A Simulation Study for Position Estimation of Multiple Devices in 2D Communication System

Youiti Kado, Toshifumi Oota, Azman Osman Lim, and Bing Zhang
National Institute of Information and Communications Technology
3-5 Hikaridai, Seika-cho, Soraku-gun, Kyoto, 619-0289, Japan
{kado, oota, aolim, zhang}@nict.go.jp

1. Introduction

Targeted devices that embedded with a RFID tag can be sensed whether they are in the sensing range of a RFID reader. When a radio wave from the tag is precisely measured and the surrounding radio environment is stable enough, the position of the tag can be estimated. However, as for in the space, there are so many factors such as reflection, atmospheric absorption, attenuation, etc that severely affect the stability of radio environment. In the two-dimensional (2D) communication system [1], such aforementioned factors are limited because the radio wave spreads out evenly throughout the surface. The 2D communication system consists of a specially structured sheet that allows its surface to propagate the radio wave and of devices equipped with a coupler that puts the radio wave in the sheet and/or draws out the radio wave from the sheet. In this paper, we conduct a simulation study to validate the position estimation of multiple devices, which placed on the surface of the 2D communication sheet by using a MATLAB simulator.

This paper is organized as follows. The next section explains the related works of 2D communication system. In Section 3, we introduce the system architecture and the radio propagation model that used in our simulation. We show some sampling data by using the maximum likelihood estimation and discuss the obtained simulation results of position estimation margin in the Section 4. Finally, we conclude this paper.

2. Related Works

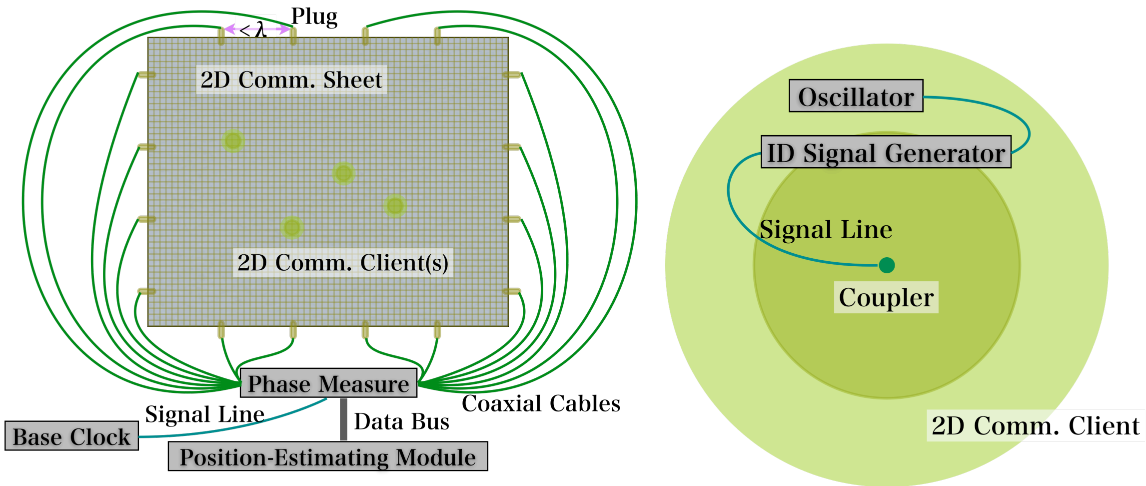
Tables or shelves are used for putting various objects on the top of them, and sensing the position of such objects is a challenging issue of the ubiquitous computing. In "Networked Surfaces" system [2], the surface is covered with tile-like conductive pads, which are operated as separate data buses. A client object is equipped with small conductive pads circle-wise at the bottom. The system is designed to sense the location and rotation of one object, but the system cannot sense many objects at the same time.

"Smart Table" that introduced in the "Smart Kindergarten" project can track and identify multiple objects simultaneously when placed on top of its surface [3]. The table consists of 24 printed circuit boards (PCBs) that connected to one serial bus. Each PCB contains 400 sensors, thus 9600 sensors in total for the entire area of the table. The sensors detect a magnetic field of a magnet tape or a metal contact. Each object has three magnet tapes or metal contacts on the back of it. The three magnet tapes or metal contacts that formed an isosceles triangle, are used to identify the position and orientation of object. In the Smart Table, position accuracy is proportional to the sensor grid density. As a result, a huge amount of sensors are necessary for the Smart Table.

In [4], the 2D communication system is applicable to sense position of multiple objects by introducing a uniquely pattern mesh conductive layer on the sheet. The objects are assumed that they can scan the unique pattern by miniature electric field probe. This concept is similar to the 2D bar code system, however the cost for designing the sheet can be high at present as the electric field scanning is more complicated than the optical scanning.

3. System Architecture and Radio Propagation Model

We propose new system architecture of 2D communication system for position estimation as shown in **Figure 1**. Arrayed plugs are installed at the sides of 2D communication sheet. A device, so called as a 2D communication client that placed on the sheet is assumed that it can generate a radio wave, which travels inside the sheet to the plugs and then the radio wave travels from the plugs to the phase measure unit via the coaxial cables. The radio wave's phase from different plugs that are measured separately in the position-estimating module and the position of the device is estimated by using the maximum likelihood method.



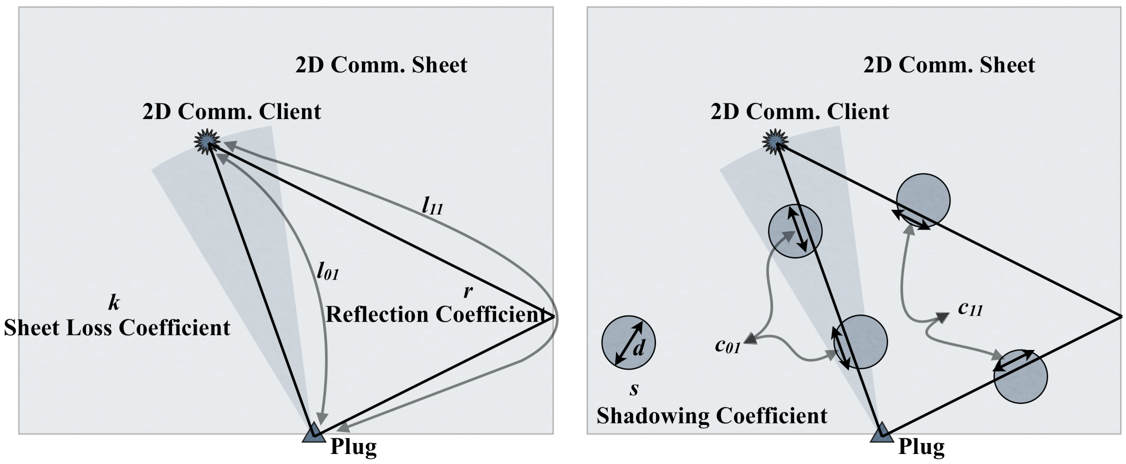
(a) Overall System (b) 2D Comm. Client

Figure 1: System Architecture for Position Estimation

In the position-estimating module, the propagated radio wave through the sheet can be modelled according to the signal attenuation across the 2D medium, in which the strength of the propagated radio wave from the device to the plug falls off with distance. We modify the Friis free space equation for 2D radio propagation model as follow:

$$10 \cdot \log_{10} \frac{\lambda \cdot k^{l}}{(2\pi)^{2} l} \qquad [\mathrm{dB}] \tag{1}$$

Equation (1) includes the sheet loss coefficient, k as illustrated in **Figure 2(a)**.



(a) Sheet Loss and Reflection (b) Shadowing

Figure 2: Radio Propagation Model for 2D Communication Medium

We take into account the reflected coherent waves, which bounded at the sides of the sheet as the reflection coefficient, r. Furthermore we consider the shadowing effect, in which the shadowing coefficient, s. In the shadowing effect, the path of the propagated radio wave from a device to a plug is chorded by the cross length of the shadowing device. We assume that the diameter of circular device is *d* and the total sum of the cross length of the shadowing devices is *c*. Then, the path strength of the propagated radio wave is diminished in the proportion of $s^{-c/d}$ as shown in **Figure 2(b)**. Therefore, the propagated radio wave that travelling from a device to a plug in 2D communication sheet can then be formulated as:

$$\frac{\sqrt{\lambda \cdot P_t}}{2\pi} \cdot \left(\sum_{n=0}^{\infty} \sum_{m=1}^{(n+1)^2-n^2} \sqrt{\frac{k^{l_{nm}} \cdot r^n \cdot s^{\frac{c_{nm}}{d}}}{l_{nm}}} \cdot \left(\cos\left(\frac{2\pi}{\lambda} \cdot l_{nm} + \omega t \right) - \sin\left(\frac{2\pi}{\lambda} \cdot l_{nm} + \omega t \right) \cdot i \right) \right). \quad (2)$$

Since the propagated radio waves at all plugs are coherent wave to each other, the phase differences between the propagated waves at different plugs are obtained through the MATLAB.

4. Simulation Results

We conduct two simulation scenarios to evaluate the shadowing effect based on the device arrangement. In Scenario 1, we place 12 shadowing objects and one 2D communication client with a diameter of 6 cm on top of the sheet. Those objects in this scenario could be assumed as the pocket-sized devices that placed on the table. We compute the position estimation margin of the 2D communication client when it is moved at 1-cm-resoluation along both axes of the entire sheet except the position of the shadowing object. In Scenario 2, assuming that objects are small items that placed on the showcase, we place 80 shadowing objects and one 2D communication client with a diameter of 4 cm. Other parameters and settings used in the simulation are listed in **Table 1**.

Table 1: Simulation Parameters and Settings

Simulation Software	MATLAB® 7.8.0.347
2D comm. Sheet Size	100 cm × 80 cm
Sampling Resolution	99 × 79 (1 cm^2)
Sheet Loss Coefficient : *k* Reflection Coefficient : *r* Number of Reflections	–0.458 dB/m (*k* = 0.9 [1/m]) 0.1; 0.5; 0.9 per one reflection 6 times
Directivity of Coupler and Plug Carrier Radio Wave	Omni-directional Frequency is 2.5 GHz (Wavelength is 12 cm)
Plug Arrangement at the Sheet Side	4 × 4 plugs with 6 cm intervals
Diameter of 2D Comm. Client and Objects : *d* Object Arrangement Shadowing Coefficient : *s*	6 cm (Scenario 1); 4 cm (Scenario 2) 3 × 4 (Scenario 1); 8 × 10 (Scenario 2) 0.7 per length of diameter size

In **Figure 3**, the simulation results are plotted according to the position estimation margins with a 64-step gray scale. The position estimation margin is the distance from the estimated location to the center of the 2D communication client. When the position estimation margin is more than 10 cm, the dot is plotted in white color. For the area that covered by the shadowing objects, the dots are plotted in black color. Therefore, we can see 12 black circles in the simulation results of Scenario 1 and 80 black circles in the simulation results of Scenario 2. For both scenarios when the reflection coefficient is set to 0.9, the simulation results show that many bright dots compared to the reflection coefficient is set to 0.5 and 0.1. We can conclude that the position estimation accuracy will increase proportional to the reflection coefficient is getting low. In practical use, we can use a wave absorber that mounted at the sides of the sheet to reduce the reflection coefficient. To further examine the simulation results, we plot the distribution of the position estimation margins for each scenario as shown in **Figure 4**. We can observe that when the number of objects that placed on the sheet decreases, the position estimation accuracy becomes a fair for the real implementation of the 2D communication system in any extent of the reflection coefficient.

5. Concluding Remarks

In this paper, we conducted the simulation studies to validate the system architecture of the position estimation for multiple devices, which placed on the surface of the 2D communication sheet through the MATLAB simulator. The simulation results reveal that a fairly accuracy for position estimation can be achieved in the 2D communication system when both the reflection coefficient and the number of placed devices are small.

References

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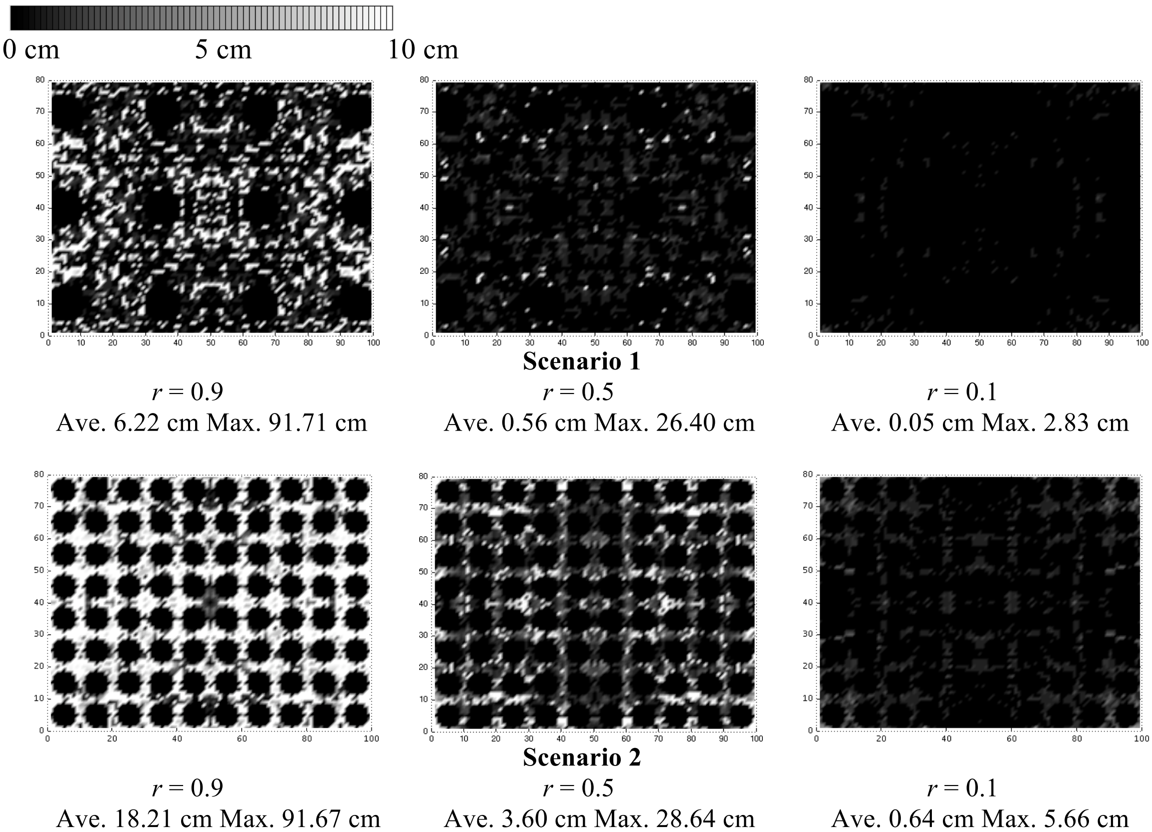

Figure 3: Contour Plot of Position Estimation Margin

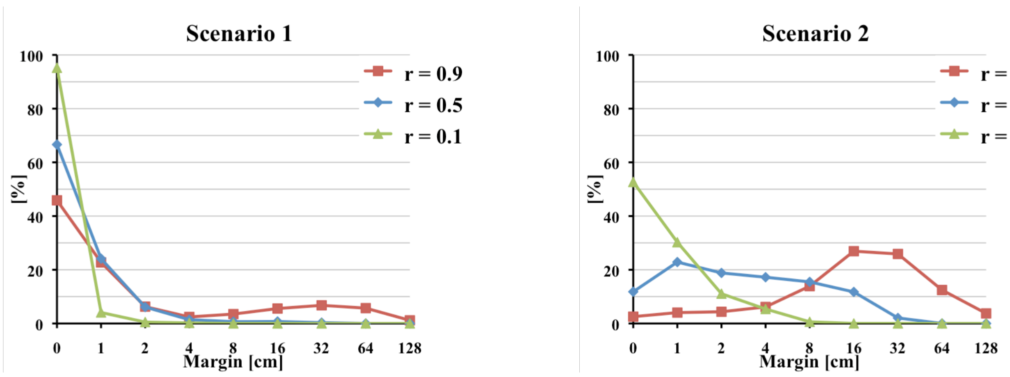

Figure 4: Distribution of Position Estimation Margin