted as

$$\mathbf{B} = \mathbf{U}\mathbf{\Lambda}\mathbf{U}^T. \tag{3}$$

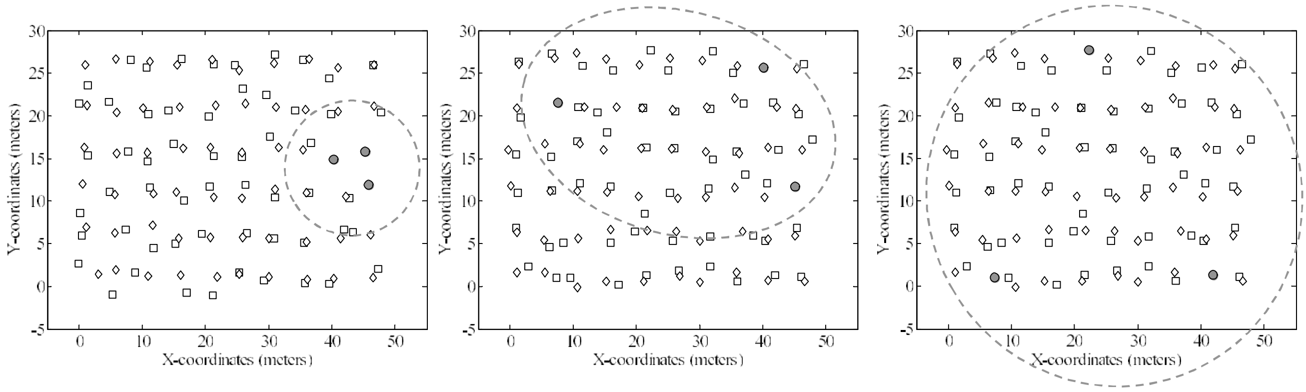
A coordinate matrix is then given by $\mathbf{X} = \mathbf{U}\mathbf{\Lambda}^{1/2}$. Node position $P_i^0(x_i^0, y_i^0)$ is obtained by extracting the first and second columns of $\mathbf{X}_i$.

When the coordinate system is relative such as MDS or the original points of coordinate systems are different, coordinate systems are not compatible with each other. In order to address this issue, we used procructes analysis [16] to rotate sets of coordinates. Procrustes analysis for coordinate rotation is operated as follows. Consider that two sets of coordinates X, Y that are not compatible with each other. Each set of coordinates is represented by matrix. Two sets of coordinates assume to have at least three shared coordinates. Objective of rotation operation of coordinates is to derive rotation matrix $\mathbf{T}$. First two sets of coordinates are multiplied as $\mathbf{A} = \mathbf{X}^T\mathbf{Y}$. We then calculate singular value decomposition for matrix $\mathbf{A}$ as $\mathbf{A} = \mathbf{L}\mathbf{D}\mathbf{M}^T$. The rotation matrix for coordinates is then derived as

$$\mathbf{T} = \mathbf{M}\mathbf{L}^T. \tag{4}$$

The coordinates Y can be compatible with coordinates X by

$$\mathbf{Z} = \mathbf{T}^T\mathbf{Y} + c, \tag{5}$$



(a) Min neighbor (b) Random (c) GDOP-based

Figure 4: Shared node placements for different selection methods. (a): Min neighbor method, (b): random method, (c): GDOP-based method. Nodes for two different network protocol represented by squares and diamonds are overlapped. Shaded circles indicate shared nodes.

where c is translation component. Finally, in order to derive the coordinates $\mathbf{R}$ that is compatible with X, Y, two set of coordinates are integrated into one set of coordinates by averaging as

$$\mathbf{R} = \frac{1}{2} * (\mathbf{X} + \mathbf{Z}). \tag{6}$$

Sets of coordinates are repeatedly integrated for other coordinates of networks based on shared nodes.

3.3 Placement for shared nodes

3.3.1 Min neighbor method

In the coordinate integration, at least three shared nodes that have same coordinates for different networks are required. Here we discuss three methods on placements for shared nodes.

Figure 4 shows three patterns of node placements for shared nodes. In Fig. 4, nodes for two different network protocol represented by squares and diamonds are overlapped and coexisted in a field. Shaded circles indicate shared nodes.

One possible method for determining shared node placement is min neighbor. In min neighbor methods, one node is randomly selected and other two nodes that are closest to it are selected as shown in Fig. 4(a). The advantage of the method is that it can be easy to place the share nodes for heterogeneous network environments.

3.3.2 Random method

Random method is that nodes for shared coordinates are randomly selected as shown in as shown in Fig. 4(b). The random method suggests that user does not take care of location for share nodes.

3.3.3 GDOP-based method

GDOP-based method selects shared nodes based on the geometrical dilution of precision (GDOP) [8]. GDOP was used to indicate the geometric conditions of the anchor nodes (i.e., GPS satellites in GPS) defined as the following equation.

Table 1: Simulation parameters.

Parameter	Value
n_p	2.5
P_t	$-50.0 - -35$ (dBm)
σ^2_{dB}	5.0(dB)
Receiver sensitivity	-73.0 (dBm)

$$GDOP = \sqrt{\frac{N_A}{\sum_{i \in S_A} \sum_{j \in S_A, j>i} A^2_{ij}}}, \tag{7}$$
$$A_{ij} = \sin \theta_{ij}.$$

In Formula (7), N_A indicates the number of anchor nodes, and S_A is the set of anchor nodes, and A_{ij} is the angle from an unknown node to anchor nodes $\{i, j\}$. When GDOP is small value, condition for anchor node to estimate unknown node would be good. GDOP takes small value when the area of anchor nodes is larger as shown in Fig. 4(c). GDOP-based method selects three nodes that have minimum GDOP when all nodes are assumed to be anchor nodes.

4 Simulation

4.1 Simulation setting

We tested the coordinate integrations using a simulation. The objective of using the simulation is to demonstrate the coordinate integrations for heterogeneous network protocols before the implementation. Simulation tool we used was Matlab. We assumed to use the received signal strength (RSS) to measure the distance. The RSS measurement can be modeled as [15]

$$P_r = P_t - 10 n_p \log_{10}(\frac{d}{d_0}) + X_\sigma. \tag{8}$$

$\overline{P_0}$ (dBm) is the mean signal strength and P_t (dBm) is the received signal strength at reference distance d_0. X_σ is zero-

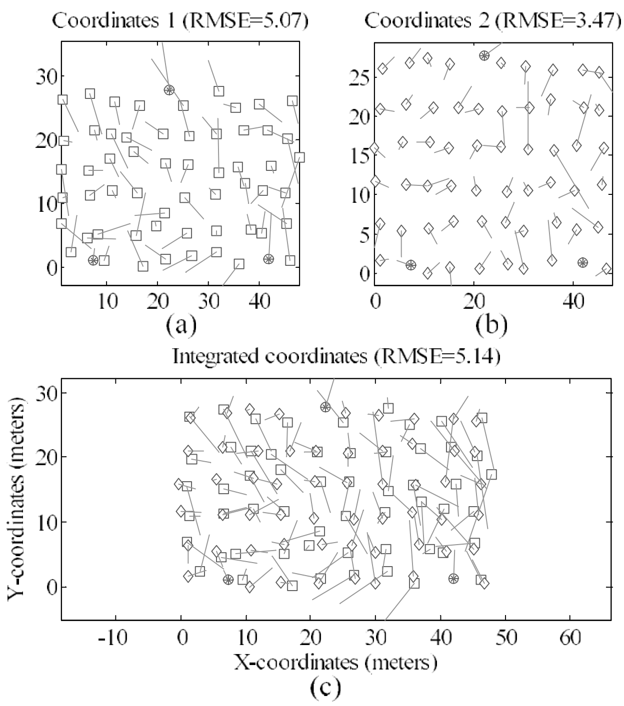


Figure 5: (a, b): relative coordinates systems for network 1 and 2. (c): relative coordinates system after coordinate integration. Actual node positions on network 1, 2 are represented by squares and diamonds, and their shared nodes are represented by asterisks. Errors are drawn by solid lines

mean Gaussian distribution with variance σ_{dB}^2 for the lognormal shadowing, and n_p is path loss exponent determined in the measurement environment [15]. Table 1 shows the parameters used in the simulation. $n_p = 2.5$ and $\sigma_{dB}^2 = 5$ were chosen in the simulation. Field size of node placement is 30 (height) × 50 (width) [m^2]. We assumed two vender sensor networks that are incompatible with each other are deployed in the filed. The number of nodes on each network was 60.

4.2 Results

Figures 5(a)(b) show each set of estimated positions using the MDS, and Fig. 5(c) shows the integrated coordinates of two networks. The shared nodes are selected by using GDOP-based methods. The two sets of estimated coordinates in different network protocols were successfully integrated into one set of coordinates based on coordinates of shared nodes by using procrustes analysis. We defined root mean square error (RMSE) as follows

$$\mathbf{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\{(X_i - X_i^t)^2 + (Y_i - Y_i^t)^2\}}, \quad (9)$$

where $(X_i, Y_i), i = 1 \ldots N$ is estimated node position and (X_i^t, Y_i^t) is actual node position. RMSE of coordinates 1, 2 and integrated coordinates were 5.0, 3.4, and 5.1 (m), respectively.

Figure 6 shows average RMSE plotted with varying node connectivity. Node connectivity shows how many nodes connect to other nodes in 1-hop on average, and it is varied by increasing communication range, i.e., increasing P_t. As shown in Fig. 6, GDOP-based method achieved best performance of other methods. GDOP-based method selects the three shared nodes that has larger regular triangles. This avoids flipping that has the wrong orientation of integrating two coordinate. On the other hand, min neighbor method had poor performance. This is because the integrated coordinates of two networks includes flipping results. Our simulation results only cover simple scenarios of integrating two coordinate systems. We are currently planning to conduct simulations with more complex scenarios including a mixed TOA/RSSI and different localization algorithms such as trilateration in large-scale heterogeneous networks. The detailed characteristics for coordinate integrations will be analyzed in the simulations.

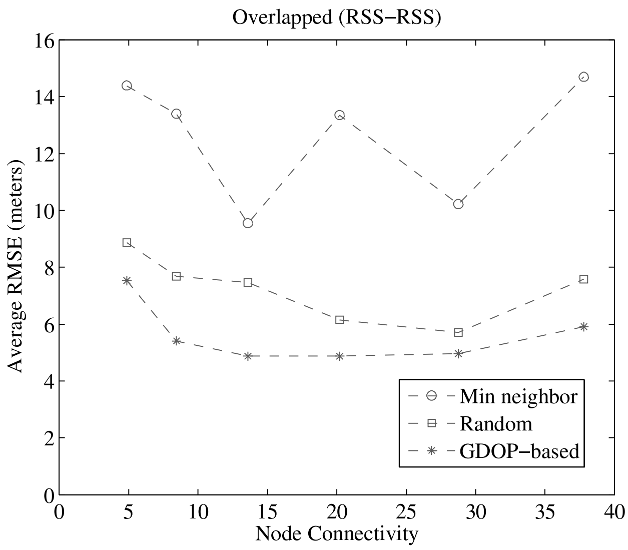


Figure 6: Average RMSE against node connectivity.

As shown in Fig. 6, GDOP-based method increased the RMSE when the node connectivity was over 20. One explanation for this result is that attenuation model of RSS used in Formula (8) gets slower and variances get larger when the communication range is longer. Hence, when the communication range is increased, RMSE gets wrong. The result suggests that nodes are required to vary communication range to achieve less RMSE.

We discuss potential applications of using location information provided by the localization technique in sensor networks. Supporting location information in sensor networks enables us to develop many kinds of location-based applications such as firefighter navigation and equipment monitoring [7]. Our target application of localization technique is a smart air conditioning system using sensor networks [17]. Existing air conditioning system only utilizes single sensor such as infra-red (IR) to measure temperature in a room and the sensing coverage is limited. The smart air conditioning system called "i-fan" uses sensor networks to measure temperature and the corresponding location by using localization techniques. Although it is future work whether i-fan satisfies the location accuracy provided by our localization system, we are aiming to develop such location-based application.

Table 2: Basic specifications for Renesas and SunSPOT sensor nodes.

	Renesas node	SunSPOT
RF module	Freescale MC13202	TI CC2420
PHY/MAC	IEEE 802.15.4	IEEE 802.15.4
Frequency	2.405–2.48GHz	2.40–2.4835GHz
Receiver sensitivity	−92dBm	−95dBm

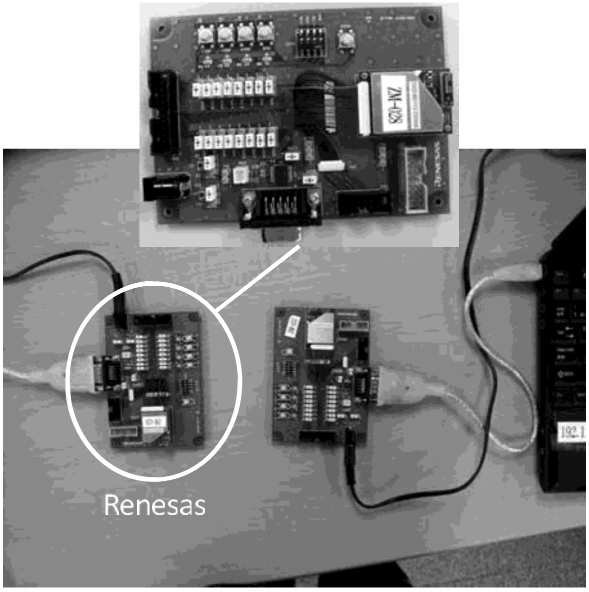


Figure 7: Snapshots of Renesas sensor nodes.

5 Implementation

Figure 8: Snapshots of SunSPOT sensor nodes.

We are currently implementing functionalities of the proposed coordinate integration by using actually released sensor nodes. We used a sensor node developed by Renesas [2] and SunSPOT developed by Sun Microsystems [3]. Table 2 shows the basic specifications for the sensor nodes.

Figure 7 shows the snapshots of Renesas sensor nodes. Renesas node has a main board with serial interface of RS-232C

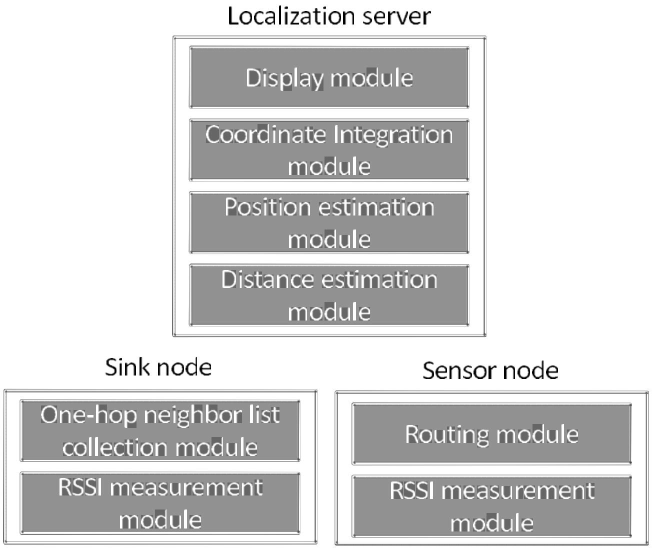


Figure 9: Required functionalities for coordinate integrations.

and equips with radio frequency (RF) modules. The RF module of Renesas node employs MC13202 developed by Freescale, and it uses IEEE 802.15.4 protocol for the PHY/MAC layers. The power is supplied by AC adapter. Renesas node provides a writable memory that a user can write the program. A user can control the microcomputer of Renesas node by writing the program. The RF module of Freescale has a functionality to store received signal strength indicator (RSSI) into registers on Renesas node. We implemented an output function of RSSI value by reading the registers of microcomputer on Renesas node.

Figure 8 shows the snapshots of SunSPOT. SunSPOT is the sensor node that can control the microcomputer by using Java program. SunSPOT has USB interface and the program can be written and debugged through the USB interface connecting to PC. SunSPOT can be operated by using battery on the board, and its power can be also supplied by using the USB cable. The RF module of SunSPOT employs CC2420 developed by Texas Instruments (TI), and it uses IEEE 802.15.4 protocol for the PHY/MAC layers. SunSPOT has **getRssi**() that is application programming interface (API) to extract the RSSI. We implemented an output function of RSSI by using the API.

Both Renesas and SunSPOT sensor nodes employ IEEE 802.15.4 protocol for PHY/MAC layer, however each protocol is only ensured to construct a sensor network within its own vender sensor nodes. One vendor sensor node cannot communicate with other vendor sensor node.

Figure 9 shows the software organization that is required to conduct the proposed integrated coordinates. Three types of nodes, i.e., localization server, sink node, and sensor node are required. We assume that a localization server execute the localization to estimate node positions. In order to conduct localization in multi-hop network, each sensor node needs to have a functionality to hold one-hop neighbor list. Each node is required to have functionalities to obtain RSSI, and relay the RSSI data to a sink node. A sink have the functionality to collect the one-hop neighbor list that is sent from sensor

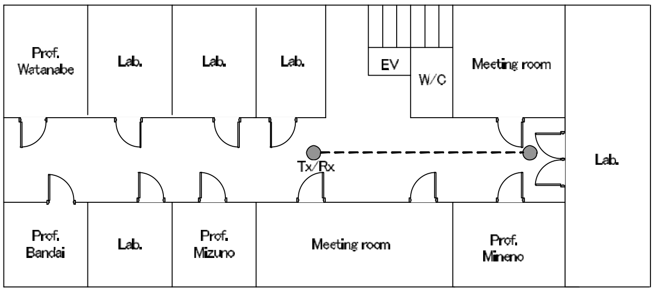


Figure 10: Floor map of RSSI experiment. Location is a corridor on the 4th floor of building in Faculty of Informatics in Hamamatsu campus of Shizuoka University, Japan.

nodes. A sink node connects to localization server, and sends the data to the server. Localization server estimates the distance from RSSI, and calculates node positions. Finally, node positions are displayed. Additionally, a functionality of data exportation of coordinates is required to implement in order to cooperate with other applications.

6 RSSI measurement experiment

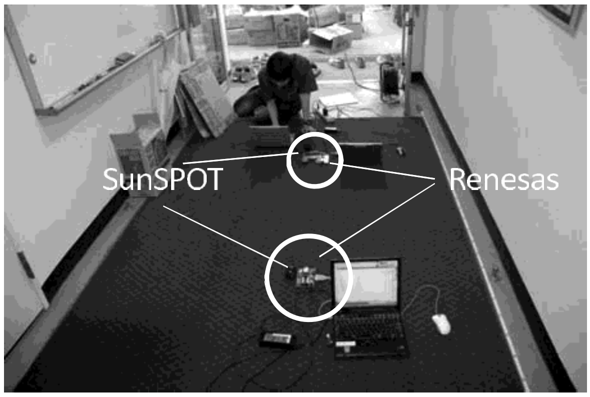
6.1 Environments

In our prototype development, a sensor node uses RSSI to estimate the distance between nodes and the position. Generally, RSSI is attenuated when the node distance is longer. Then, RSSI can be used for a parameter to indicate the node distance. The advantage of using RSSI is that it can be extracted for most sensor nodes since RSSI is available if a node has radio capability. Although RSSI can be used for distance estimation, attenuation degree of RSSI depends on multiple factors such as radio frequency and measurement environments. Therefore, we conducted experiments to know how RSSI is attenuated based on node distances. Figure 10 shows a floor map that we conducted RSSI measurement experiments. The experiment location is a corridor on the 4th floor of building in Faculty of Informatics in Hamamatsu campus of Shizuoka University, Japan. RSSI was measured inside the buildings (Fig. 11(a)). The building is made by reinforced concrete. SunSPOT and Renesas nodes were closely placed parallel as shown in Fig. 11(b). We observed RSSI measurements by increasing the distance between transmitter and receiver (Fig. 11(b)). Transmission powers of both nodes were set to -7(dBm). We observed RSSI measurements 1000 times at each measurement points.

6.2 Results

Figure 12 and Fig. 13 shows results for RSSI measurement of Renesas and SunSPOT against the distance. As shown in Fig. 12, most RSSIs of Renesas node were attenuated monotonously as the node distances were longer. The maximum measurement distance to exchange the packets for RSSI measurements was 10 (m). We finalized the experiment at 10 (m) since the packet losses were too many when the node distances were over 10 (m).

(a) Corridor for RSSI measurement



(b) Node placements for experiments

Figure 11: Snapshots of RSSI measurement environments.

It is noted that Fig. 12 and Fig. 13 appear that the number of plotted RSSI points are few. This is because RSSI values obtained from our experimental sensor platforms only read out in the form of an integer value. Much RSSI values are overlapped because of the integer format.

Figure 13 shows results for RSSI measurement of SunSPOT. RSSIs of SunSPOT were also attenuated as the node distances were longer. However, when the node distance was around 3 (m), RSSI was more attenuated than other points, which we could not observe in Renesas node even if the measurement location were same. The result suggests that attenuation of RSSI depends on each vendor of sensor node. The maximum measurement distance for SunSPOT was 7 (m).

RSSI value of Renesas at 1 (m) was -55 (dBm) and RSSI value of SunSPOT at 1 (m) was -25 (dBm) as compared in Fig. 12 and Fig. 13. The result suggests RSSI values are not compatible with vendors of sensor nodes. We need the calibration mechanism to use RSSI values for multi-vendor sensor network environments.

7 Summary

In this paper, we proposed the coordinate integration for heterogeneous network protocols. In the heterogeneous network environments, we revealed an issue that coordinates generated by localization techniques in one network protocol is not compatible with other coordinates generated by another network. This issue is happened when original point for coor-

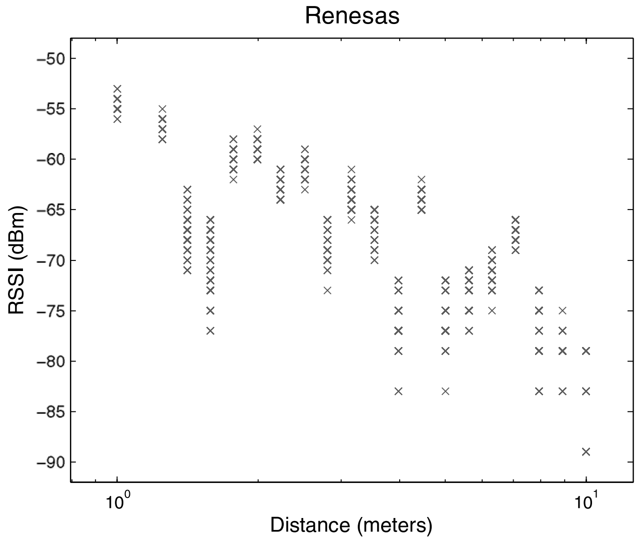


Figure 12: Experimental results of Renesas for RSSI measurements.

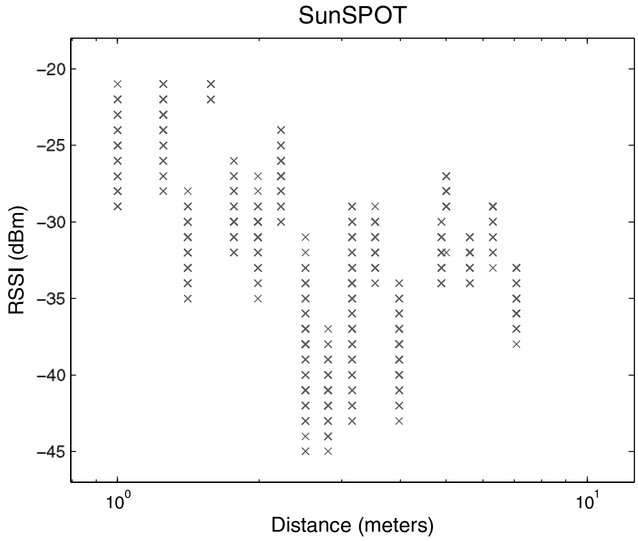


Figure 13: Experimental results of SunSPOT for RSSI measurements..

dinates of anchor nodes is not same as other coordinates of anchor nodes or when the coordinates are relatively determined by using anchor-free localization technique. In such environments, we described coordinate integration that each coordinates can be compatible when at least three share nodes that share the same coordinates are used. We used the simulation to verify that the operations of coordinate integration worked well. Simulation results revealed that placements for shared nodes had impacts on the positioning accuracy in proposed coordinate integrations. We also conducted RSSI measurement experiments inside the university building, and it was revealed that RSSI values were not compatible when vendors of sensor nodes were different.

We are currently implementing functionalities of proposed coordinate integration on Renesas and SunSPOT sensor nodes. In future work, we specify attenuation function of RSSI for multi-vendor sensor networks environments. We plan to evaluate the proposed coordinate integration for heterogeneous network protocol environments in the real environments.

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