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Target Localization via Correlated Link Inference

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***Abstract*— We propose a new approach for target localization via correlated link inference. The proposed method takes advantage of the motion-induced difference of received signal strength(RSS) made in a wireless peer-to-peer network. By using the multipath channel model, the signal strength on a wireless link is largely dependent on the power contained in multipath components that travel through space containing moving targets. The effect of target obstruction is dominated by RSS attenuation and RSS enhancement. We locate targets by imaging both RSS attenuation and RSS enhancement. Experimental results with 14 nodes RF sensor network deployed in indoor office environment are presented.**

***Index Terms*— Device-Free Localization, Radio Tomographic Imaging, Correlated Link Inference**

I. Introduction

Location finding is an important application of wireless sensor network (WSN). Traditional approaches need to carry a device, such as frequency identification (RFID) and GPS. Recently, device-free localization (DFL) has attracted much attention in WSN research community [1]. Wilson and Patwari developed a new technology for DFL, referred to radio tomographic imaging (RTI) [2], [3]. RTI utilizes the attenuation of received signal strength (RSS) caused by targets in wireless network to image moving targets. The signal strength on a wireless link is largely dependent on the power contained in multipath components that travel through space containing moving targets. The difference of RSS caused by moving targets on links between many pairs of nodes can be used to image targets within the wireless network area. The RSS measurements used in RTI are based on shadowing model [2], [3]. Shadowing based RTI is reliable for outdoor environment. For heavily obstructed area in indoor environment, Wilson and Patwari developed an extension of RTI for through-wall motion tracking, referred to variance-based radio tomographic imaging (VRTI) [4]. VRTI utilizes RSS variance as an indicator of motion based on multipath channel model. In this paper, we utilize the difference of RSS in correlated links to infer the locations of targets. It integrates the difference in average signal strength and multipath channel model used in RTI and VRTI respectively. For indoor environment, most jitter of the wireless signal are caused by the presence of the targets near the wireless links. some of the multi-path components may be affected, and links which pass though that target will experience shadowing losses. When target appear in network area, some wireless multi-path components may be reflected by the target and arrive receiver, so the link's RSS value of between this pairs node has a slight strengthening. Motivated by this observation, we classify the difference of RSS into two parts: RSS attenuation and RSS enhancement. We locate targets by imaging both RSS attenuation and RSS enhancement via correlated link inference.

The rest of the paper is organized as follows. The linear formulation of RTI is reviewed in section II. After that, section III details the proposed approach. Experimental results on real-data are reported in section IV. We conclude this paper in section V.

II. Radio Tomographic Imaging

Given a RF sensor network, the RF signal is affected by the presence of the targets near the wireless links. We can infer the location of attenuating targets from pairwise RSS measurements which caused by shadowing correlations between links. The network area is partitioned off into a grid of pixels $\mathbf{x} \in \mathbb{R}^n$. The amount of radio power attenuation describes each pixel's value. The attenuation of unique two-way links (the communication between any pair of distinguishable nodes.) can be denoted as $\mathbf{y} \in \mathbb{R}^m$. This can be formulated as a linear model, give the form of

$$\mathbf{y} = A\mathbf{x} + \mathbf{n}. \tag{1}$$

The link shadowing is a linear combination of the values in pixels, plus noise $\mathbf{n}$. $\mathbf{y} \in \mathbb{R}^m$ is the RSS measurements described in next subsection . $A \in \mathbb{R}^{m\times n}$ is the weight matrix of the model parameters $\mathbf{x}$. Each row of the transfer matrix A on the link i can be expressed a weighted sum of the losses in each pixel.

A. RSS measurements

When wireless nodes communicate, the received signal strength (RSS) $y_i(t)$ of a particular link i at time t is denoted as

$$y_i(t) = P_i - L_i - S_i(t) - F_i(t) - v_i(t), \tag{2}$$

where

- P_i is the transmitted power in dB,
- L_i is the static loss in dB due to antenna patterns, distance, and device inconsistencies,

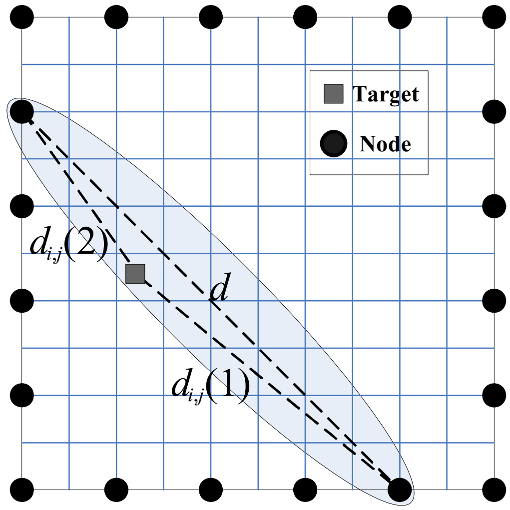

Fig. 1. Elliptical weight model, the weighted pixels for a single link in a RF sensor network are darkened in an ellipse with foci at each node location.

- $S_i(t)$ is the shadowing loss in dB caused by the targets which attenuate the signal,
- $F_i(t)$ is the fading loss in dB due to constructive and destructive interference of narrow-band signals in multipath communication,
- $v_i(t)$ is the measurement noise.

The shadowing loss $S_i(t)$ for each link can be expressed approximately as a sum of attenuation that causes in each pixel, as shown in Fig. 1. The mathematical form is given by

$$S_i(t) = \sum_{j=1}^{n} A_{ij} x_j(t), \tag{3}$$

where $x_j(t)$ is the attenuation in pixel j at time t, A_{ij} is the weight for pixel j for link i, the definition is presented in next subsection. We take the difference RSS measurements for RF tracking problem, since all static losses can be removed over time. The difference in RSS $\triangle y_i$ from time t_a to t_b is given by

$$\begin{aligned} \triangle y_i &= y_i(t_b) - y_i(t_a) & (4)\\ &= S_i(t_b) - S_i(t_a) + F_i(t_b) - F_i(t_a) & (5)\\ &\quad + v_i(t_b) - v_i(t_a), & (6) \end{aligned}$$

where can be rewritten as

$$\triangle y_i = \sum_{j=1}^{n} A_{ij} \triangle x_j + n_i, \tag{7}$$

where the noise n_i is the sum of fading and measurement noise

$$n_i = F_i(t_b) - F_i(t_a) + v_i(t_b) - v_i(t_a), \tag{8}$$

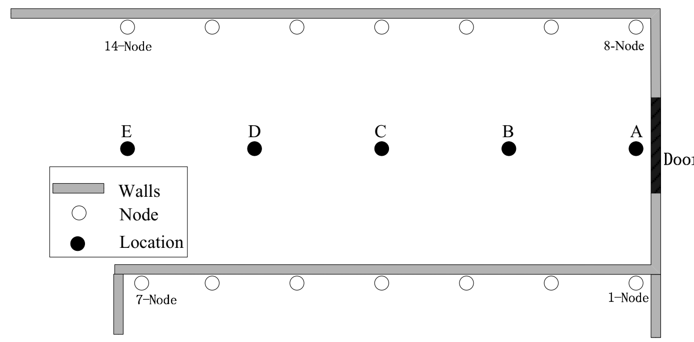

Fig. 2. The Layout of a 14-node RF sensor network.

and

$$\triangle x_j = x_j(t_b) - x_j(t_a), \tag{9}$$

is the difference in attenuation at pixel j from time t_a to t_b. Then we get the all link difference RSS measurements, the matrix form is described as follows

$$\triangle y = A \triangle x + n. \tag{10}$$

To simplify the notation, $\mathbf{x}$ and $\mathbf{y}$ are used in place of $\triangle x$ and $\triangle y$, respectively. Finally, we get the linear formulation (1). To image the scene of network, the RSS measurements $\mathbf{y}$ are taken as the difference from time t_a to t_b. It needs the calibration period (time $t = t_a$), the network area is vacant from targets.

B. Elliptical weight model

Weight matrix A for link shadowing can be described by an ellipsoid with foci at each pair of nodes locations [2], [3], [4], [5], as shown in Fig. 1. The weight is defined by

$$A_{ij} = \frac{1}{N_i} \times \begin{cases} 1, & \text{if } d_{ij}(1) + d_{ij}(2) \le d + \lambda, \\ 0, & \text{otherwise.} \end{cases} \tag{11}$$

where N_i is the total number of pixels affected by link i, d is the link distance between the nodes, $d_{ij}(1)$ and $d_{ij}(2)$ are the distance from pixel j to the two nodes for link i, and λ is the width of the ellipse. If a pixel falls inside the ellipse, it is weighted, otherwise, the weight is set to zero. In [2], [3], [4], A_{ij} is normalized by square root of the link distance d. We introduce a more reasonable normalization constant N_i.

III. Correlated Link Inference

The RSS measurements used in RTI discussed above are based on shadowing model [2], [3]. Shadowing based RTI is reliable for outdoor environment. For heavily obstructed area in indoor environment, Wilson and Patwari developed an extension of RTI for through-wall motion tracking, referred to variance-based radio tomographic imaging (VRTI) [4]. VRTI utilizes RSS variance as an indicator of motion based on multipath channel model. In this paper, we utilize the difference of RSS in correlated link to infer the locations of targets. It integrates difference in average signal strength and multipath channel model used in RTI and VRTI respectively.

For indoor environment, most jitters of the wireless signal are caused by the presence of the targets near the wireless links. some of the multipath components may be affected, and links which pass though that target will experience shadowing losses. When target appear in network area, some wireless multipath components may be reflected by the target and arrive receiver, so the RSS value of links between this pair nodes has a slight strengthening. Motivated by this observation, we classify the difference of RSS into two parts: RSS attenuation $\mathbf{y}^-$ and RSS enhancement $\mathbf{y}^+$. So we re-formulate the linear model of RTI as

$$\mathbf{y}^- = A\mathbf{x}^- + \mathbf{n}^-, \quad (12)$$

$$\mathbf{y}^+ = A\mathbf{x}^+ + \mathbf{n}^+, \quad (13)$$

where $\mathbf{x}^-$ and $\mathbf{x}^+$ correspond to the pixels that caused $\mathbf{y}^-$ and $\mathbf{y}^+$ respectively. $\mathbf{x}^-$ indicates the probable locations of the targets, $\mathbf{x}^+$ indicates the improbable locations of the targets. We define $\mathbf{y}^-$ and $\mathbf{y}^+$ as follow

$$\mathbf{y}^- = \begin{cases} \mathbf{y}_i, & \text{if } \mathbf{y}_i > y_u, \\ 0, & \text{otherwise.} \end{cases} \quad (14)$$

$$\mathbf{y}^+ = \begin{cases} \mathbf{y}_i, & \text{if } \mathbf{y}_i < y_l, \\ 0, & \text{otherwise.} \end{cases} \quad (15)$$

where y_u and y_l are the thresholds given in Table I. Then we obtain the pixels $\mathbf{x}$

$$\mathbf{x} = \mathbf{x}^- \wedge \neg\mathbf{x}^+, \quad (16)$$

where $\neg\mathbf{x}^+$ is the logical complement of $\mathbf{x}^+$.

IV. Experimental results

A. Experiment setup

A wireless peer-to-peer network containing 14 nodes is deployed as shown in Fig. 2. The network was deployed in a indoor office. The nodes were placed in two side of a rectangular perimeter (i.e. front-back node deployment). Seven nodes locate on the interior of the office, and other 7 nodes are external. Each radio was placed on a stand to keep them on the same two-dimensional plane at approximately half human torso level.

The network is comprised of CC2430 series nodes made by Crossbow corporation. The nodes utilize the IEEE 802.15.4 protocol, transmit in the 2.4GHz frequency band. To avoid network transmission collisions, a simple token passing protocol was used. Each node is assigned an ID number and programmed with a known order of transmission. When a node transmits, each node that receives the transmission, examines the sender identification number and reserves the RSS from transmit node. The receiving nodes check to see if it is their turn to transmit, and if not, they wait for the next node to transmit. If the next node does transmit, or the packet is corrupted, a timeout cause each receiver to move to the next node in the schedule so that cycle is not halted. A base-station node that receives all broadcasts is used to gather signal strength information which sent by each node, and save it to a computer for real-time processing. In all our experiments, the same set of image reconstruction parameters is used, as shown in Table I.

TABLE I
RECONSTRUCTION PARAMETERS.

Parameter	Value	Description
Δp	0.2(m)	pixel width
λ	0.05(m)	width of the weighting ellipse
y_u	0.2(dB)	The threshold to identify RSS attenuation
y_l	-0.2(dB)	The threshold to identify RSS enhancement
x_u	1(dB)	The threshold to identify probable pixels
x_l	-0.1(dB)	The threshold to identify improbable pixels

B. Effect of multipath channel

We take links between node 3 (coordinate (5, 0)) and node 12 (coordinate (3, 1.5)) as the observed links. As shown in Fig. 3, a target stands in different positions, link's RSS appears different effect of obstruction. When a target present in the location of A or E that are far way the link between node 3 to node 12, the link of between node 3 and node 12 not show a significant change. However, when a target present in position C where on the line-of-sight between node 3 to node 12, the RSS attenuates significantly up to 10dB. More sophisticated, when a target present in the location B or D, the RSS enhances slightly. This effect can be explained in multipath channel modal as shown in Fig. 4. When a target moving into the network area, the target not only causes some links shadow attenuation, but also makes some other links which do not pass through the target enhance RSS slightly.

C. Statistical analysis of difference of RSS

As discussed above, we observe the difference of RSS can be categorized into RSS attenuation, RSS enhancement and RSS unchanged. If there is no target present in the wireless network, the RSS remaines almost constant [6]. According to the thresholds y_u and y_l given in Table I, the statistical chart of difference of RSS is presented in Fig 5. When the network area was vacant, most of link's RSS is unchanged. The ratios of attenuated, enhanced and unchanged links are roughly 40%, 40% and 20% respectively when a target presents at different positions. This motivates us to infer the locations of targets by utilizing both RSS attenuation and RSS enhancement.

D. Example image

Utilize the proposed approach descried in section III, we present a typical image result. Fig. 6 displays a target standing at position C (coordinate (4, 0.8)).

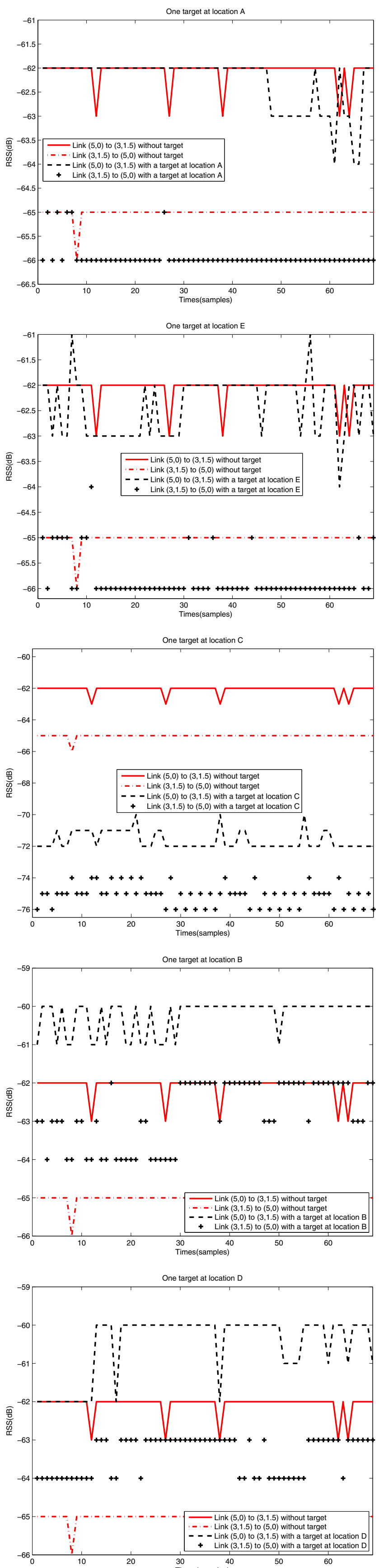

Fig. 3. A comparison of the effect of target obstruction.

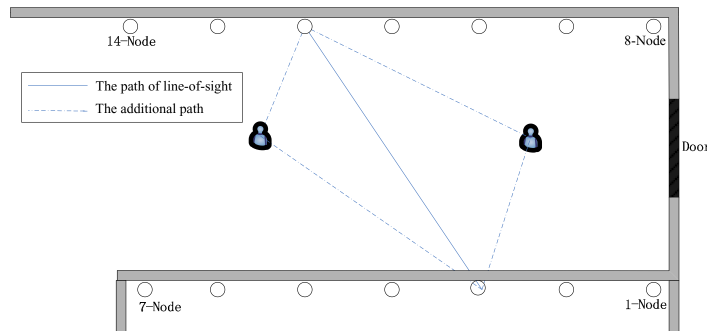

Fig. 4. The effect of multipath channel.

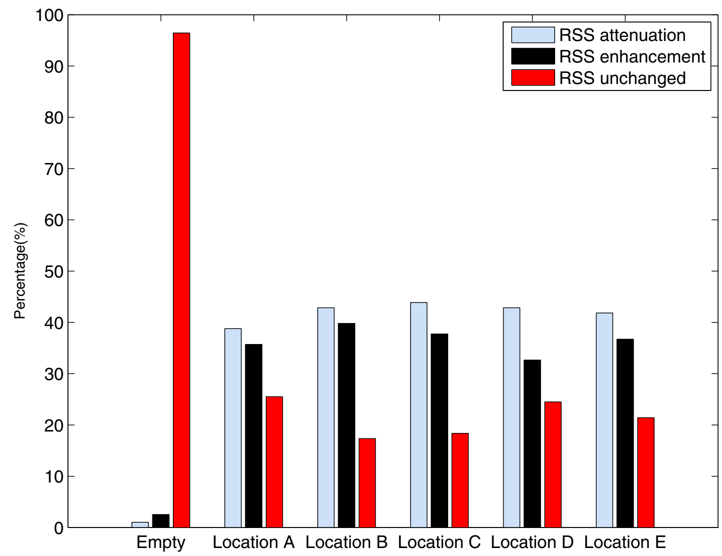

Fig. 5. Statistical chart of difference of RSS.

V. Conclusion

In this paper, we re-evaluate the effect of targets present in wireless network area, and observe that targets not only cause shadowing attenuation when pass through some links, but also enhance some links which don't pass through the targets. We locate targets by imaging both RSS attenuation and RSS enhancement. Experimental results with 14 nodes RF sensor network deployed in indoor office validate our observations.

Acknowledgment

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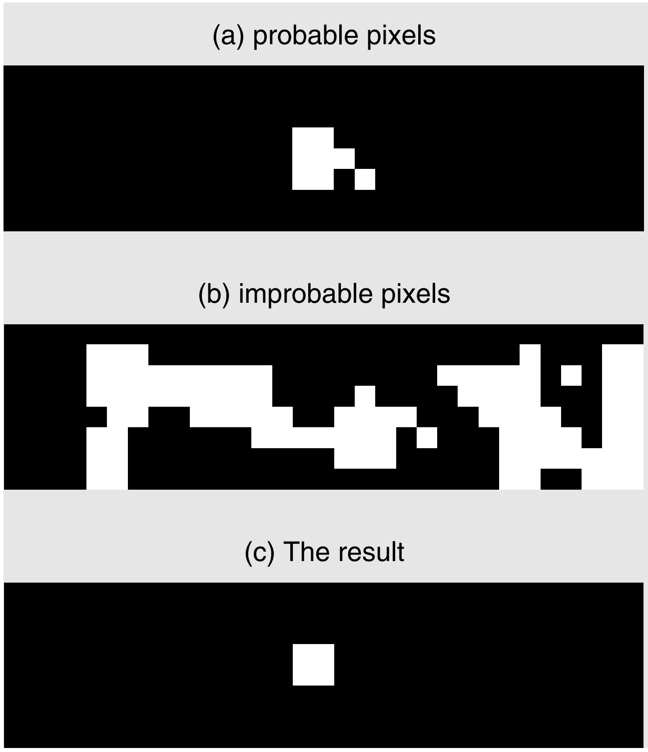

Fig. 6. Reconstructed image for a target standing at B (coordinate (4, 0.8)).

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