

学位論文の要旨

Abstract of Thesis

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学位論文題目 Title of Thesis (学位論文題目が英語の場合は和訳を付記)

Indoor Localization Using Leaky Coaxial Cable in Wireless Communication System
無線通信システムにおける漏洩同軸ケーブルを使用した屋内位置推定

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In the last couple of years, due to the large-scale commercialization of the fifth-generation (5G) mobile communication technology and the explosive growth of the number of smart devices, various services and applications have emerged to change people's lives. The localization of users and devices is of great value in a wide range of fields such as autonomous vehicles, health care, industrial and manufacturing automation, and robotics. It can also benefit many novel systems including Internet of Things (IoT), Internet of Vehicles (IoV), smart home systems, smart buildings, etc. On the other hand, location information also plays a key role in technologies such as beamforming in 5G mobile communication and even in technologies in the future sixth-generation (6G) mobile communication.

Most of the existing localization methods in wireless communication consider the communication systems using conventional monopole antennas. However, the large power loss of the signal in the air and the influence of metal objects on the shielding and interference of radio waves limit the performance of conventional monopole antennas. It is often necessary to increase the number of access points (AP) with additional complexity and cost to guarantee entire wireless coverage. This problem can be solved by using the leaky coaxial cable (LCX) for wireless communication and localization. LCX can be used as antennas, the signal waves can be transmitted and received through the periodically arranged slots over LCX. The wireless coverage of LCX is uniform and the interference between cells is low. As a long and flexible cable, LCX can bypass various metal obstacles to adapt to various irregular spaces. Since the power loss of signal in the cable is small, LCX can cover a wider area with fewer APs in some application scenarios such as smart factories, tunnels, railway stations, and underground shopping malls. LCX has been researched in wireless communication for several years. It has been employed in train and the train ground communication system. The employment of using LCX to provide wireless power transfer (WPT) for moving objects was researched in the past years. In other research, the authors find that LCX can be used in multi-input multi-output (MIMO) communication. In addition, LCX-MIMO can improve the channel capacity using user location information. Whether it is LCX-based WPT, LCX-MIMO channel capacity improvement based on location information, or providing user location information within coverage, LCX-based wireless localization is the key to the realization of these technologies.

This thesis presents the contributions and achievements of the researches in improving the accuracy of LCX localization and enhancing the performance of LCX localization in indoor multipath environments.

An LCX channel model based on the GBSB model is proposed in this thesis. Different from the original model that regards one LCX as one antenna, the proposal uses one LCX as two antennas according to the bi-directional radiation characteristics of LCX in the MIMO system. This LCX channel model also considers the LOS signal condition and the NLOS signal condition in an indoor environment. Based on the proposed LCX channel model, a brief Fisher Information analysis is performed for LCX-based localization and the impact of different LCX configurations on the position error bound (PEB) is evaluated through the Cramer-Rao lower bound (CRLB).

Most conventional localization methods using LCX usually use one LCX or two placed in parallel for 2-D location detection. From the localization performance results in previous research and the results of PEB analysis, it can be found that the localization accuracy of the direction perpendicular to LCX is worse than that of the direction parallel to LCX. Based on this fact, as an enhancement, an LCX localization method using two LCXs perpendicular to each other is proposed to improve the localization performance of the LCX system. The proposal measures the TDOA of the received signal from the target UE to estimate the location information. The TDOA is measured using the multiple signal classification (MUSIC) algorithm which is usually used for direction of arrival (DOA) estimation. The results of the experiment in an anechoic chamber show that the localization performance integrating both location information from two LCXs perpendicular to each other is better than that of the conventional method.

Due to the problem of the NLOS signal propagation in the indoor multipath environment and the noise in the signal measurement process, the conventional range-based localization methods using LCX do not have promising localization performance. Based on the idea of fingerprinting-based systems, a localization method using multiple LCXs with a machine learning approach is proposed for an indoor multipath-rich environment. Different from conventional range-based localization methods based on TOA or TDOA, the proposed system considers improving the localization accuracy by machine learning RSSI from LCX. From the perspective of low cost in hardware requirements and low computational complexity, the RSSI-based method is one of the simplest localization methods for indoor environments because of the easy measurement of RSSI value. It presents a probabilistic neural network (PNN) approach by utilizing time-series data of RSSI from LCX, and the proposal is aimed at the two-dimensional (2-D) localization in a trajectory. The RSSI data samples are measured at the LCX side using the LCX channel model with both LOS and NLOS propagation components. It compared the performance of the RSSI-based PNN (RSSI-PNN) method and the conventional TDOA method over the same environment. The numerical simulation experiments are provided as a performance investigation for the proposal. The results show the performance of the RSSI-PNN method is promising and is better than that of the conventional range-based TDOA method.

Localization methods based on machine learning usually need to collect a large number of data samples in advance for training, and the computational complexity is high. The probabilistic approach such as the particle filter is a good method to enhance the localization without the collection of data samples. Based on the motivation, a particle filter-based localization method using LCX in an indoor environment is proposed. The key idea of a particle filter is to use discrete random samples (particles) instead of the conventional integral calculation. Particles are used to approximate the probability density function of the nonlinear system to achieve the minimum variance estimation of the system state. The proposed localization system uses multiple LCXs as the access points to receive the signals from the target user, and the TOA of the signals at different end sides of the LCX will be utilized as the indicator for filtering in the localization process. The proposal uses TOA in this LCX localization system mainly because the timing information of the signals is more mature and has promising performance in the previous research of LCX localization compared to RSSI and channel state information (CSI), which have relatively high randomness and instability in the measurement phase. On the other hand, different from the range-based approach used in the conventional LCX localization method, which directly converts the timing information of the signal into location information in a single observation, the particle filter-based method provides an effective framework to track the variable of TOA as it evolves over time. The observation sequence of the TOA is used to estimate the hidden state

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of the target, that is, the location information. Different from localization methods in the previous work, the proposed particle filter-based method can be applied not only in the 2-D localization scenario but also in the 3-D localization scenario. Thus, this proposal may play a key role in smart manufacturing which requires multi-dimensional location information for unmanned aerial vehicles (UAVs) and robotics.

In addition to the above research on LCX-based localization methods, a study on capacity loss due to the error of user location information in the LCX-MIMO channel is also provided. In the previous research, the authors found that compared with the equal power (EP) allocation method, the power allocation method for the LCX system using position information (PI) can improve its capacity with the same level of computational complexity. However, the research assumed that the position information of the user is known perfectly without any localization error. In a real environment, the localization error cannot be avoided because of many factors such as localization algorithm error and resolution of signal processing. In order to investigate the practicability of the proposed power allocation method and the level of system capacity loss, the relationship between the LCX-MIMO channel capacity loss and the localization error is studied when using the PI-based power allocation method. The research examines the capacity loss of the LCX-MIMO system over the 2.4 GHz and 5 GHz bands with the conventional EP method, the water-filling (WF) algorithm-based power allocation method, and the PI-based allocation method. The channel capacity of the LCX-MIMO channel is investigated considering the user location error and carried out measurements in the anechoic chamber and simulated the LCX-MIMO channel over a multipath environment using the proposed LCX channel model. From the experimental results, no matter whether the environment is with strong or weak multipath effect, the PI-based power allocation method can obtain a good channel capacity even if the user positional information error occurs. In other words, this research aims to find the tolerance of localization error for the LCX-MIMO system with acceptable capacity loss.

A study on the simultaneous localization of multiple target users using LCX will be the future work. Due to the development of IoT, there will be more and more target users who need to be provided with location information in future wireless communications, so the simultaneous localization technology that effectively provides locations for a large number of targets in a short period of time will become critical.