

Impact of Inter-Tag Interference on Adaptive Multi-Source Ambient Backscatter Communication

Enzo B. Fiock, Carlos H. N. V. Amorim, Jorge G. S. Costa, Daynara D. Souza,
R. M. Rodrigues, André M. Cavalcante and João C. W. A. Costa

Abstract—Ambient Backscatter Communication (AmBC) enables ultra-low-power transmission using ambient radio-frequency (RF) signals for massive Internet of Things (IoT) applications. In dense deployments, however, active tags may cause inter-tag interference, often overlooked in prior work. This paper evaluates a multi-source AmBC system across interference-coupling levels. Three fixed-operation schemes and an adaptive scheme are compared via Monte Carlo simulations. Interference reduces average sum spectral efficiency, with adaptive operation being more robust than fixed-operation schemes. This contrast is evident at 32 dBm, where severe interference causes about 55% loss for HTB, a fixed-operation scheme, compared with only 20% for the adaptive scheme.

Keywords—Ambient Backscatter Communication, Inter-Tag Interference, Spectral Efficiency, Energy Harvesting, Massive IoT.

I. INTRODUCTION

Ambient Backscatter Communication (AmBC) is an ultra-low-power wireless communication technology that enables information transmission through the reflection and modulation of ambient radio-frequency (RF) signals. Its high energy and spectral efficiency make it a promising candidate for massive Internet of Things (IoT) applications and future 6G networks [1], [2]. In this architecture, backscatter devices (BDs), also known as tags, modify their antenna impedance to modulate and reflect ambient signals, eliminating the need for active RF signal generation [3].

In a practical IoT scenario, ambient sources (ASs) correspond to existing RF transmitters, such as 5G base stations or Wi-Fi access points, which provide the RF illumination required for backscatter communication. BDs are ultra-low-power IoT sensors that harvest energy from these ambient signals and transmit their own information by modulating and reflecting the incident waves. The reflected signals are then received by the backscatter receiver (BR), which detects the data sent by each BD. This architecture enables batteryless sensing while reusing the existing wireless infrastructure.

Although this architecture enables energy-efficient IoT applications and significant improvements have been achieved in terms of transmission rate and communication range [4],

balancing energy harvesting and information transmission remains a major challenge in AmBC systems. To address this issue, Power Splitting (PS) and Harvest-Then-Backscatter (HTB) strategies have been widely adopted in RF energy harvesting systems [5]. In PS, each tag simultaneously divides the received RF power between energy harvesting and information backscattering, allowing both operations to be performed at the same time. In contrast, HTB separates these tasks by dedicating an initial portion of the transmission frame to energy harvesting and using the remaining interval for backscatter communication. Consequently, PS generally favors continuous transmission, whereas HTB may harvest more energy under low-power conditions at the cost of a shorter transmission interval. Building upon these strategies, [6] proposes an Adaptive Multi-Source AmBC technique that dynamically selects between PS and HTB operation modes according to the system conditions, improving performance compared to conventional schemes.

Most existing studies do not explicitly account for interference among tags. In dense IoT scenarios, simultaneous tag transmissions may degrade the signal-to-interference-plus-noise ratio (SINR) and reduce the achievable rate. Motivated by this gap, this paper investigates the impact of inter-tag interference in Adaptive Multi-Source AmBC systems with multiple RF sources and multiple tags. For comparison, a traditional AmBC baseline employing a fixed reflection coefficient is also evaluated. Unlike the adaptive scheme, it does not adjust its operation according to channel or harvested-energy conditions. The PS, HTB, Adaptive, and Traditional schemes are evaluated under different transmit power and interference levels, allowing the robustness of each strategy to be assessed.

II. SYSTEM MODEL

This work adopts a multi-source AmBC model based on [6], with K ASs, J BDs, and one M -antenna backscatter receiver (BR). The AS–BR, AS–BD, and BD–BR channels, denoted by g_k , f_k , j , and h_j , respectively, undergo independent Rayleigh fading with distance-dependent path loss.

The total RF power received by BD j from all ASs is

$$S_j = \sum_{k=1}^K P_k |f_{k,j}|^2, \quad (1)$$

where P_k is the transmit power of AS k . The harvested power is modeled as

$$P_{T,j} = \eta S_j, \quad (2)$$

where η is the energy harvesting efficiency.

Enzo B. Fiock¹, Carlos H. N. V. Amorim¹, Jorge G. S. Costa¹, Daynara D. Souza¹, R. M. Rodrigues¹, André M. Cavalcante² and João C. W. A. Costa¹. ¹Applied Electromagnetism Laboratory, Federal University of Pará - UFPA, Belém, Brazil, ²Ericsson Research, Ericsson Telecomunicações Ltda., Indaiatuba, Brazil. E-mails: enzo.fiock@itec.ufpa.br; carlos.vieira.amorim@itec.ufpa.br; jorge.costa@itec.ufpa.br; daynara@ufpa.br; rmr@ufpa.br; andre.mendes.cavalcante@ericsson.com; jweyl@ufpa.br. This work was partially supported by Ericsson Telecomunicações Ltda, CNPq and CAPES.

For the PS mode, the reflection coefficient is

$$\alpha_j = \left[1 - \frac{P_c}{\eta S_j} \right]^+, \quad (3)$$

where P_c is the circuit power consumption and $[x]^+ = \max(x, 0)$. When the harvested energy is insufficient to power the circuit, the effective PS reflection coefficient decreases.

The effective BD–BR channel gain and the effective AS–BR gain after receive combining are respectively defined as

$$H_j = |\mathbf{w}_j^H \mathbf{h}_j|^2, \quad G_{k,j} = |\mathbf{w}_j^H \mathbf{g}_{k,j}|^2, \quad (4)$$

where $\mathbf{w}_j$ is the receive combining vector associated with the detection of BD j . The receiver noise power is assumed to be the same for all BD detections and is denoted by σ^2 .

Differently from [6], this work explicitly includes residual inter-tag interference.

For $x \in \{\text{PS}, \text{HTB}\}$, the SINR of BD j is modeled as

$$\gamma_j^x = \frac{\theta_j^x S_j H_j}{D_j + I_j^x}, \quad (5)$$

where the superscript x denotes the operation mode. Thus, γ_j^{PS} and γ_j^{HTB} represent the SINR of BD j under PS and HTB operation, respectively. The reflection factors are $\theta_j^{\text{PS}} = \alpha_j$ and $\theta_j^{\text{HTB}} = \beta_j$, where β_j is the HTB reflection coefficient obtained from the optimization procedure adopted in [6].

The term

$$D_j = \xi \sum_{k=1}^K P_k G_{k,j} + \sigma^2 \quad (6)$$

represents the denominator contribution due to residual AS–BR direct-link interference and receiver noise. The parameter ξ models the residual direct-link interference after cancellation.

The inter-tag interference terms are given by

$$I_j^{\text{PS}} = \frac{\rho}{J^2} \sum_{\substack{l=1 \\ l \neq j}}^J \alpha_l S_l H_l, \quad I_j^{\text{HTB}} = \rho \sum_{\substack{l=1 \\ l \neq j}}^J \beta_l S_l H_l. \quad (7)$$

The parameter $\rho \in [0, 1]$ is a dimensionless residual interference-coupling factor. It models the fraction of the backscattered contribution generated by active tags that leaks into the detection process of a given desired tag. Therefore, $\rho = 0$ represents an ideal interference-free or perfectly separated multi-tag case, while larger values represent stronger residual coupling among tags. In this work, $\rho = 0.1$, $\rho = 0.3$, and $\rho = 0.5$ are used to represent weak, moderate, and severe inter-tag interference conditions, respectively.

For the PS scheme, the spectral efficiency of BD j is

$$R_j^{\text{PS}} = T \log_2 (1 + \gamma_j^{\text{PS}}), \quad (8)$$

where T is the normalized transmission interval.

For the HTB scheme, the time spent on energy harvesting reduces the effective backscatter transmission time, yielding

$$R_j^{\text{HTB}} = [T - \tau_j]^+ \log_2 (1 + \gamma_j^{\text{HTB}}), \quad (9)$$

where τ_j is the HTB harvesting time.

The adaptive scheme selects the most suitable feasible operating mode for each BD according to its harvested energy

and channel condition. In contrast, the traditional AmBC baseline uses a fixed reflection coefficient and does not adapt its operation mode.

Finally, the average sum spectral efficiency is

$$R_{\text{sum}} = \mathbb{E} \left[\sum_{j=1}^J R_j \right], \quad (10)$$

where R_j is computed from the corresponding PS, HTB, adaptive, or traditional AmBC strategy.

III. NUMERICAL RESULTS

The simulations consider $K = 3$ ASs, $J = 5$ BDs, and a BR with $M = 4$ antennas operating at 915 MHz. The main parameters are summarized in Table I. The results are averaged over 10^4 Monte Carlo realizations. As shown in Fig. 1, the network is deployed in a $7 \text{ m} \times 7 \text{ m}$ area, with the BR located at the center (3.5, 3.5). The ASs and BDs are randomly distributed within the region, forming the RF illumination and backscatter links used in the simulations.

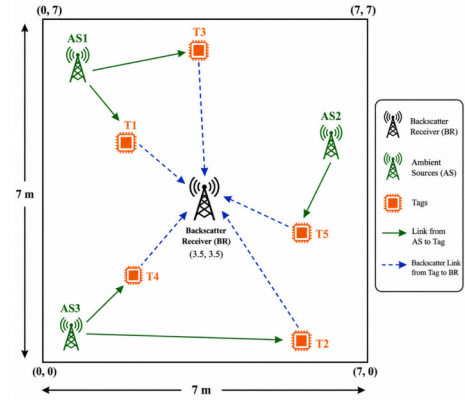


Fig. 1: Example of multi-source multi-tag AmBC topology.

TABLE I: Simulation parameters.

Parameter	Value
Number of ASs, K	3
Number of BDs, J	5
BR antennas, M	4
Carrier frequency	915 MHz
Deployment area	$7 \text{ m} \times 7 \text{ m}$
Energy harvesting efficiency, η	0.6
Circuit power, P_c	$100 \mu\text{W}$
Noise power, σ^2	10^{-12} W
Monte Carlo realizations	10^4
Interference factors, ρ	0, 0.1, 0.3, 0.5

Fig. 2 presents the average sum spectral efficiency versus transmit power for different inter-tag interference levels. The solid curves represent the interference-free case, while the dashed curves represent the cases with an interference factor of $\rho = 0.1$, $\rho = 0.3$, and $\rho = 0.5$. These values correspond to weak, moderate, and severe residual inter-tag coupling, respectively, as described in Section II.

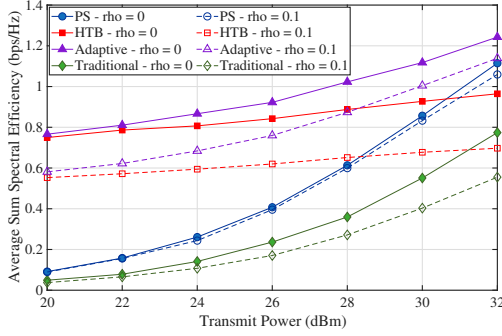
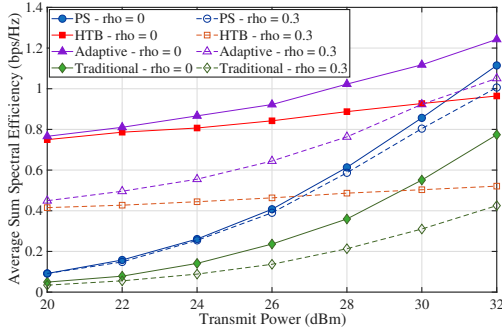
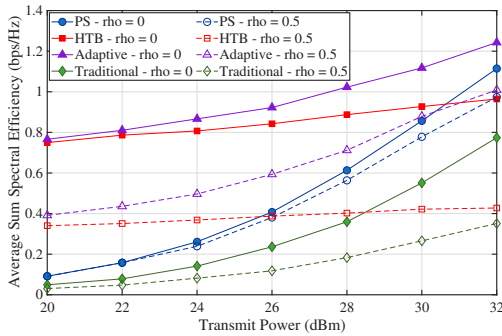

 (a) $\rho = 0$ versus $\rho = 0.1$.

 (b) $\rho = 0$ versus $\rho = 0.3$.

 (c) $\rho = 0$ versus $\rho = 0.5$.

 Fig. 2: Average sum spectral efficiency versus transmit power for $J = 5$ tags under ideal and interference-impaired scenarios.

Looking at the results at 32 dBm, the adaptive scheme provides the best overall performance, reaching approximately 1.25 bps/Hz in the interference-free case. When inter-tag interference is considered, its spectral efficiency decreases to about 1.14 bps/Hz, 1.06 bps/Hz, and 1.00 bps/Hz for $\rho = 0.1$, $\rho = 0.3$, and $\rho = 0.5$, respectively. This corresponds to reductions of approximately 9%, 15%, and 20% compared to the ideal case, showing that the adaptive method is still able to maintain good robustness even as the interference increases.

HTB, on the other hand, shows a stronger degradation. At the highest transmit power, its rate drops from about 0.96 bps/Hz without interference to around 0.70 bps/Hz, 0.52 bps/Hz, and 0.43 bps/Hz, corresponding to losses of about 27%, 46%, and 55%. This occurs because fixed HTB operation is more sensitive to interference from simultaneously active tags. In contrast, PS grows more sharply with transmit power and is less affected by interference, becoming competitive at the highest power levels.

The traditional scheme remains the most limited, especially for $\rho = 0.5$, staying below the other methods. Therefore, the results indicate that inter-tag interference reduces the spectral efficiency of the system, but the adaptive mode can mitigate part of this loss by selecting the most suitable operating strategy according to the channel and energy conditions. This is relevant for dense IoT deployments, where multiple low-power devices may attempt to communicate using the same ambient RF resources.

IV. CONCLUSIONS

This paper investigated inter-tag interference in a multi-source multi-tag AmBC system. Results showed that residual interference among active tags reduces the average sum spectral efficiency, indicating that neglecting this effect may lead to optimistic performance estimates in dense IoT scenarios. The degradation was more pronounced for HTB and traditional AmBC, while the adaptive strategy remained the most robust by selecting the best operating mode according to each BD's channel and energy conditions. Future work may include interference-aware scheduling, adaptive reflection optimization, receiver-side interference cancellation, and more realistic models based on tag positions and channel correlation.

REFERENCES

- [1] International Telecommunication Union, *Analysis on requirements and use cases of ambient power-enabled IoT*, ITU-T, Geneva, Switzerland, Technical Report YSTR.Ambient IoT, Jan. 2025.
- [2] D. Van Huynh, D. T. Hoang, X. Lu, D. Niyato, P. Wang and D. I. Kim, *Ambient Backscatter Communications: A Contemporary Survey*, IEEE Comm. Surveys & Tutorials, vol. 20, no. 4, pp. 2889–2922, 2018.
- [3] V. Liu, A. Parks, V. Talla, S. Gollakota, D. Wetherall and J. R. Smith, *Ambient Backscatter: Wireless Communication Out of Thin Air*, ACM SIGCOMM, pp. 39–50, 2013.
- [4] A. N. Parks, A. Liu, S. Gollakota and J. R. Smith, *Turbocharging Ambient Backscatter Communication*, ACM SIGCOMM, pp. 619–630, 2014.
- [5] X. Lu, P. Wang, D. Niyato, D. I. Kim and Z. Han, *Wireless Networks with RF Energy Harvesting: A Contemporary Survey*, IEEE Comm. Surveys & Tutorials, vol. 17, no. 2, pp. 757–789, 2015.
- [6] D. Cheng, F. Wu, C. Zhang and Y. Liu, *Adaptive Multi-Source Ambient Backscatter Communication Technique for Massive Internet of Things*, Electronics, vol. 14, no. 1532, 2025.