WPT Architecture

From the perspective of WPT, the end-to-end power transfer efficiency writes as:

$$e = \frac{P_{\mathrm{dc,ST}}}{P^t_{\mathrm{dc}}} = \underbrace{\frac{P^t_{\mathrm{rf}}}{P^t_{\mathrm{dc}}}}_{e_1} \cdot \underbrace{\frac{P^r_{\mathrm{rf}}}{P^t_{\mathrm{rf}}}}_{e_2} \cdot \underbrace{\frac{P^r_{\mathrm{dc}}}{P^r_{\mathrm{rf}}}}_{e_3} \cdot \underbrace{\frac{P_{\mathrm{dc,ST}}}{P^r_{\mathrm{dc}}}}_{e_4} \tag{1}$$

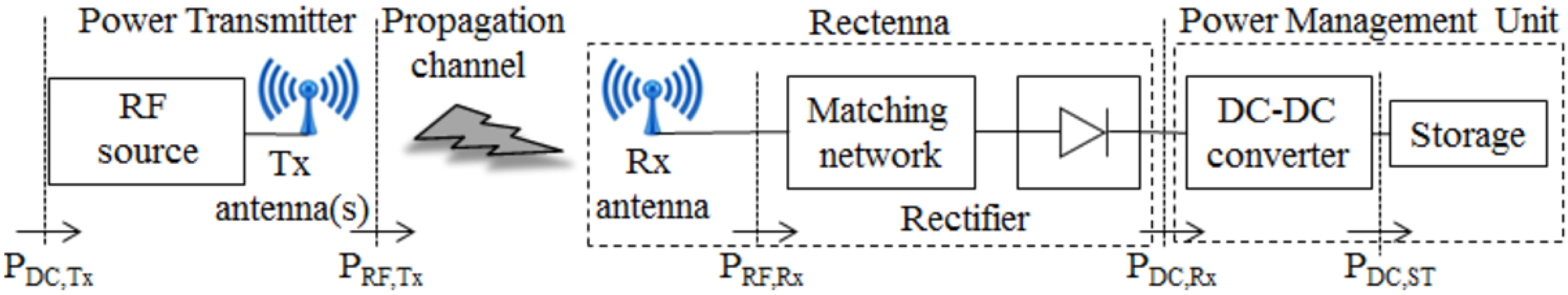

Figure: Block diagram of a conventional far-field WPT architecture [1]. We particularly focus on the rectenna behavior.

The waveform design influences e_1, e_2 and e_3.

The Diode Model

$$i_{\mathrm{d}}(t) = i_{\mathrm{s}}\left(e^{\frac{v_{\mathrm{d}}(t)}{nv_{\mathrm{t}}}} - 1\right) \xrightarrow{\text{Taylor expansion}} i_{\mathrm{d}}(t) = \sum_{i=0}^{\infty} k_i'(v_{\mathrm{d}}(t) - a)^i \xrightarrow{\text{Expectation \& Truncation}} z_{DC} = \sum_{i \text{ even}, i \geqslant 2}^{n_o} k_i R_{\mathrm{ant}}^{i/2} \mathbb{E}\left[y(t)^i\right] \tag{2}$$

Rate-Energy Region

$$C_{R-I_{DC}}(P) \triangleq \left\{(R, I_{DC}) : R \leqslant I, I_{DC} \leqslant z_{DC}, \frac{1}{2}\left[\|\mathbf{S}_I\|_F^2 + \|\mathbf{S}_P\|_F^2\right] \leqslant P\right\} \tag{3}$$

Problem Formulation

We can convert the characterization of R-E region into an energy maximization problem with average transmit power budget P and rate constraint $\bar{R}$

$$\max_{\mathbf{S}_P, \mathbf{S}_I, \rho} \quad z_{DC}\left(\mathbf{S}_P, \mathbf{S}_I, \mathbf{\Phi}_P^\star, \mathbf{\Phi}_I^\star, \rho\right) \tag{4}$$

$$\text{subject to} \quad \tfrac{1}{2}\left[\|\mathbf{S}_I\|_F^2 + \|\mathbf{S}_P\|_F^2\right] \leqslant P, \tag{5}$$

$$I\left(\mathbf{S}_I, \mathbf{\Phi}_I^\star, \rho\right) \geqslant \bar{R} \tag{6}$$

The optimization can be transformed into standard Geometric Programming (GP) problems using Arithmetic Mean-Geometric Mean (AM-GM) inequality.

Geometric Programming

- Monomial: $g(x) = c x_1^{a_1} x_2^{a_2} \cdots x_n^{a_n}, c > 0, a_i \in \mathbb{R}$
- Posynomial: $f(x) = \sum_{k=1}^{K} c_k x_1^{a_{1k}} x_2^{a_{2k}} \cdots x_n^{a_{nk}}, c_k > 0$
- Signomial: $f(x) = \sum_{k=1}^{K} c_k x_1^{a_{1k}} x_2^{a_{2k}} \cdots x_n^{a_{nk}}, c_k \in \mathbb{R}$

A standard GP is an optimization problem of the form

$$\text{minimize} \quad f_0(x) \tag{7}$$

$$\text{subject to} \quad f_i(x) \leqslant 1, \quad i = 1, \dots, m \tag{8}$$

$$g_i(x) = 1, \quad i = 1, \dots, p \tag{9}$$

where f_i are posynomial functions, g_i are monomials, and x_i are the optimization variables.

AM-GM Inequality

The arithmetic mean of non-negative real numbers is greater than or equal to the geometric mean of the same list

$$\frac{x_1 + x_2 + \cdots + x_n}{n} \geqslant \sqrt[n]{x_1 x_2 \cdots x_n} \tag{10}$$

The transformation is based on a conservative approach to approximate the terms with posynomials in the denominator by new posynomials.

Algorithms

- Decoupling: guarantee the same performance by a joint space-frequency design with lower computational complexity
- Lower bound: the theoretical worst performance of the proposed design
- PAPR: practical constraint at the transmitter
- MIMO (suboptimal): consider the information and energy received in different rectennas

B. Clerckx, A. Costanzo, A. Georgiadis, and N. Borges Carvalho, "Toward 1G Mobile Power Networks: RF, Signal, and System Designs to Make Smart Objects Autonomous," *IEEE Microwave Magazine*, vol. 19, no. 6, pp. 69–82, 2018.