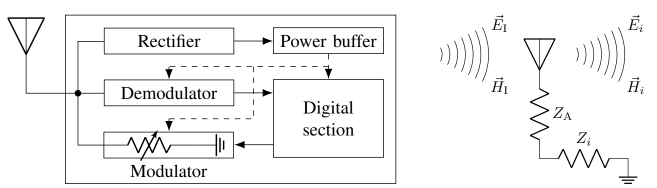
Backscatter Modulation Design for Symbiotic Radio Networks



(a) Block diagram (b) One-port network model

Fig. 1. For a passive tag, the rectifier and demodulator rely on the incident electromagnetic wave for energy harvesting and downlink information decoding, while the load-switcher manipulate the reradiated signal for backscatter modulation.

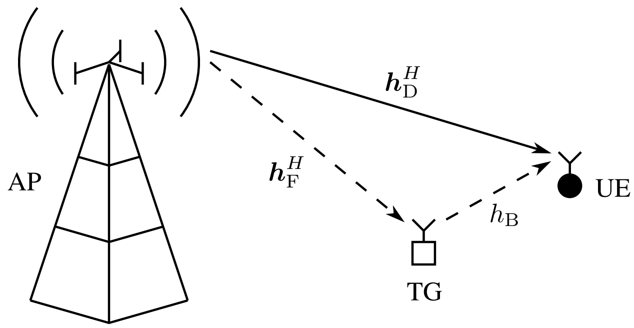


Fig. 2. A single-user single-tag symbiotic radio system.

I. Backscatter Model

A. Backscatter Principles

Consider a bistatic backscatter system that consists of an excitation source, a dedicated reader, and a passive tag. The excitation source generates a carrier wave signal, the dedicated reader decodes the tag message, and the tag simultaneously harvests energy, backscatters its own message, and demodulates the downlink information if necessary. As shown in Fig. 1(a), a typical passive tag consists of a scattering antenna, an energy harvester, a integrated receiver[1], a load-switching modulator, and on-chip components (e.g., micro-controller, memory, and sensors). A portion of the impinging signal is absorbed by the tag while the remaining is backscattered to the space, as illustrated in Fig. 1(b). According to Green's decomposition [2], the backscattered signal can be decomposed into the *structural mode* component and the *antenna mode* component. The former is fixed and depends on the antenna geometry and material properties[2], while the latter is adjustable and depends on the mismatch of the antenna and load impedance. Hence, the equivalent reflection coefficient at tag state i is defined as[3]

$$\Gamma_i = \frac{Z_i - Z_{\mathrm{A}}^*}{Z_i + Z_{\mathrm{A}}}, \tag{1}$$

where Z_i is the designable antenna load impedance at state i and Z_{A} is the antenna input impedance.

Remark 1. *The reflection coefficient plays an important role in various network designs. For example, $\Gamma_i = 0$ (perfect matching) achieves maximum power transfer that is optimal for Wireless Power Transfer (WPT), $|\Gamma_i| = 1$ (perfect mismatching) achieves fully signal reflection that is optimal for Intelligent Reflecting Surface (IRS), and $\Gamma_i \neq \Gamma_j$ (adjustable matching) enables backscatter modulation.*

B. Backscatter Modulation

Tags perform backscatter modulation by switching the load impedance between different states. For M-ary Phase Shift Keying (PSK), the reflection coefficient Γ_i maps to the desired signal constellation point c_i as [5]

$$\Gamma_i = \alpha c_i = \alpha e^{\jmath\left(\frac{2\pi i}{M} + \phi\right)}, \tag{2}$$

where $\alpha \in [0, 1]$ is the reflection efficiency at a given direction, and ϕ is a fixed phase offset.

Remark 2. *For passive tags, the reflection efficiency α controls the tradeoff between the backscatter strength and harvestable power. Interestingly, when $\alpha = 1$, the reflection coefficient set $\{\Gamma_i\}$ of the M-PSK backscatter coincides with that of an ideal discrete M-state uniform IRS. The optimal strategy for the IRS is to choose one reflection state with probability 1 to boost the equivalent channel, while the optimal strategy for the modulator is to utilize all constellation points with equal probability. It inspires one to adaptively design the p.m.f. of tag symbols to jointly benefit the backscatter modulation and passive beamforming.*

II. System Model

[1] For example, [1] prototyped a compact-size pulse position demodulator based on an envelope detector, which brings great potential to coordination, synchronization, and reflection pattern control.

[2] We assume the structural mode reflection can be modeled as part of the environment multipath and covered by channel estimation [3].

[3] We assume the linear backscatter where Γ_i is irrelevant to the incident electromagnetic field at the tag [4].

References

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