Poster: Backscatter Communication for Wireless Robotic Materials

Dilushi Piumwardane, Carlos Pérez-Penichet, Christian Rohner, Thiemo Voigt*

Uppsala University, Sweden. *Uppsala University and RISE SICS.

dilushi.piumwardane@it.uu.se, carlos.penichet@it.uu.se, christian.rohner@it.uu.se, thiemo.voigt@it.uu.se

Abstract

Robotic Materials can change their physical properties programmatically by integrating sensing, actuation, computation and communication. Wireless devices distributed in a dense network within the material can perform the latter while operating with energy harvested from the environment through backscatter communications using devices assisted by an external unmodulated carrier.We propose this paradigm for robotic materials and employ simplified analytical models to study the necessary unmodulated carrier strength. We find that relaying a message over multiple hops requires less intense carriers than doing a single transmission and that multiple distributed carrier generations reduce the necessary output power of individual carrier generators.

1 Introduction

Wireless robotic materials [2] are composite materials that programmatically alter their properties such as shape or color in response to external stimuli or commands. Ideally, communication devices for robotic materials would operate without batteries on harvested energy from their environment.

A new class of battery-free communication devices with dramatically reduced power consumption combine, on a single device, backscatter communication techniques to transmit standard wireless protocols such as 802.15.4 [4] with recent advances in receiver architectures to receive the same protocols [5]. We refer to this combination as carrier-assisted transceivers. This new communications paradigm is ideal for robotic materials due to its ability to operate on small amounts of energy that can be harvested from the environment. The need for an external unmodulated carrier and the relatively short communication range, however, introduce unprecedented challenges. We employ analytical models to study the feasibility of employing carrier-assisted communications to relay messages within a robotic material in different configurations and network densities.

Our goal is to reduce the necessary output power of the carrier generator which is of great importance to reduce, e.g., radiation exposure in vulnerable groups and to reduce power consumption. Our contribution is that we introduce the suitability of carrier-assisted communications to robotics materials. We show that multi-hop relays within the material can reduce the necessary carrier output power. We demonstrate a further reduction of carrier output power with multiple carrier generators.

2 Background

Carrier-assisted transceivers use an external unmodulated carrier for transmissions and receptions with drastically lower power consumption compared to conventional radio transceivers. To transmit the devices employ backscatter communications, reflecting an external Radio Frequency (RF) signal to convey information. For reception they employ a receiver with an external carrier instead of a local oscillator [5]. These devices are adequate for smart robotic materials because of their ultra-low power consumption.

The need for an external carrier implies important differences in modelling radio links for these devices. We use the Radar Range equation [1] to describe the power (P_r) of a backscattered signal observed at a receiver. We model the sensitivity of carrier-assisted receivers, which depends on the strength of the unmodulated carrier [3].

3 Evaluation

We base our analysis on the assumption that the signal power at the receiver P_r must overcome the sensitivity threshold S_{th} of the receiver for successful decoding of the data. This leads to the condition $P_r > S_{th}$. Substituting the Radar Range equation and the sensitivity model into the condition, we obtain the following equation for the minimum required carrier output power:

$$P_t > \frac{\sqrt{C}}{G_t G_b G_r \sqrt{\alpha}\frac{|\Delta\Gamma|}{2}} \frac{4\pi R_1}{\lambda} \frac{4\pi R_2}{\lambda} \frac{4\pi R_3}{\lambda} \quad (1)$$

3.1 Single Carrier Generator

We first study the properties of a multi-hop scenario with a single carrier generator assuming the robotic material is embedded within carrier-assisted devices forming a dense network.

International Conference on Embedded Wireless Systems and Networks (EWSN) 2019
25–27 February, Beijing, China

ISBN: 978-0-9949886-3-8

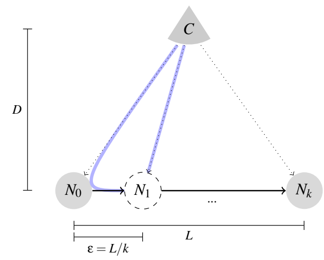

Figure 1. Single-hop and multi-hop scenarios with a single carrier generator (C). Carrier-assisted devices (N_0 $\dots N_k$) are arranged on a regular linear grid of $k+1$ nodes covering the distance L.

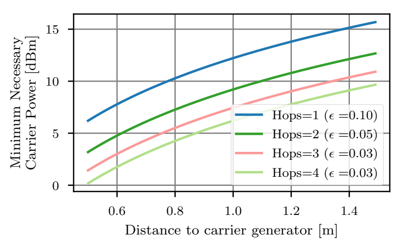

Figure 2. Minimum Carrier Power required for Multiple Hops. As the carrier generator moves away from the nodes, the necessary output power increases. Increasing the number of hops decreases the distance offsets the necessary carrier output power.

Setup. We analyze a setup that consists of one carrier generator and k carrier-assisted devices arranged in a uniform unidimensional grid of spacing ε covering a distance L. We approximate the distance from the carrier generator to the devices as a constant D. Figure 1 represents this setup. We evaluate the minimum carrier generator power needed for the reception using Equation 1. In our analysis we change the density of the network by altering the number k of carrier-assisted nodes deployed over the distance L. We evaluate the dependency of the minimum necessary carrier generator power with the network density.

Result. Figure 2 shows the results. The necessary carrier output power decreases with the distance between transmitter and receiver (ε) as expected. As the carrier generator moves away from the nodes, the necessary output power increases. Increasing the number of hops decreases the distance between consecutive nodes, offsetting the necessary carrier output power. This implies that we can relax the requirements on the carrier's output power by increasing the number of hops and hence the networks' node density.

3.2 Multiple Carrier Generators

We evaluate how multiple carrier generators help reduce the necessary carrier output power of the individual carrier generators in wireless robotic materials.

Setup. We analytically evaluate the same scenario as in Section 3.1 but place multiple carrier generators distributed uniformly in parallel to the line of carrier-assisted nodes that cover the segment L. Figure 3 shows the setup. The distances from the carrier generators to the carrier-assisted devices is much larger than the separation among them ($r_{10} \dots r_{jk} \gg$ $\varepsilon = L/k$).

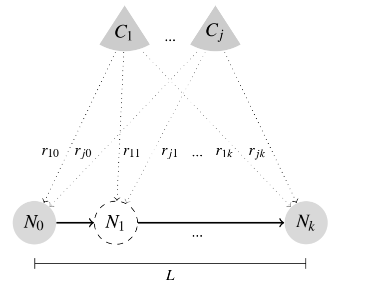

Figure 3. Multiple carrier generators providing carrier for multiple carrier-assisted devices. Messages are relayed by k nodes to traverse the distance L.

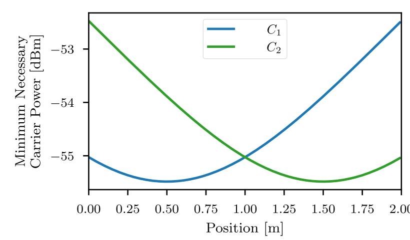

Figure 4. The carrier generator requires minimum power when it is aligned with the carrier-assisted node. The further the distance, higher the power required. After a threshold the carrier source can be transferred to another carrier generator to reduce the necessary power.

Result. Figure 4 depicts the result of the experiment. The further the distance, the higher the power required from any individual carrier generator. After a threshold distance a neighboring carrier generation can take over in assisting to relay a message. This implies that delegating the task of carrier generation to multiple nodes helps reduce the minimum power required from any individual carrier generator.

Suitable Number of Carrier Generators. The result above is useful in situations where one needs to convey a message over a given distance in the robotic material subject to limited carrier power. In such a case, it is possible to compute the number of necessary carrier generators to supplying sufficient carrier power to all nodes.

4 Acknowledgments

This work has been partly funded by the Swedish Research Council (Grant 2017-045989) and VINNOVA.

5 References

[1] C. A. Balanis. *Antenna Theory: Analysis and Design, 3rd Edition*. Wiley-Interscience, Hoboken, NJ, 3 edition edition, Apr. 2005.

[2] N. Correll, P. Dutta, R. Han, and K. Pister. Wireless robotic materials. In *ACM SenSys*, Delft, Netherlands, 2017.

[3] D. Piumwardane, C. Pérez-Penichet, C. Rohner, and T. Voigt. Backscatter communication for wireless robotic materials. In *CoWireless: Workshop on Recent Advances in Wireless Coexistence for Heterogeneous IoT*, Beijing, China, 2019.

[4] C. Pérez-Penichet, F. Hermans, A. Varshney, and T. Voigt. Augmenting IoT Networks with Backscatter-enabled Passive Sensor Tags. In *HotWireless*, New York, NY, USA, 2016.

[5] C. Pérez-Penichet, C. Noda, A. Varshney, and T. Voigt. Battery-free 802.15.4 Receiver. In *IPSN*, Porto, Portugal, 2018.