PhD proposal

for research in wireless information and power transfer

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Education experience

Education

Imperial College London 2018 – 2019
MSc Communications and Signal Processing, expected distinction
University of Liverpool 2016 – 2018
BEng Communications and Electronics, with distinction
Xi'an Jiaotong-Liverpool University[1] 2014 – 2016
BEng Telecommunications, with distinction

[1] A UK-China 2+2 bachelor programme

Work experience

Internship

China Mobile Group Jun 2018

- *Network maintainer*

- Deployed emergency response vehicles for events
- Maintained base stations
- Investigated the coverage of smartcells

China Mobile Group Design Institute Jul 2017

- *Assistant*

- Summarized business solutions of NB-IoT and FDD LTE
- Simulated FDD coverage of Guangdong Province with tower and cell distribution
- Measured LTE performance (RSRP, SINR, CSFB rates) for F and D bands in typical regions

Courses

- Antennas and array processing
- Communication systems
- Computer vision
- Data structure and microprocessors
- Electromagnetics and RF engineering
- Information and coding theory
- Instrumentation and control
- Integrated circuits
- Machine learning
- Power systems
- Probability and stochastic processes
- Signal processing
- Wireless communications

Skills and honors

Skills (in descending order)

- Data collection and analysis
- Comprehension and innovation
- Asking questions
- Programming
- Self-learning
- Academic writing
- Communication and collaboration
- Project management
- Critical thinking

Honors

University achievement award	2016
IET student prize	2018

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Cross-Layer Optimization for 4G Broadband Wireless Communication Networks

Why?

- To meet requirements of various services
- To improve system performance (throughput, delay, packet drop rate)
- To increase spectrum and power efficiency

Where?

- Downlink traffic in OFDM systems
- PHY layer (CSI, capacity)
- MAC layer (traffic characteristics)

What?

- Joint optimization of resource allocation and data scheduling
- Adaptive algorithms with low complexity
- Adjustable weight configuration (queue- and packet-based)

Algorithms

Subcarrier allocation

- Maximum Weighted Capacity (MWC): balance QoS and capacity
- Proportional Fairness (PF): equalize rate for users

Power allocation

- Weighted Water-Filling (WWF): based on subcarrier allocation under equal power assumption (low-complexity but suboptimal)

Data scheduling

- Modified Largest Weighted Delay First (M-LWDF): serve the queues on service nature, delay, and queue length
- Packet Dependent (PD): data is sent packet by packet with individual weight design (depends on QoS, delay, and packet size)

Conclusion and limitations

We investigated the performance for conventional services (background, voice, video) and extended the research to networks with haptic traffic.

Conclusion

- With a flexible transmission scheme, PD provides larger throughput and lower packet drop rate than M-LWDF, especially for heavy traffic (large number of users, low SNR, multiple service types).
- By properly choosing the number of packets for weight calculation, the proposed design requires lower overall complexity than conventional queue-based ones.
- The low-complexity suboptimal power allocation performs similarly to the optimal strategy, as subcarrier allocation has more significant impact on system performance.

Limitations

- Only SISO case is considered.
- There exists fairness issues.

Signal Optimization for Wireless Information and Power Transmission

Why?

- To provide perpetual and reliable energy supply for low-power devices
- To reduce the use of batteries and get rid of wires, with increased operation range
- To improve rate-energy tradeoff in WIPT

Where?

- Transmitter (waveform design, resource allocation)
- Receiver (information decoding (ID) and energy harvesting (EH))

What?

- Nonlinear harvester model and superposed waveform
- Fundamental dependency of harvested power on signal design
- Waveform optimization and rate-energy region characterization

System architecture

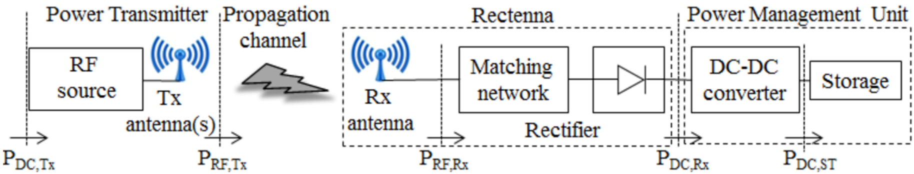


Figure: Block diagram of WPT [1]

RF-to-DC conversion efficiency e_3: rectenna and waveform design

Rectenna model

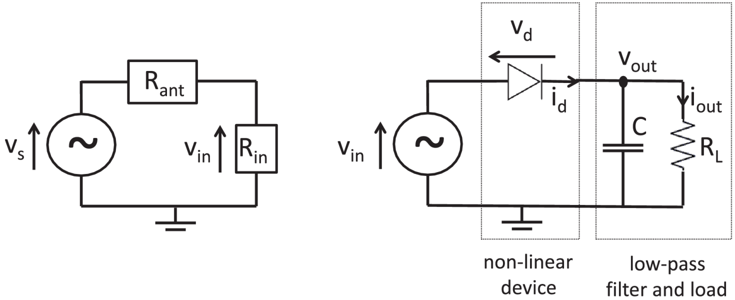


Figure: Rectenna equivalent circuit (left) and a single diode rectifier (right) [1]

- Diodes account for the nonlinearity
- Taylor expansion of diode characteristic equation (small-signal model)
- Truncate to the n_o-th order
  - diode linear model ($n_o = 2$): output power is proportional to input power
  - diode nonlinear model ($n_o > 2$): significant contributions of higher order terms

Waveform design and receiver architecture

A superposed signal containing modulated information waveform and multisine power waveform is demonstrated to bring a two-fold benefit:

Benefits of proposed waveform

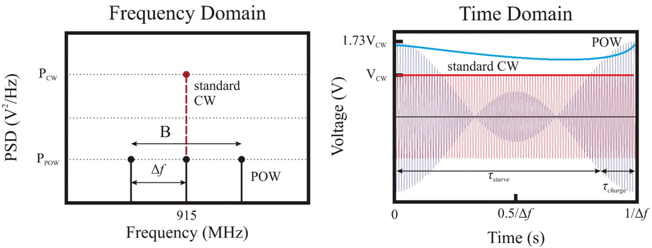
- **rate**: multisine is deterministic with no interference on information component
- **energy**: multisine reduce the threshold to enjoy the benefit of diode nonlinear model (-20 dBm to -30 dBm)

Two receiver architectures are available:

Receiver architectures

- Time Switching (TS): switch between EH and ID on time basis
- Power Splitting (PS): split the received signal into separate portions

Multisine



(a) Frequency domain (b) Time domain

Figure: Comparison of 3-subcarrier multisine and continuous wave (modified from [2]). The thick lines are typical rectifier output voltage.

Characteristics

- High peak-to-average power ratio (PAPR)
- Concentrated power triggers the diode
- Pulse amplitude determined by number of tones N

Algorithms

The optimization is based on geometric programming (GP) using CVX. We aim to maximize harvested current subject to transmit power and rate constraints. The following cases are being investigated:

Algorithms

- Decoupling spatial and frequency design
- Lower-bound (assume interference from power waveform)
- No multisine waveform
- PAPR constraint
- MIMO (suboptimal by GP)

Conclusion and limitations

We explored the impact of subcarrier number and SNR on rate-energy tradeoff. PAPR and MIMO require further simulations.

Conclusion

- With a large number of subcarrier ($N \geqslant 4$), the superposed waveform is useful to enlarge the rate-energy region.
- TS is favoured for large N and low SNR; PS on the contrary.
- Number of Rx has significant influence on rate-energy tradeoff.

Limitations

- GP is suboptimal for multiple Rx.
- The iterative algorithms are sensitive to initialization and take long time to solve for large N and Rx.
- It requires perfect CSIT.
- (To be fixed) If initialized with previous solutions, the algorithm may collapse due to precision issues.

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Questions and ideas

Let's start with some questions and novel ideas:

Questions

- What's the optimal resource allocation strategy for MIMO?
- How to reduce the complexity while maintaining the performance?
- Are there any other harvester models?

Ideas

- Improve RF-to-DC conversion efficiency with multiple rectifiers [3]
- Encode information with PAPR of multisine rather than individual waveform [4, 5]
- Switch between single and multi-tone transmission adaptively to CSI and rate requirement [4]

Motivations

In industry

- To prolong the lifetime for mobile devices
- To reduce the cost in battery recharging and replacement
- To make devices smaller and lighter

In academia

- To propose a low-complexity suboptimal waveform design for WIPT
- To investigate the performance of tone-index multisine modulation on FF and FS channels
- To explore the possibility of dual-mode WIPT for MIMO systems with multiple harvesters

Proposed system architecture

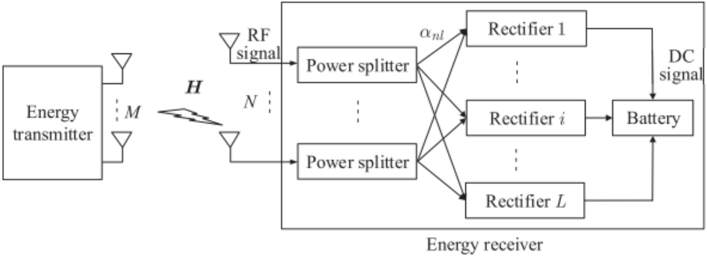

Figure: System architecture of the MIMO multi-rectifier WIPT system [3]

Each receive antenna is followed by a power splitter to reallocate the power:

- when the received power level is relatively low, the splitters will combine all energy branches in one rectifier to enjoy the benefit of harvester nonlinearity.
- when the power is sufficiently high, the components will be equally divided to avoid the saturation of diode breakdown region.

Transmitter

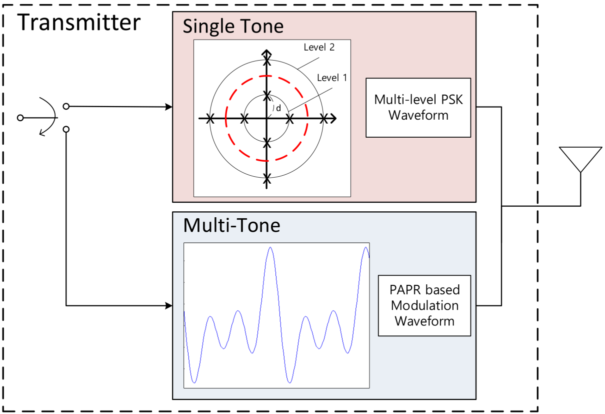

Figure: Transmitter architecture [4]

Transmitter

Transmitted waveform

- **single-tone**: phase- and amplitude-modulated, optimized for information transmission
- **multi-tone**: PAPR-modulated, optimized for power transmission
- The transmission mode depends on the adaptive mode-switching algorithm to design

Receiver

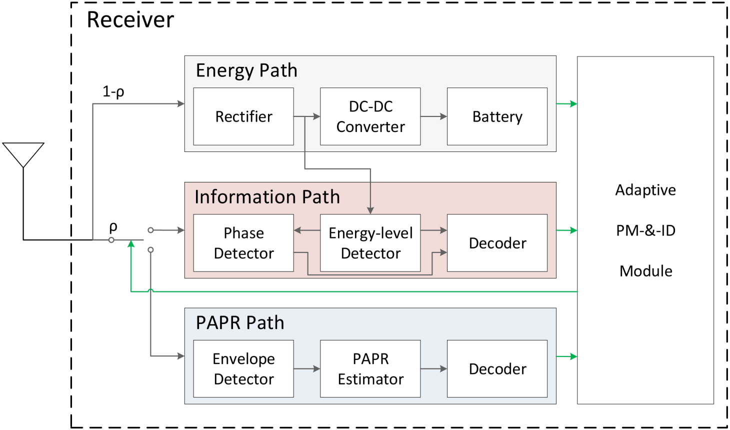

Figure: Receiver architecture [4]

Receiver

Receiver blocks

- **energy path**: harvest energy and supply information path or store in battery
- **information path**: demodulate phase and amplitude information [for single-tone mode]
- **PAPR path**: decode PAPR-based information [for multisine mode]

Two possible ways:

- One unified energy path, harvests power only
- One energy path for each receiver, decodes amplitude information as well

Comments

Advantages

- Optimization on the mode-switching design is with lower complexity than superposed waveform.
- We expect a significant larger rate-energy region with multi-harvester MIMO.
- The operation range can also be increased.

Opportunities

- Harvester model: diode models vs logistic curve fitting models [6]
- CSIT: perfect vs imperfect
- Receiver strategy: PS, TS vs antenna switching [7]

Timeline

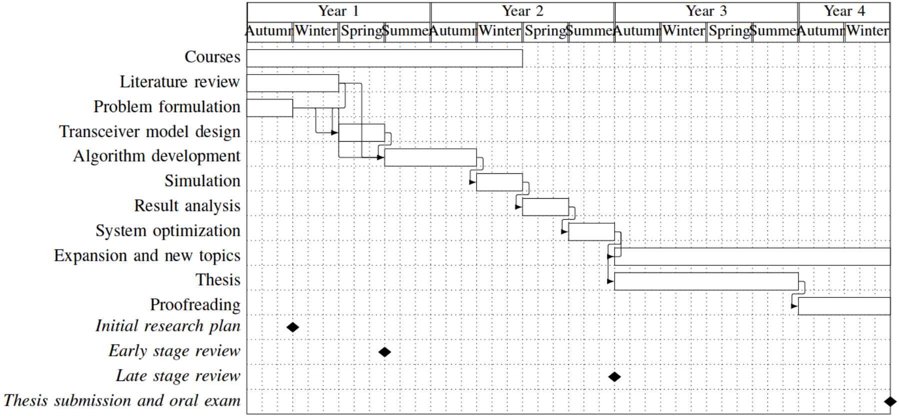

Figure: Gantt chart of the project

Thank you!

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J. J. Park, J. H. Moon, K. Y. Lee, and D. I. Kim, “Dual Mode SWIPT: Waveform Design and Transceiver Architecture with Adaptive Mode Switching Policy,” *IEEE Vehicular Technology Conference*, vol. 2018-June, pp. 1–5, 2018.

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