Study on Multi-Hop Wireless Power Transfer Node

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Summary

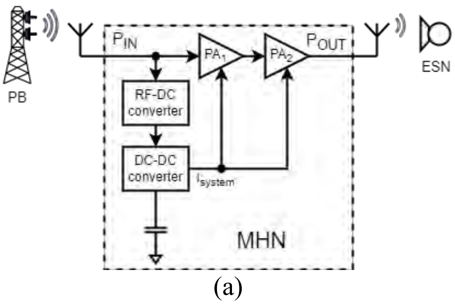
This work presents the multi-hop wireless power transfer (WPT) node designed for the Sub-GHz range. The impact of the distance on WPT performance is studied using simulations and experimental measurements.

1. Introduction

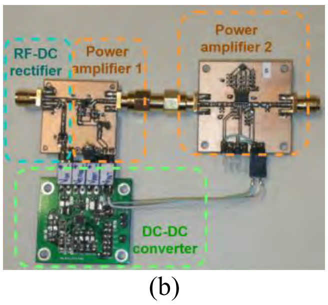
The growing number of low-power wireless devices and sensors lead to the integration of the Internet of Things (IoT) and Wireless Sensor Networks (WSNs) in various branches of the industry, agriculture, and medicine [1]. With such wide application, the powering of the autonomous sensor nodes (SNs) posed a challenge since batteries are the most common power source of the SNs. The growing interest in overcoming this challenge was directed toward developing far field wireless power transfer (WPT). While the given powering technique is feasible, the main challenge is the WPT performance enhancement.
Recent advances in enhancing WTP performance have two main focuses: network level and device level improvements. The device-level improvements focus on enhancing the performance of the WPT nodes. This includes improving the performance of the RF-DC converters, energy storage solutions, and the design of power-carrying signal waveforms [2]. The network-level improvements are focused on incorporating and combining new technologies to increase the performance of WPT on a network scale. The network-scale solutions also define criteria for the device-level, and thus affect the overall performance of the WPT system more. One such emerging network-scale solution for enhancing the performance is the multi-hop power transfer.
The concept of multi-hop routing has already been applied for data transfer [3], providing higher energy efficiency for the same data transfer quality. Applying this established technology to the wireless power transfer simplifies WPT's overall infrastructure by reducing the number of power beacons and designing some SNs as power transceivers (multi-hop nodes, MHNs). The transceivers store enough energy for the operation of the SN and transmit some energy to another SN (edge sensor node, ESN) not covered by the power beacon (PB).
This work studies the concept of the multi-hop node first proposed in [4] using simulation-based and experimental-based studies for the sub-GHz range.

2. Multi-Hop Node and Its Parameters

The multi-hop node (MHN) block diagram is given in Fig.1 (a). The multi-hop node consists of an RF-DC rectifier, a DC-DC converter, and an RF amplifier cascade. The MHN design requires balancing multiple requirements, such as high output power, low current consumption, high gain, and high RF-DC power conversion efficiency, efficient DC-DC converter. The proposed MHN design includes two cascades of amplifiers to provide a sufficient gain level for efficient amplification.



(a)



(b)

Figure 1. Block diagram of the multi-hop node (a) and multi-hop node prototype (b).

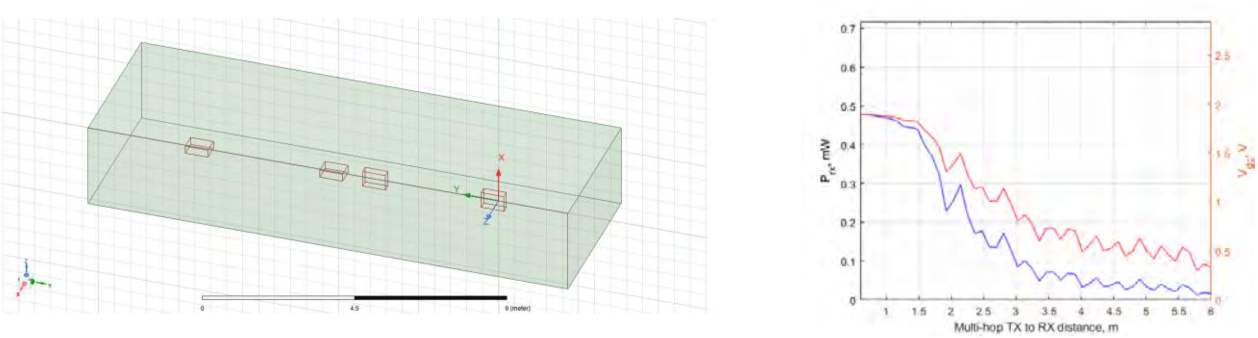
Table 1. MHN node parameters

P_{in}, dBm	-10	-9	-8	-7	-6	-5	-4
Gain, dB	33.4048	32.4532	31.4915	30.5222	29.5417	28.5575	27.5646
P_{out}, dBm	23.4048	23.4532	23.4915	23.5222	23.5417	23.5575	23.5646
I_{system}, mA	180.4545	184.2296	187.7049	191.0421	194.2359	197.0953	199.4761

The proposed MHN prototype is shown in Fig. 1 (b), while the characteristics of the prototype are represented in Table 1. The first stage amplifier consumes a relatively low current, while the second stage gives a high output power level. The RF input of the prototype is matched to 50 Ω impedance. The RF-DC rectifier return loss is below -20 dB during the energy harvesting.

3. The impact of the antenna separation on the multi-hop WPT performance

The distance between WPT system nodes plays a crucial role in the system's performance; therefore, accurate estimation of the effect of the inter-node distance on the wireless power transfer system (WPTS) efficiency is of particular importance. The model comprises four Uda-Yagi antennas with a maximum gain of 13 dBi located 1.02 m above the floor, namely, the transmitting antenna of the power transmitting end of the power transfer system, the receiving and transmitting antenna of the multi-hop node, and the receiving antenna at the receiving end equipped with an RF-DC converter. The RX power is calculated by separately analyzing three parts of the WPTS and then combining the individual results to find the amount of power at the input of the RF-DC converter. Finally, with the aid of the Harmonic Balance Method (HBM), the DC output power is calculated. The antenna-to-antenna power transfer is modeled using Ansys HFSS (SBR+ solver). The HFSS model of a laboratory room accommodating all three components of the power transfer system is illustrated in Fig. 2 (a). The room model's width and height are 5.5 m and 2.65 m, respectively. The relative dielectric permittivity and the electrical conductivity of the walls are 5.31 and 0.19 S/m, respectively. The calculated received power as a function of the distance between the multi-hop node transmitting antenna and the receiving antenna at the receiving end is presented in Fig. 2 (b).



(a) (b)

Figure 2. The received power (blue) and the rectified voltage against the distance between the multi-hop node transmitting antenna and the receiving antenna at the receiving node, with the transmitted power of 0.5W, the distance between the power transmitter antenna and the receiving antenna of the multi-hop node of 4.5m, and multi-hop node amplifier gain of 23 dB.

4. Discussion

The study has presented the multi-hop WPT node (MHN) design for the sub-GHz range and the impact of the distance between different SNs on WPT performance. However, the efficiency of the WPT multi-hop system depends on such factors as powering signal level and frequency, the distance between all elements of the multi-hop WPT system, design of MHN and ESN, MHN gain capabilities, RF-DC conversion efficiency of ESN, wireless transmission environment properties. Therefore, considering many influencing parameters, the studies on experimental verification and MHN design optimization should be continued.

5. Acknowledgements

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