An Efficient Radiative Wireless Power Transfer Algorithm

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Abstract

Radiative wireless power transfer(RWPT) is a key technology to supply energy to sensors in wireless sensor network(WSN). For power transfer efficiency, the accurate estimation on receiver position is required. In this paper, a receiver localization algorithm for the RWPT is proposed. The proposed algorithm transmits reference beams from the transmitter and estimates the position by comparing the received power based on the receiver feedback for each reference beam. While considering the low complexity, the proposed algorithm is verified through simulation and experiment that the power transmission efficiency is improved by about 18% compared to the existing methods.

Ⅰ. Introduction

In WSN, wireless charging is essential for permanent operation of sensor nodes. A key element of this wireless charging technology is wireless power transfer(WPT) technology, which has categories of magnetic induction, magnetic resonance, and electromagnetic radiation methods. Although both magnetic resonance and magnetic induction method that are magnetic field-based power transfer have high energy efficiency, the range of power transfer operation is limited within near-field [1],[2]. In contrast, the electromagnetic radiation method, also known as RWPT, has a much higher spatial freedom because the power transmission distance can reach several meters(far-field), and it is possible to transmit power to multiple receivers with a single transmitter. Although transferred power is low due to loss over distance, it is considered as a suitable wireless power transfer method for WSN because received power is sufficient for wireless sensor nodes.

In general, the use of directional antennas in RWPT is essential to increase the power efficiency and operating distance of sensors. For the operation of directional antennas, adaptive beamforming is used to estimate the position of receiver in order to transmit power efficiently in the desired direction and/or to transmit a beam with maximum efficiency to several receivers. Adaptive beamforming is divided into two types: digital beamforming [3] and analog beamforming [4]. Analog beamforming is more suitable for WSN compared to digital beamforming, but there are also many problems to apply as it is. WSN does not have a complex frame structure in mobile communications. In addition, unlike the beam management [4], there is a difference that the distance between the transceivers is several meters in RWPT. In beam management, it is only necessary to satisfy the signal strength enough to obtain information, but in the WPT, power efficiency increases as the direction is correct, so the importance of accuracy in estimation is high. Many studies have been conducted on how to more accurately estimate the location of receivers to address such issues [5]. However, there is a problem that it takes a long time to find an optimal beam to the receiver.

Therefore, we propose a receiver localization algorithm that has been improved so that beam management method can be used effectively for RWPT in WSN. The proposed algorithm applies a weighted beam selection that can improve the operation process in beam management to the RWPT and greatly improve the accuracy of location estimation.

Ⅱ. System Model

The proposed algorithm is carried out through beam scanning process, feedback process, and receiver location estimation process. In the first process, the transmitter divides the space into several subspaces and assigns a set of beams that can cover each subspace, such as beam management. Then, the receiver position is calculated using reference values collected through beam scanning. In the beam scanning phase, the transmitter transmits N sequential beams at intervals in the area to be scanned. Before transmitting the next beam, the receiver reports the received power for the corresponding beam. Then, transmitter apply the WBS with the feedback values.

However, problems with the algorithm itself often result in large errors between the estimated angle and the actual angle. First is the case where the effect on the other beam is greater than the beam on either side of the point where the receiver is located. If the beam spacing becomes too wide, the gain for the side-lobe of other beam will be greater than from the main-lobe, resulting in an estimate of the position in the wrong direction. It can be solved by reducing the beam gap. Second, the receiver exactly matches one of the angles transmitted by the reference beam. In the following cases, the position of the receiver is calculated at an angle between the two beams, so if the weight is not

more than 10 times different, it will move away from the actual position. To compensate for this, the algorithm should be improved in consideration of the situation described above.

The improved method combines the conventional method with the WBS as follows. Consider the received power $P_{r,k}$, the angle of the receiver is correctly located in one of the transmission angles of the reference beam. The improved algorithm compares the gap with the second largest value, $P_{r,k+1}$ or $P_{r,k-1}$, before applying WBS. If the gap is greater than the threshold, selects conventional method. If the gap is less than the threshold, the receiver angle is calculated by applying WBS. We call this method advanced WBS(AWBS), and the described process is illustrated in Alg. 1.

Algorithm 1 Advanced Weighted Beam Selection

for $i = 1, 2, \ldots, N$ do
    Transmit the beam at $\theta_{Tx,i}$
    Feedback the measured P_{r_i} at the receiver.
end for
$k = \arg\max P_{r_i}$
if $|P_{r,k} - P_{r,k\pm1}| \geq \delta_{max}$ then
else f $P_{r,k-1} \geq P_{r,k+1}$ then
    $\theta_{est} = \frac{P_{r,k-1} \cdot \theta_{k-1} + P_{r,k} \cdot \theta_k}{P_{r,k-1} + P_{r,k}}$
else if $P_{r,k-1} < P_{r,k+1}$ then
    $\theta_{est} = \frac{P_{r,k} \cdot \theta_k + P_{r,k+1} \cdot \theta_{k+1}}{P_{r,k} + P_{r,k+1}}$
end if

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Ⅲ. Performance Analysis

Based on the systems described above, simulations and experiments were conducted. The error estimation is calculated as the difference between the estimated angle and the angle at which the receiver is located. To evaluate only the effects of beam spacing, no measurement error was assumed due to receiver impairment.

Fig. 1(a) is a graph of the error in estimating position. The result shows that the WBS has reduced errors in all spacing compared to the conventional method. We can see that the wider the spacing, the greater the difference in error values. It can also be seen that there is little difference between the WBS and AWBS error values near 14.5 degrees, and that the WBS method has a minimum error at that beam spacing.

Results through simulation were verified through experimentation. Transmitter with 2.4GHz 8x8 multiple antennas and single antenna receiver were built and implemented for the experiment. In contrast to the simulation, the received power was selected as a comparison target because it was difficult to measure the angle with the transmitter from the location of the actual receiver during the experiment.

Fig. 1(b) shows the results of the above experiment. We can see that WBS and AWBS show better efficiency compared to conventional method. In the case of 1 meter, the efficiency increased by 8.1% from 5 degrees and the largest increase from 25 degrees to 38%. In the case of 2 meters, efficiency gains were 6.6% from 5

degrees, while efficiency gains were up to 49.4% from 25 degrees.
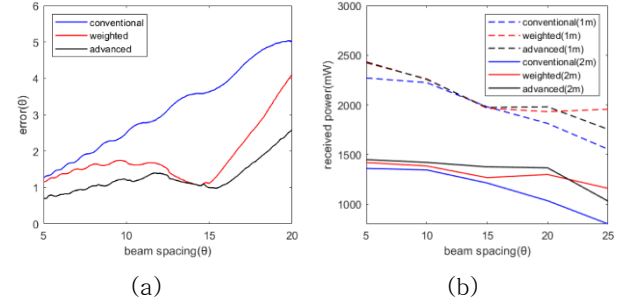
Figure 1. (a) Errors according to beam spacing. (b) Received power according to beam spacing.

Ⅲ. Conclusion

In this paper, we introduce a receiver localization algorithm for efficient power transfer in RWPT system used in WSN. The proposed algorithm shows improved accuracy of location estimation and the efficiency of estimation time compared to the conventional method, which was verified through simulation and experiments in the actual environment. It has also implemented and validated a simple yet easily feasible receiver feedback structure that can be used in WSN.

References

[1] G. A. Covic and J. T. Boys, "Inductive power transfer," *Proceedings of the IEEE*, vol. 101, no. 6, pp. 1276–1289, June 2013.

[2] A. Karalis, J. D. Joannopoulos, and M. Solja˘ci´c, "Efficient wireless nonradiative mid-range energy transfer," *Annals of physics*, vol. 323, no. 1, pp. 34–48, 2008.

[3] M. Sheng, L. Wang, X. Wang, Y. Zhang, C. Xu, and J. Li, "Energy efficient beamforming in miso heterogeneous cellular networks with wireless information and power transfer," *IEEE Journal on Selected Areas in Communications*, vol. 34, no. 4, pp. 954–968, 2016.

[4] M. Giordani, M. Polese, A. Roy, D. Castor, and M. Zorzi, "A tutorial on beam management for 3gpp nr at mmwave frequencies," *IEEE Communications Surveys Tutorials*, vol. 21, no. 1, pp. 173–196, 2019.

[5] M. Giordani, M. Polese, A. Roy, D. Castor, and M. Zorzi, "A tutorial on beam management for 3gpp nr at mmwave frequencies," *IEEE Communications Surveys Tutorials*, vol. 21, no. 1, pp. 173–196, 2019.