Empirical Validation of Energy-Neutral Operation on Wearable Devices by MISO Beamforming of IEEE 802.11ac

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Outline

- Introduction
- System Analysis
- Performance Evaluation
- Empirical Validation
- Conclusion

Introduction

- Existing energy harvesting focus on duty cycling harvesting and multiple antennas
- Space and power division harvesting can concentrate wireless power in one direction
- The MISO beamforming of IEEE 802.11ac represents a promising solution to increase wireless energy harvesting

Technology for energy-neutral operation

- E = P x t

Beamforming | UHF RFID reader
Wi-Fi tag

Principle

The MISO beamforming of IEEE 802.11ac improves energy harvesting for wearable devices to achieve energy-neutral operation

Available Distances of the Node

- Available power for harvesting
  - Available power by the SISO

$$P_{rx}^{ant} = P_{tx}^{ant} \, A_{gain}^{ary} \, G_{tx}^{ant} \, G_{rx}^{ant} \left(\frac{\lambda}{4 \, \pi \, D} \right)^2 \frac{1}{\chi_{fad}^{sha}}, \qquad (1)$$

where the *array gain* A_{gain}^{ary} is given by

$$A_{gain}^{ary} = 10 \log_{10} (N_{tx}). \qquad (2)$$

where N_{tx} is the *number of transmit antennas*

  - Available power by the MISO

$$P_{rx\_en}^{ant} = P_{tx}^{ant} \, B_{gain}^{bf} \, A_{gain}^{ary} \, G_{tx}^{ant} \, G_{rx}^{ant} \left(\frac{\lambda}{4 \, \pi \, D} \right)^2 \frac{1}{\chi_{fad}^{sha}}, \qquad (3)$$

where B_{gain}^{bf} is given by

$$B_{gain}^{bf} = 2 \, \pi \, / \, \theta_{bf}^{ml}, \qquad (4)$$

where θ_{bf}^{ml} is the main lobe degree of the beamforming

Available Distances of the Node

- Average power consumption of the node

$$P_{node}^{avg} = V_{node}\, I_{node}^{avg}, \tag{5}$$

where I_{node}^{avg} is the *average current of the node* that is given by

$$I_{node}^{avg} = I_{node}^{active}\, R_s + I_{node}^{idle}\,(1 - R_s). \tag{6}$$

- Improvements of harvesting power and available distances
  - Harvesting power improvement P_{imp}^{har} from Eqn. (1) and (3) is given by

$$P_{imp}^{har} = P_{rx\_en}^{ant}(Freq\,, D) - P_{rx}^{ant}(Freq\,, D). \tag{7}$$

  - Distance improvement D_{imp} is given by

$$D_{imp} = D_{en}\,(P_{ava}\,, Freq) - D\,(P_{ava}\,, Freq). \tag{8}$$

Performance Evaluation

- Available distances of the node

Table: Simulation parameters for the available distances and improvements

Description	Parameter	Value	Units
No. of APs	N_{ap}	1	set
No. of transmit antennas	N_{tx}	4	set
Frequency of AP	F_{ap}	$2.4, 5$	GHz
Transmit power of AP	P_{ap}	23.45	dBm
Antenna gain of AP	G_{tx}	6	dBi
Antenna gain of node	G_{rx}	5	dBi
No. of node	N_n	1	set
Idle current of node	I_{node}^{idle}	0.4	μA
Active current of node	I_{node}^{active}	19.6	mA
Voltage of node	V_{node}	2.2	V

Performance Evaluation

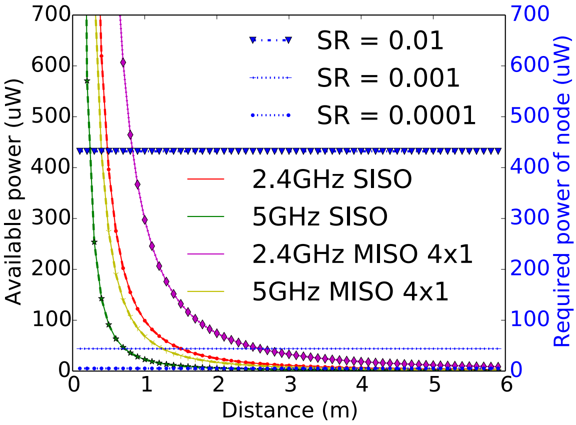

Figure: Available distances based on harvesting and required powers

Performance Evaluation

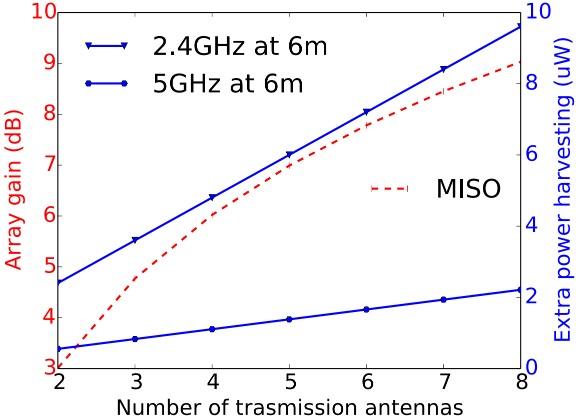

Figure: Harvesting power improvement

Performance Evaluation

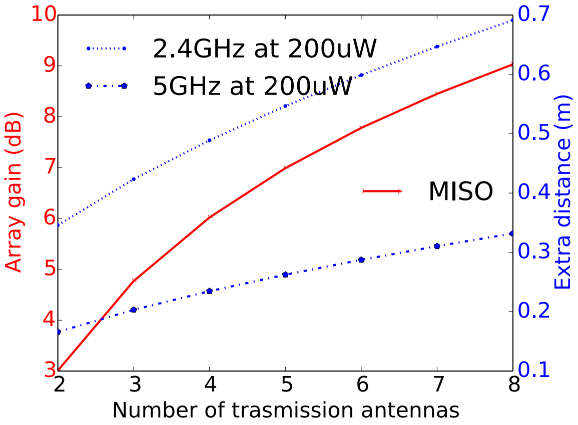

Figure: Distance improvement

Performance Evaluation

- Improvement is a function of the main lobe degree of the beamforming

Table: Improvements on available power and distance

θ_{bf}^{ml}	45°	120°
P_{har}^{imp}	87.5 %	66.67 %
D_{imp}	64.64 %	42.26 %

Performance Evaluation

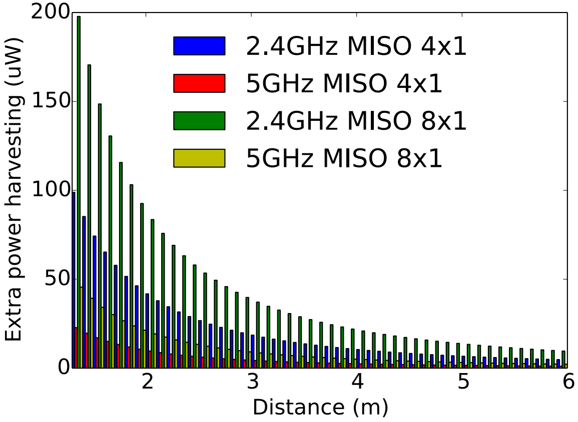

Figure: Extra harvesting power as a function of the distance and the number of antennas

Experiment Setup

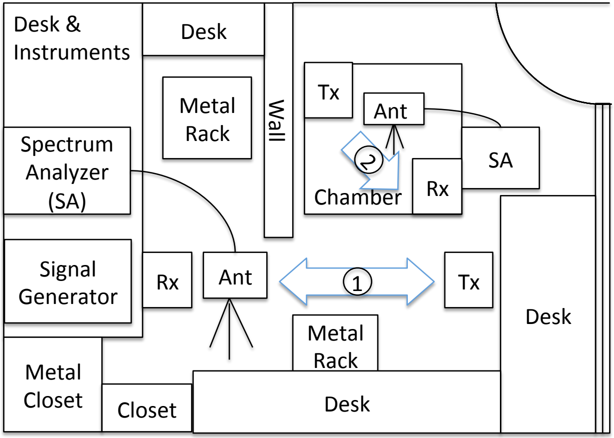

Figure: Floor map for the experiments

Experiment Setup

Figure: Place 1

Experiment Setup

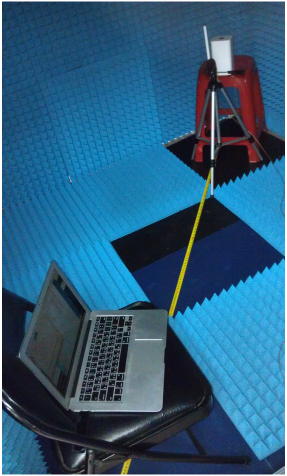

Figure: Place 2

Scenarios

- Case 1 : Moving AE in the Corridor
- Case 2 : Moving Monitoring Antenna in the Corridor
- Case 3 : Moving Monitoring Antenna in the Chamber

Empirical Experimental Results

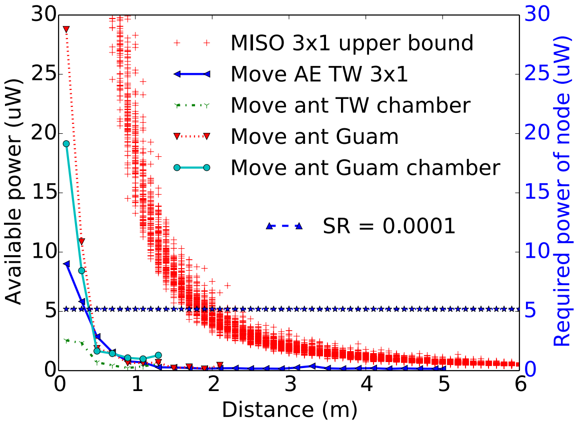

Figure: Empirical experimental results

Characterisations of Experiments

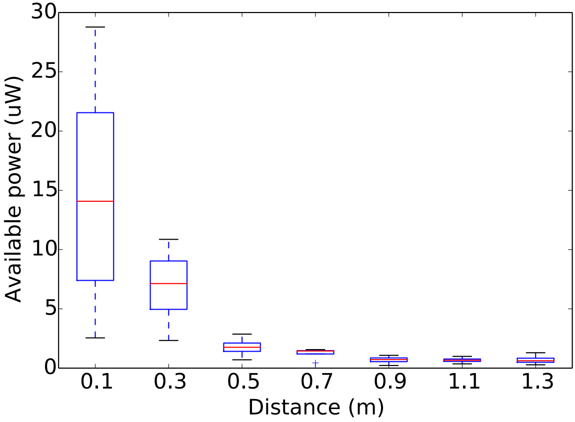

Figure: Characterizations of experiments

Conclusion

- We propose an approach to analysis energy harvesting from an AP and investigate benefits from beamforming
- Emiprical experiments validate the proposed system model
- Future work
    - System model considers Body Area Network (BAN) scenario (ex: channel model or loss)
    - More experiments regarding BAN

Thank you for your attention

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