Author Responses to Review Comments

We are grateful to the the reviewer for the insightful and invaluable comments. Based on the comments, we have prepared a much better manuscript. The changes made in the revised manuscript according to the comments of the reviewer are highlighted in blue. Below, we response in detail to the comments of the reviewer (each comment is shown in *italics*).

Reviewer Comment 1: *In the abstract "Nevertheless, existing methods are mostly developed based on the fixed RFID model where RFID readers are fixed deployed in the monitoring area and RFID tags are attached on the moving objects targeting to locate. Moreover, most existing methods estimate the locations of moving objects by using the active RFID tags (powered by on-board battery), which incurs large localization errors and high costs". This is not true. There are many investigations with mobile RFID readers and fixed tags. You should not ignore them. On the contrary, you need to survey the state-of-the-art and compare with them to claim you contribution. Incorrect expression again, most RFID localization methods use passive.*

response: We appreciate this valuable comment. We have revised the inappropriate elaboration mentioned by the reviewer and rewritten the Abstract and part of the Introduction. Moreover, in the experiments, we add a newest state-of-the-art indoor localization method (denoted by 'PHL') to compare with our proposed MRLIHT.

The revised Abstract and part of Introduction is shown below.

Abstract. RFID (Radio Frequency Identification) technology has been widely used in indoor location tracking, especially serving for human beings, due to its advantage of low cost, non-contact communication, resistance to hostile environment and so forth. Over years, many indoor location tracking methods have been proposed. However, tracking *mobile* RFID readers in real time has been a daunting task, especially for achieving high localization accuracy. In this paper, we propose a new *Mobile RFID* (M-RFID) based Localization approach for Indoor Human Tracking, named MRLIHT. Based on the M-RFID model where RFID readers are equipped on the moving objects (human beings) and RFID tags are fixed deployed in the monitoring area, MRLIHT implements the real-time indoor location tracking effectively and economically. First, based on the readings of multiple tags detected by an RFID reader simultaneously, MRLIHT generates the *response regions* of tags to the reader. Next, MRLIHT determines the *potential location region* of the reader where two algorithms are devised. Finally, MRLIHT estimates the location of the reader by dividing the potential location region of the reader into finer-grained grids. The experimental results demonstrate that the proposed the MRLIHT performs well in both accuracy and scalability.

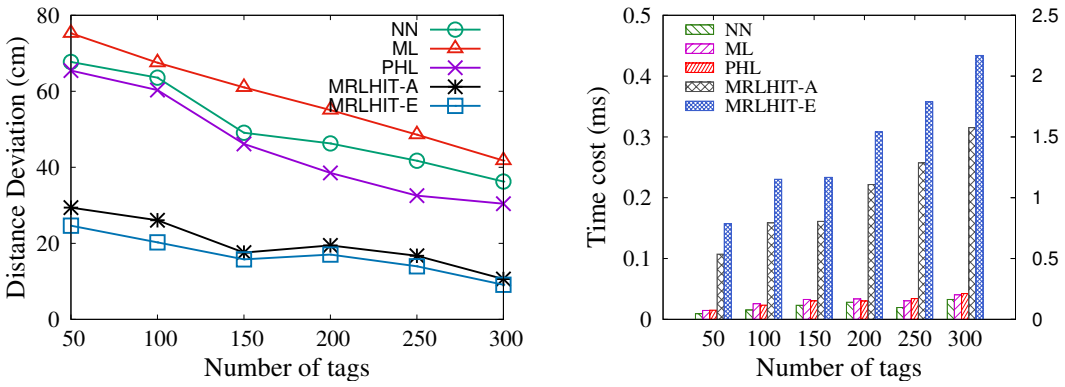
Introduction. RFID (Radio Frequency Identification) [1-3] is a technique of automatic identification using radio frequency transmission. RFID technology is widely used in many real-world

applications, e.g., real-time tracking, activity recognition, etc, and impacts almost all aspects of people's daily life. An RFID system consists of readers and tags, where readers communicate with tags through radio signals. RFID tags are categorized as either active or passive. Active tags are powered by on-board batteries and broadcast their own signals continuously, while passive tags are powered by the electromagnetic energy transmitted from RFID readers. Since the maturely developed GPS-based localization systems do not perform well for indoor location tracking applications, RFID-based localization technologies have become popular in a number of indoor tracking schemes. In this paper, we aim to propose an effective RFID-based localization approach for indoor human tracking, which can be pervasively used in the large-scale and high-accurate tracking applications.

Over years, many RFID-based indoor human/object tracking methods have been proposed. They can be categorized as F-RFID model based and M-RFID model based tracking, where in F-RFID (i.e., fixed RFID) model, RFID readers are pre-deployed at some fixed points in the monitoring area and RFID tags are attached on the moving objects, while in M-RFID (i.e., mobile RFID) model, RFID readers are equipped on the moving objects and RFID tags are fixed deployed at some points in the monitoring area. Generally, the two models are used for different application scenarios. In large-scale monitoring applications, since the cost of RFID readers are very high, the deployment of fixed readers are generally sparse, which results that the location information of moving individuals (mobile tags) are discontinuous. In other words, there are phenomena of location information missing. To tackle this issue, some existing works estimate the missing location information based on pre-defined motion model. Nevertheless, in most cases, the motion of individuals is arbitrary and cannot be predicted. On the other hand, to alleviate the sparseness of RFID readers, some existing works use the *reference tags* to instead replacing more readers. However, the localization accuracy is unsatisfactory (incurring meters of localization errors). In addition, to estimate the locations of moving human/objects based on F-RFID model, the positions of fixed readers which are stored in external storage medium (e.g., databases or files) are needed. The location information requirements incurs extra query costs, and thereby reduces the tracking efficiency.

Moreover, in the revised manuscript, we replotted Figure 8 and Figure 9. Moreover, we add more discussions about the experimental results as follows.

Fig. 1 shows the performance of various methods by varying the the number of tags detected by a reader simultaneously. It can be observed from Fig. 1(a) that the lowest distance deviation is achieved by the proposed MRLIHT. The reason is that we consider the uncertainty of the reading rate of a tag by a reader and first extend the candidate locations of a reader into a PLR rather than some certain points. On the other hand, by refining each grid, the positioning accuracy is further



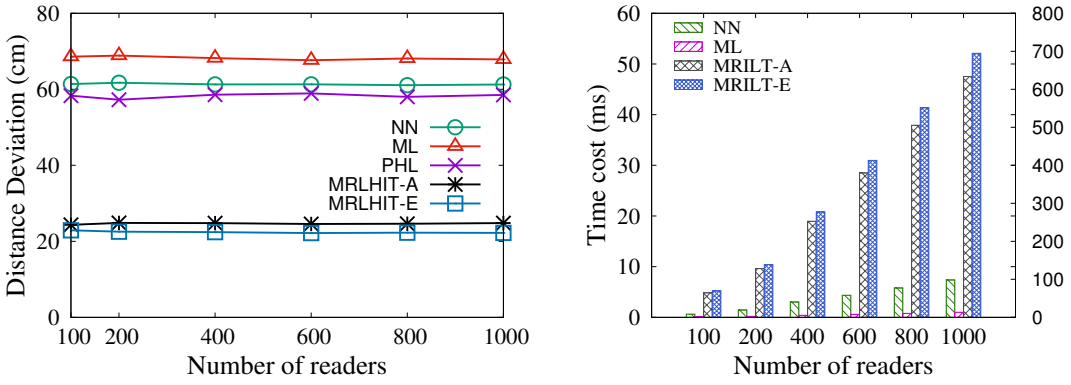
(a) Distance deviation (b) Time cost

Fig. 1. Varying the number of tags detected simultaneously with $\delta_d = 20cm$, $\delta_s = 3$, $grid_size = 60cm$

improved. Moreover, in NN and ML, the distance between an RFID reader and tags it detected are computed based on the reading rate model whose parameters are learned based on the historical data. During the parameter learning, it inevitably derives some deviations (due to the uncertainty of the reading rate). As a result, the localization algorithms (i.e., NN and ML) without considering this uncertainty derive a large localization deviation. By comparison, in PHL, since the phases are directly collected from reference tags, the distances (between an RFID reader and tags it detected) estimated based on those phases contain relatively small deviations. Therefore, the localization accuracy of PHL is higher than those of NN and ML, but it is lower than our proposed approaches obviously.

As shown in Fig. 1(b), with the increase of the number of tags, it is not surprising that the time cost rises. The time costs of NN, ML and PHL are lower than those of MRLIHT-A and MRLIHT-E, but their localization accuracies are also lower. We can observe that the time costs of ML and PHL are close to each other, because both of them estimate the locations of indoor humans based on the multilateration. The main difference between ML and PHL is that the distance between an individual (reader) and a tag is computed based on the RSS and phase difference, respectively.

Fig. 2 reports the evaluation of the scalability in terms of accuracy and efficiency by varying the number of readers. As shown in Fig. 2(a), the accuracy remains stable with the increase of the count of readers. However, the accuracy of the proposed MRLIHT is higher than existing methods obviously. For the time costs, as shown in Fig. 2(b), all methods increase linearly with the increase of the number of readers. The time costs of MRLIHT-A and MRLIHT-E are $47.5284ms$ and $694.6388ms$ with 1000 readers, respectively. In other words, we can estimate the locations of 20,000 and 1500 readers in one second based on MRLIHT-A and MRLIHT-E, respectively.



(a) Distance deviation (b) Time cost

Fig. 2. Varying the number of readers with $\delta_d = 20cm$, $\delta_s = 3$, $grid_size = 60cm$

Therefore, MRLIHT-A is more suitable for the large-scale monitoring applications without much accuracy sacrifice.

Reviewer Comment 2: *Line 26-30, "However, the indoor location tracking based on F-RFID model has the following limitations:". The fixed reader and mobile reader are used for different application scenarios. For example, product items on the shelf and in distribution, mobile tag is more suitable. How many mobile readers you want to uses if you make it mobile? Therefore, this comparison is meaningless if there is not a fixed application scenario. Just say "moving object" is not appropriate. Maybe human indoor localization can be better.*

response: We thank the reviewer for this suggestion. To make the applications of the proposed approach more clear, in the updated manuscript, we revised the "moving object(s)" to "human being(s)" and revised the title of the manuscript to "MRLIHT: Mobile RFID based Localization for Indoor Human Tracking". Moreover, we believe that our revision for Comment 1 also help address this suggestion properly.

Reviewer Comment 3: *Language problems. The following changes are suggested for consideration: Non-contacting → non-contact, Read rate → reading rate.*

response: Thank your for pointing this out. We have fixed it.