Adaptive Mode Switching Algorithm for Dual Mode SWIPT with Duty Cycle Operation

Sungkyunkwan Univ. (SKKU)

Engineering Research Center (ERC)

Jong Jin Park, Jong Ho Moon, Kang-Yoon Lee, and **Dong In Kim**

Motivation : Unified Design of WIT & WPT

WIT **Wireless Information Transfer**	Low receive sensitivity (-60dBm) Long range (~km) Objective: Data rate Modulation and coding scheme (MCS)

WPT **Wireless Power Transfer**	High receive sensitivity (over -10dBm) Short range (~m) Objective: Power efficiency Power management module (PMM)

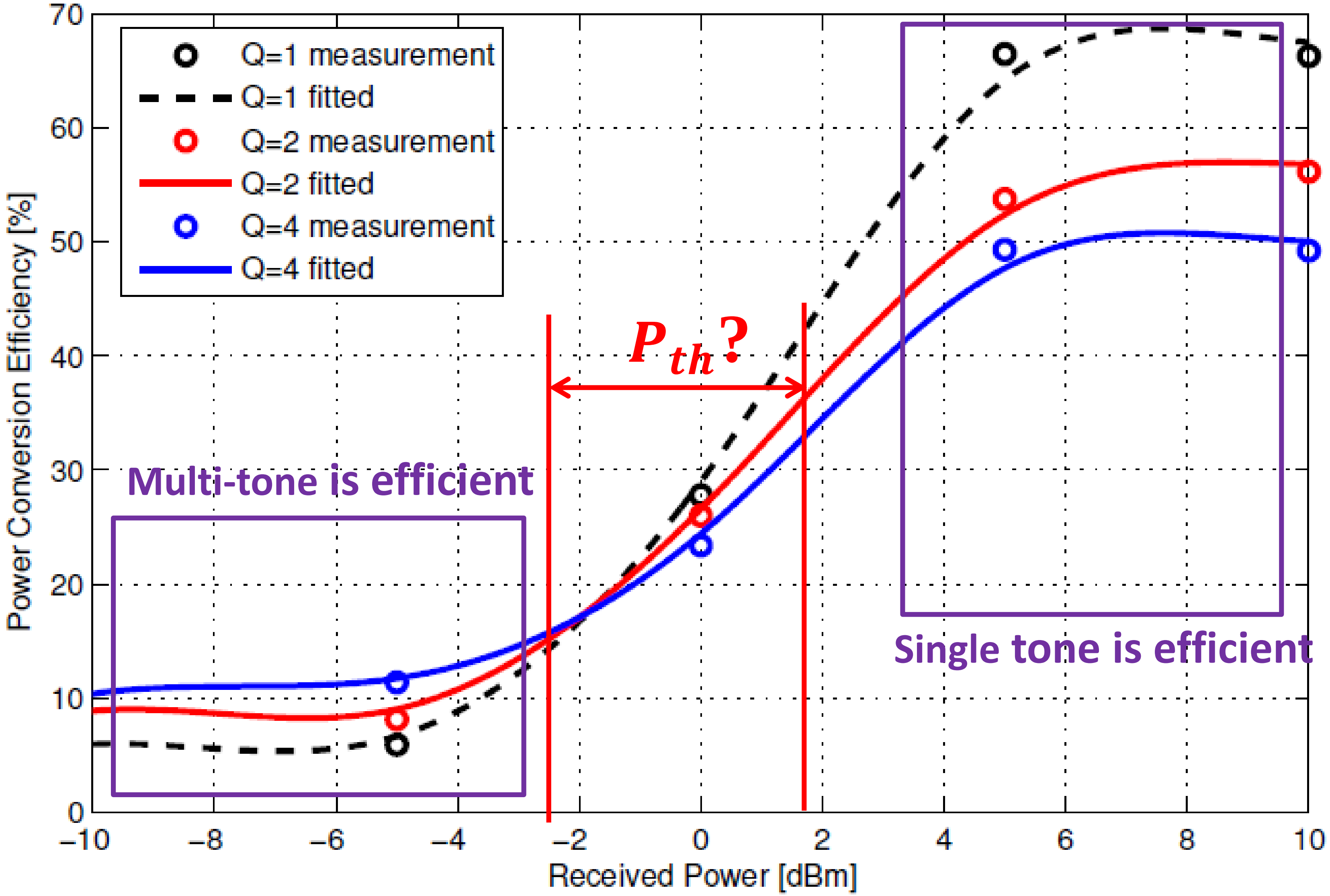
SWIPT

Simultaneous Wireless Information and Power Transfer

For unified SWIPT…

- Requires wide range of receive sensitivity
- Duty cycle operation for self-powering
- Adaptive mode switching (MS) between ID and EH
- Needs R-E tradeoff optimization

Motivation: RF-to-DC PCE of SWIPT



- To improve R-E tradeoff performance
  : Cross-over of PCE !
  → **Mode Switching btw. single/multi-tone**
  - Single tone for high rate, short range
  - Multi-tone for low rate, long range
- Adaptable Mode Switching (MS) threshold (P_{th}) for flexible R-E tradeoff optimization

*PCE: Power Conversion Efficiency

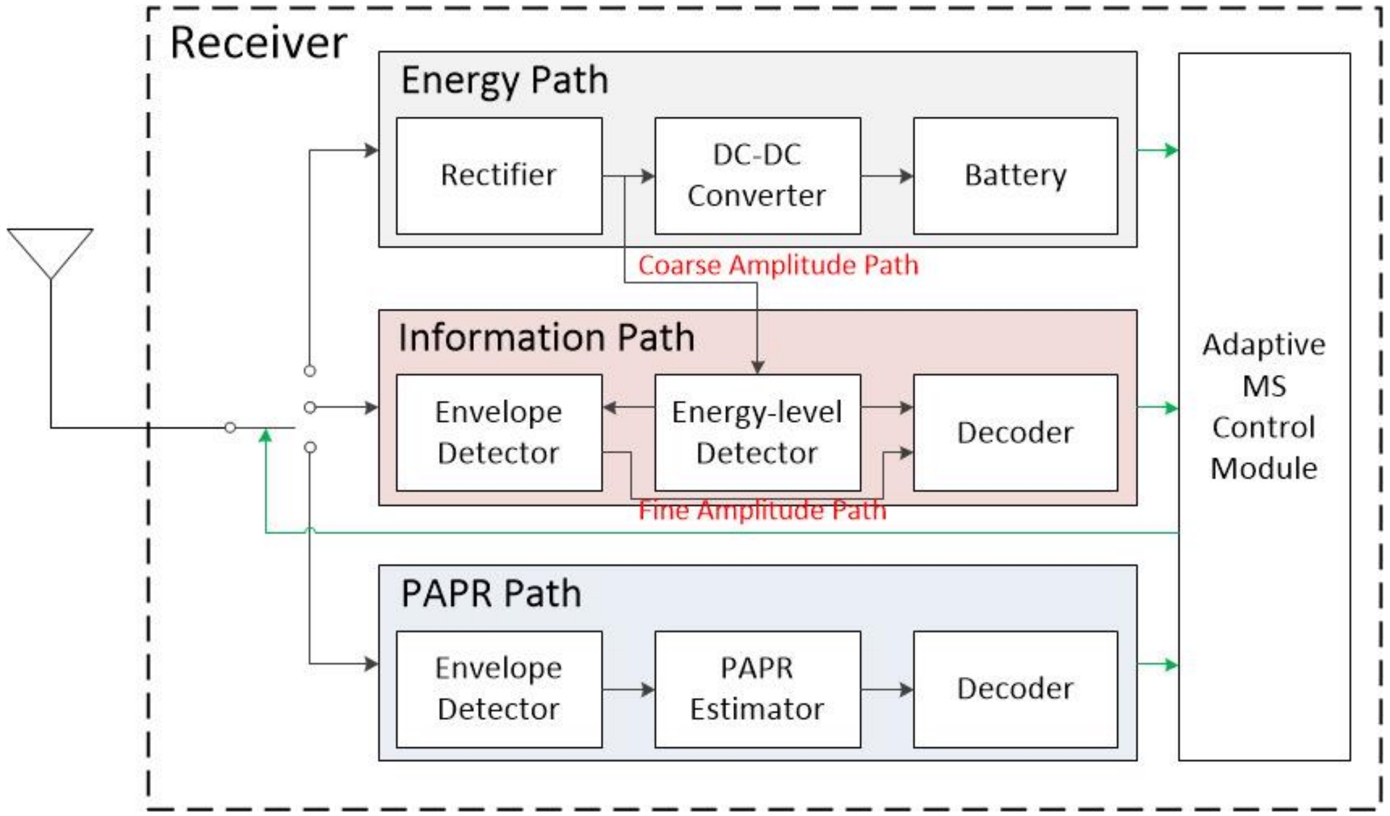
Main Contribution:

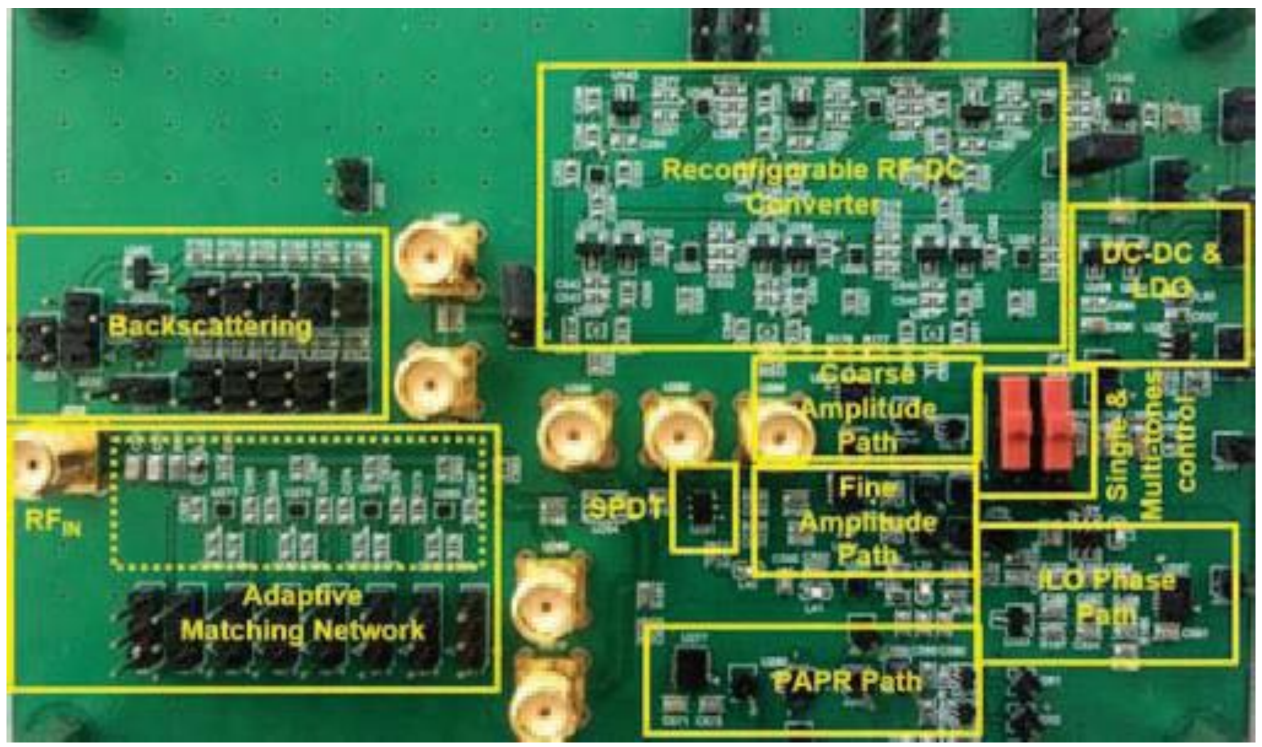
✓ Duty Cycle based Dual Mode SWIPT system

✓ Mixed time-scale Adaptive Mode Switching algorithm

System Model: Dual Mode SWIPT

- Dual Mode SWIPT Receiver





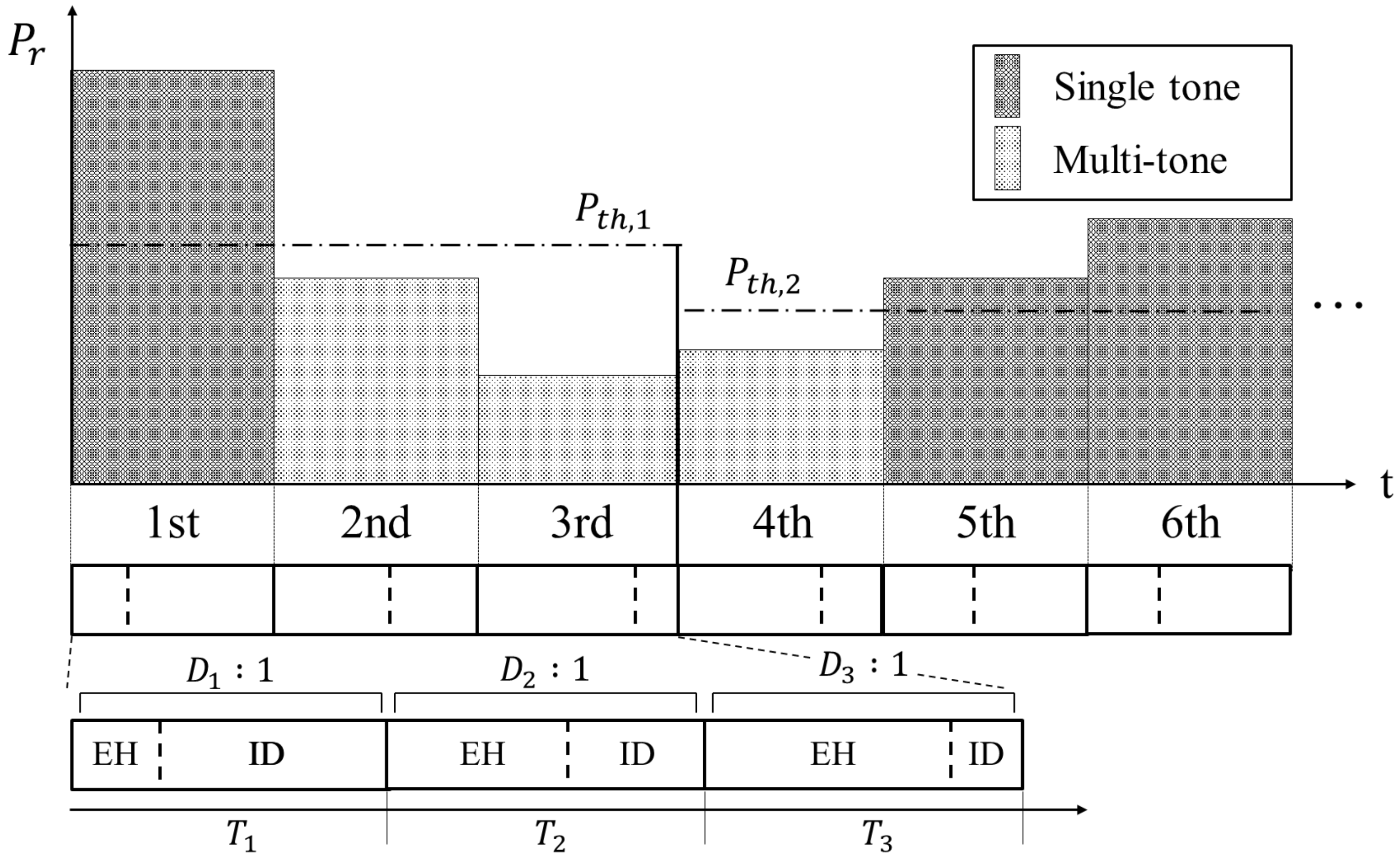
- Harvested energy at Energy Path

$$E_{EH} = \frac{D_v}{D_v + 1} T_v \times \widehat{\Psi}_{EH}(P_R) \times P_R$$

- Data rate at Information/PAPR Path

$$R_v = \begin{cases} \frac{1}{D_v + 1} (1 - p_{out}(M)) \log_2 M , & \text{for single tone} \\ \frac{1}{D_v + 1} \frac{1}{BT_m} (1 - p_{out}(Q)) \log_2 Q , & \text{for multi-tone} \end{cases}$$

$\widehat{\Psi}_{EH}$: Estimated PCE function p_{out}: Outage probability
M: Modulation index Q: # of multi-tone

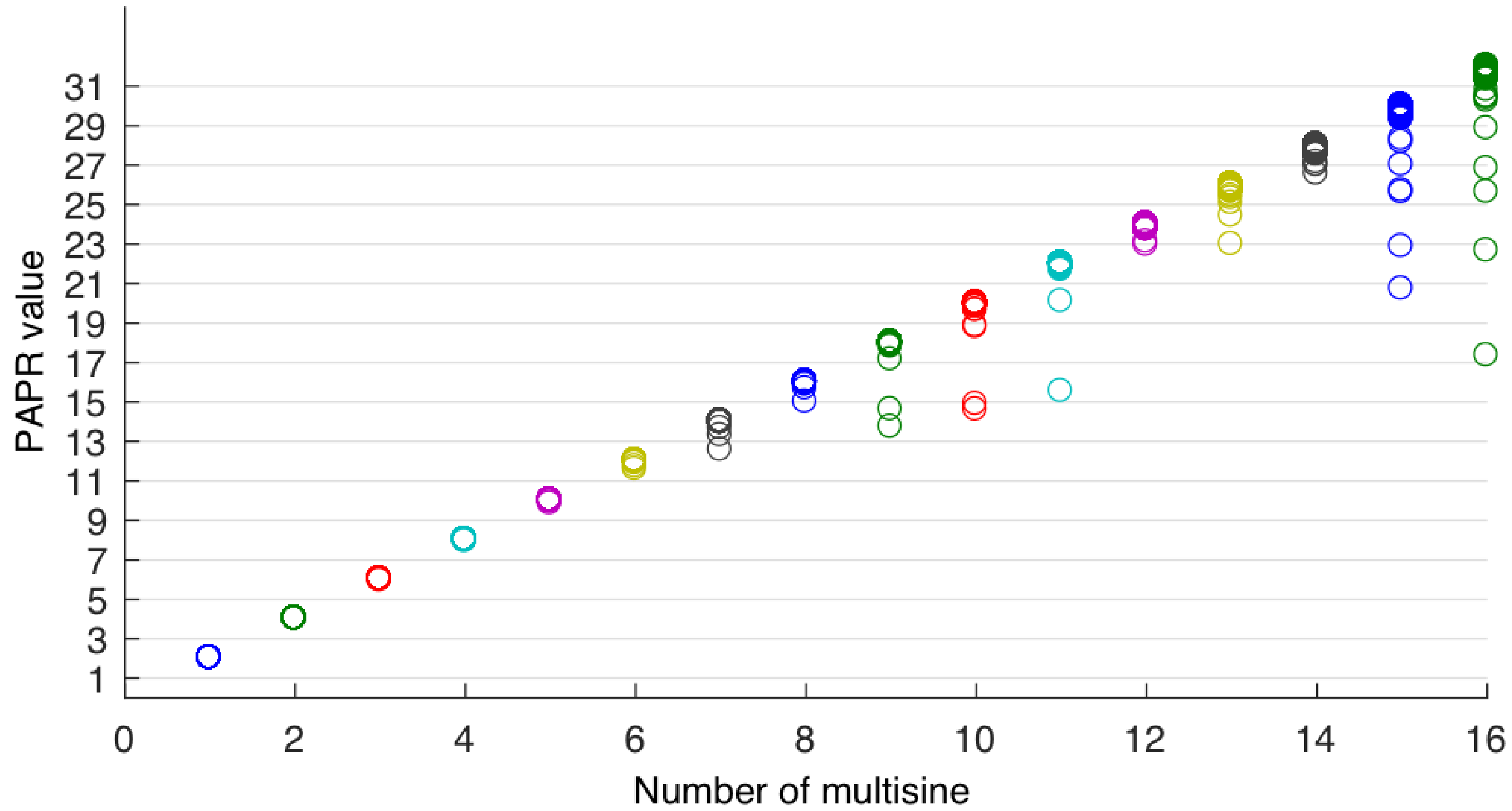


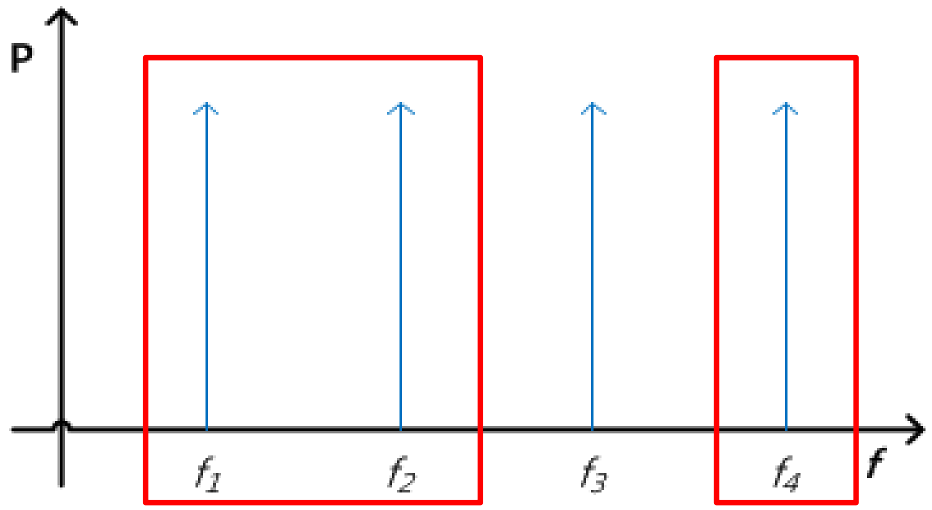
- P_{th} is updated over each long–term window.
- Duty ratio (D_v) is calculated in each channel block.

System Model: Multi-tone/PAPR Modulation

- Example of PAPR modulation:

2bits	N	$PAPR_{RX}$	F_N
[0 0]	1	2	$\{f_{(1)}\}$
[0 1]	2	4	$\{f_{(1)}, f_{(2)}\}$
[1 1]	3	6	$\{f_{(1)}, f_{(2)}, f_{(3)}\}$
[1 0]	4	8	$\{f_1, f_2, f_3, f_4\}$



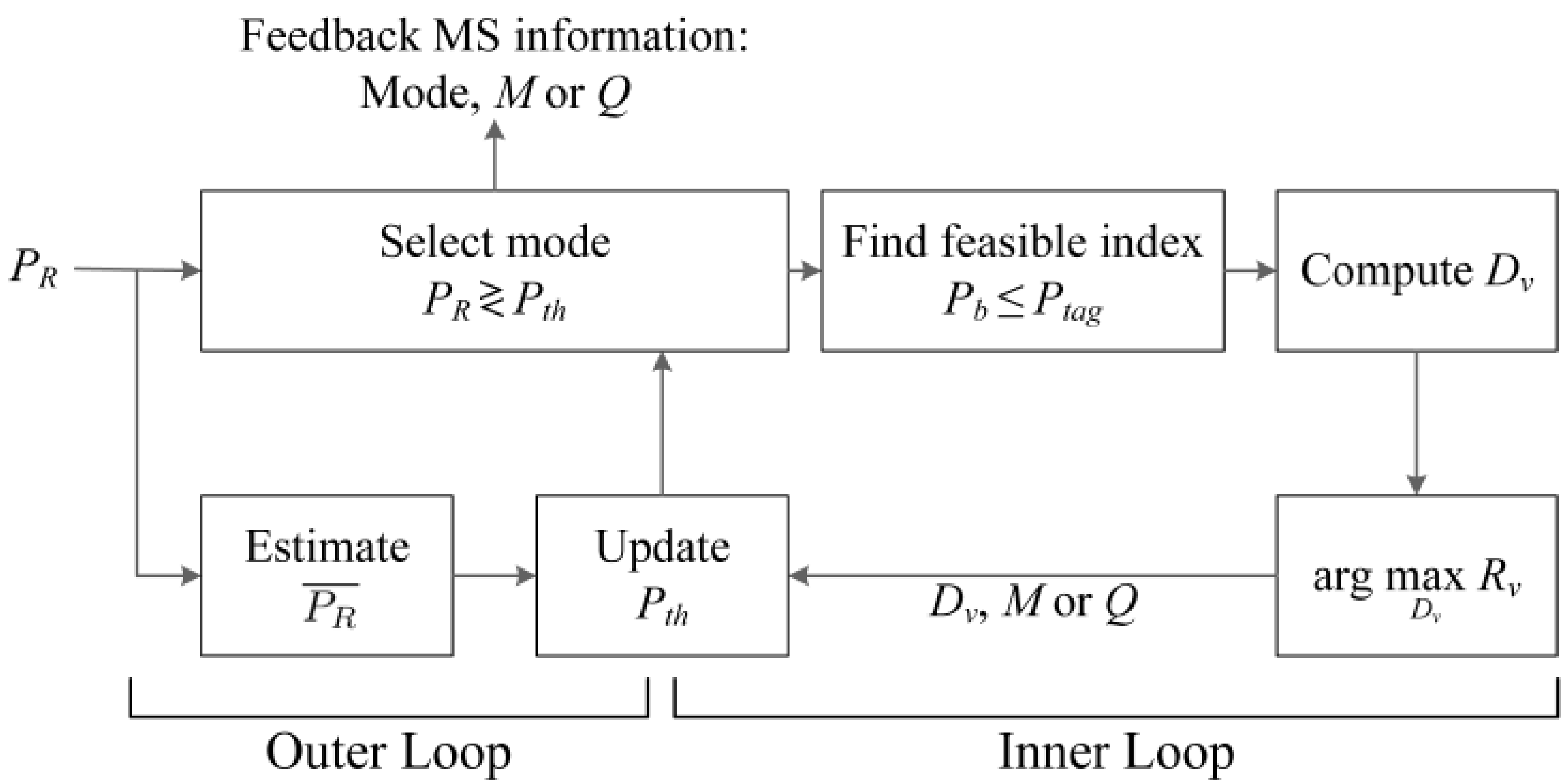


- Receiver just estimates the PAPR value, thus low complexity and low energy consuming.
- The received PAPR at the PAPR estimator:

$$PAPR = \frac{\max_{t\in[0,T_m]} |y_{ID}(t)|^2}{\frac{1}{T_m}\int |y_{ID}(t)|^2 \, dt} \simeq 2N$$

Adaptive Mode Switching Algorithm

- Adaptive MS control module do..
  - Adjust duty ratio (D_v) for self-powering (MS between ID/EH)
  - Proper mode selection between single tone and multi-tone
  - Optimize modulation index (M) and # of multi-tone (Q) for R-E tradeoff
  - Adaptable MS threshold (P_{th}) for flexible R-E tradeoff



  - Outer loop: Update P_{th} → MS between single and multi-tone
  - Inner loop: Update D_v, M or Q → MS between ID and EH

Global Optimization

$$(\text{P1}):\ \max_{P_{th}}\ \mathbf{E}_{\boldsymbol{v}}[R_v]$$
$$\text{s.t.}\quad E_{EH} \geq E_{C,i}$$
$$p_b \leq p_{tag}$$

Long-term Optimization

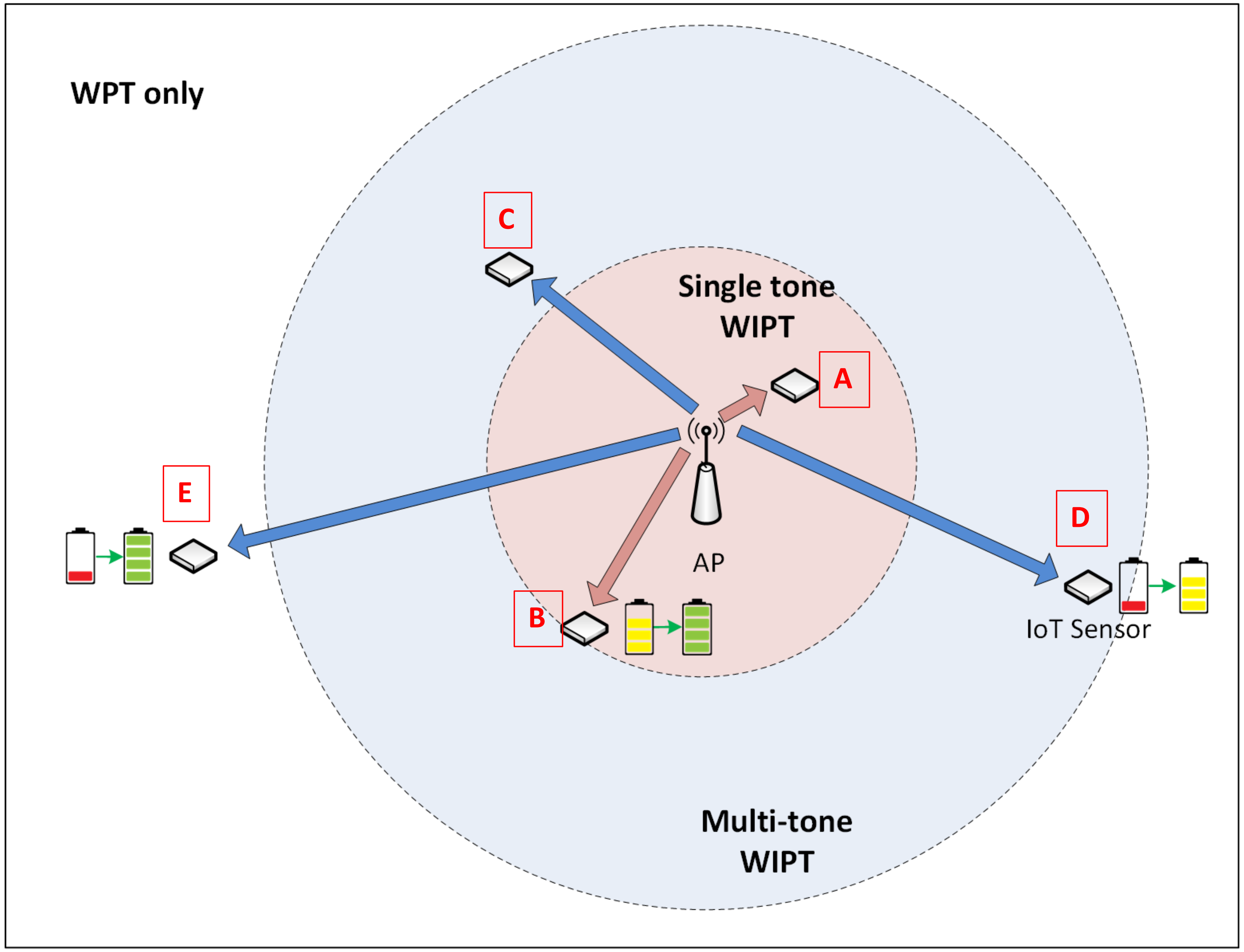
$$(\text{P2}):\ \max_{P_{th}}\ \mathbf{E}_{\boldsymbol{v}}[R_v^*]$$

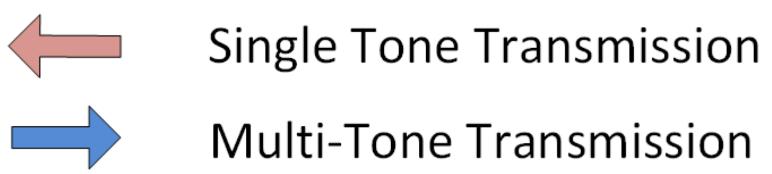
Short-term Optimization

$$(\text{P3}):\ \max_{D_v}\ R_v$$
$$\text{s.t.}\quad D_v \geq \frac{P_{C,i}}{P_{EH}}$$
$$p_b \leq p_{tag}$$

Adaptive Mode Switching Algorithm

- Mode selection example:

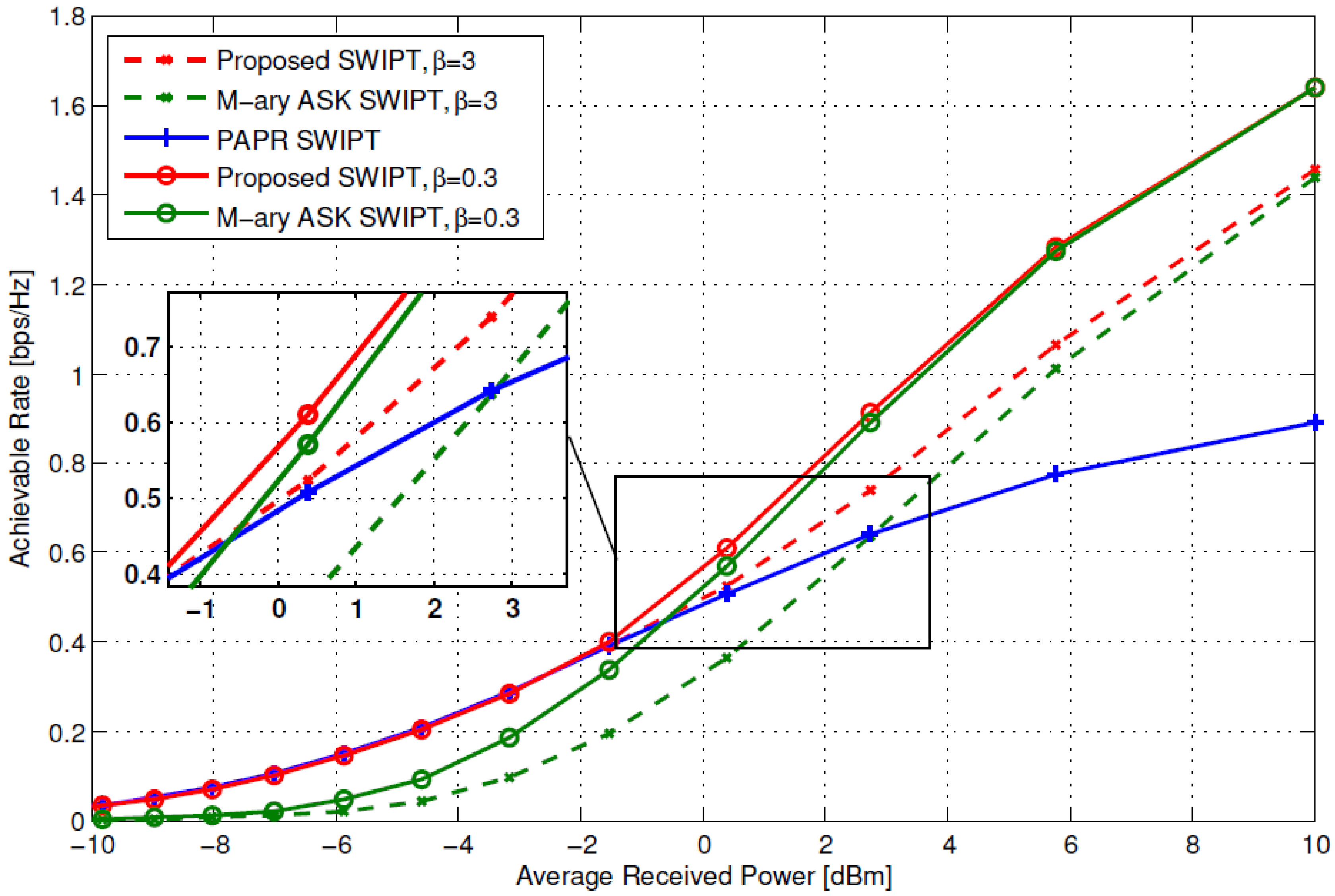




Case	Operation Description
A	Short range, large M for high data rate
B	Single tone but *outage occurred*, switch to multi-tone SWIPT
C	Multi-tone SWIPT, small Q for R-E tradeoff
D	Long range, large Q for self-powering
E	Self-powering *infeasible*, WPT only with maximum Q

Boundary between single and multi-tone is subject to change as P_{th} is updated via each long-term optimization (P2).

Results



Parameter	Value
Fading channel	Frequency-flat Rayleigh fading, 900MHz center freq.
Path-loss exponent	2.5
Transmit power	40dBm
Bandwidth	1MHz
Noise power	-130dBm/Hz
Smoothing parameter	0.3472
Circuit power consumption	Single tone 0.2mW, Multi-tone 0.12mW
Target BER	0.01

β: the ratio of power consumption for channel estimation to that for information decoding (i.e., $\beta = P_{ch,est}/P_{C,s}$).

- Channel estimation affects power consumption:
  - As β increases, the rate is penalized since more power is required.
  - Large β forces P_{th} to be increased → more likely multi-tone mode selection.