Huixin DONG, Wei KUANG, Fei XIAO, Lihai LIU, Feng XIANG, Wei WANG, Jianhua HE, 2022. Ultra-low-power backscatter-based software-defined radio for intelligent and simplified IoT network. *Frontiers of Information Technology & Electronic Engineering*, 23(1):19-30. https://doi.org/10.1631/FITEE.2100321

Ultra-low-power backscatter-based software-defined radio for intelligent and simplified IoT network

Front Inform Technol Electron Eng

Key words: Backscatter; Ultra-low-power SDR; IoT networks

Corresponding author: Fei XIAO
E-mail: feixiao@hust.edu.cn
ORCID: https://orcid.org/0000-0003-0889-1779

Motivation

- Internet of Things (IoT) network, known for high energy efficiency and low maintenance cost, has gained great attention for its application, such as smart factory and logistics.
- Protocol design of IoT communication system is a hotspot of IoT research. However, researchers are handicapped by the lack of an energy-efficient software-defined radio (SDR) platform for fast implementation and experimental evaluation in power-constrained IoT scenarios.

Front Inform Technol Electron Eng

Table 1 Comparision between different SDR platforms

Platform	Sleep power	Standalone	Cost
USRP B200mini	Not support	No	$733
LimeSDR mini	Not support	No	$159
PlutoSDR	Not support	No	$159
μSDR	320 mW	Yes	$149
Galiot	350 mW	Yes	$60
TinySDR	33 μW	Yes	$55
Our design	10 μW	Yes	$60

Platform design

- Configurable baseband process and modulation method
- Passive downlink communication based on envelope detector
- Robust energy harvester and power management with suitable duty-cycle
- Ultra-low mixer based on radio frequency (RF) switch and selectable terminal impedance

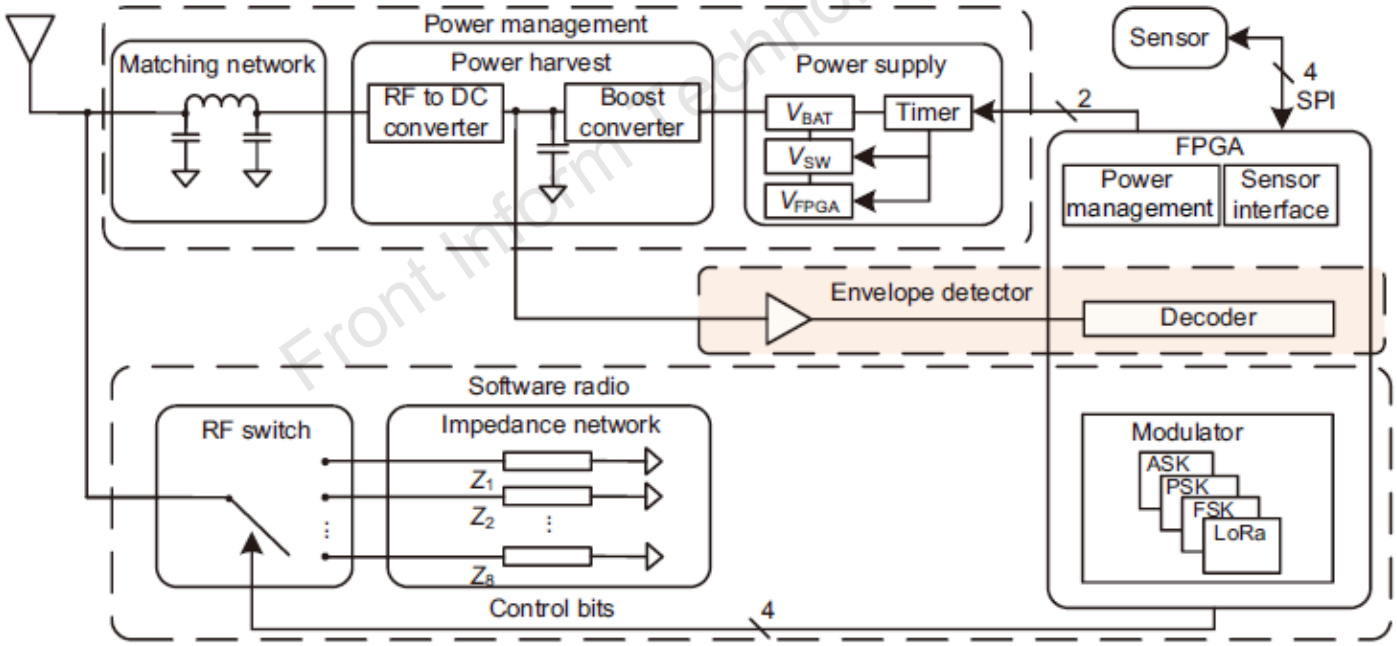

Fig. 2 Hardware system block diagram

Front Inform Technol Electron Eng

Platform and BOM table

- Prototype is fabricated in FR4 substrate.
- Integrate the modules of baseband process, modulation and demodulation, power management, and mixer without using any active RF front-end components.

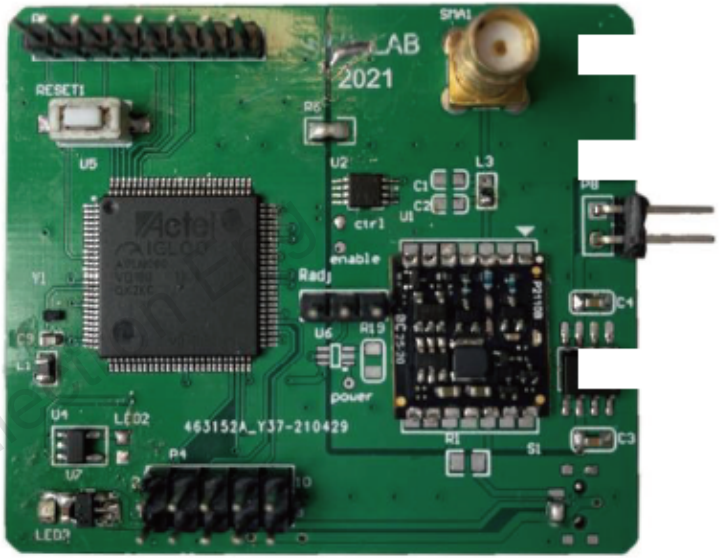

Fig. 1 Battery-free backscatter platform for IoT networks

Table 2 Bom table of the platform

Component	Sleep power	Active power	Cost	Description
AGLN250	Shut down	200 μW	$10	FPGA
ADG904	Shut down	5.4 μW	$6	RF switch
SiT1576	Shut down	10.8 μW	$1	Oscillator
TPL5111	65 nW	65 nW	$0.5	Timer
P2110B			$35	Energy harvester
AVXbest Cap	5 μW		$5.4	Super-capacitor
TPS78218	1.5 μW	1.5 μW	$0.2	LDO
TPS73612	1.5 μW	1.5 μW	$0.8	LDO
Lumped elements	2 μW	2 μW	$0.1	

Experiment setup

Experiment scene

- A single-tone carrier transmitter with a power amplifier to amplify the signal to 29 dBm.
- Oscilloscope to show the working states of the platform, i.e., sleeping to charge and waking to work.

Evaluation results

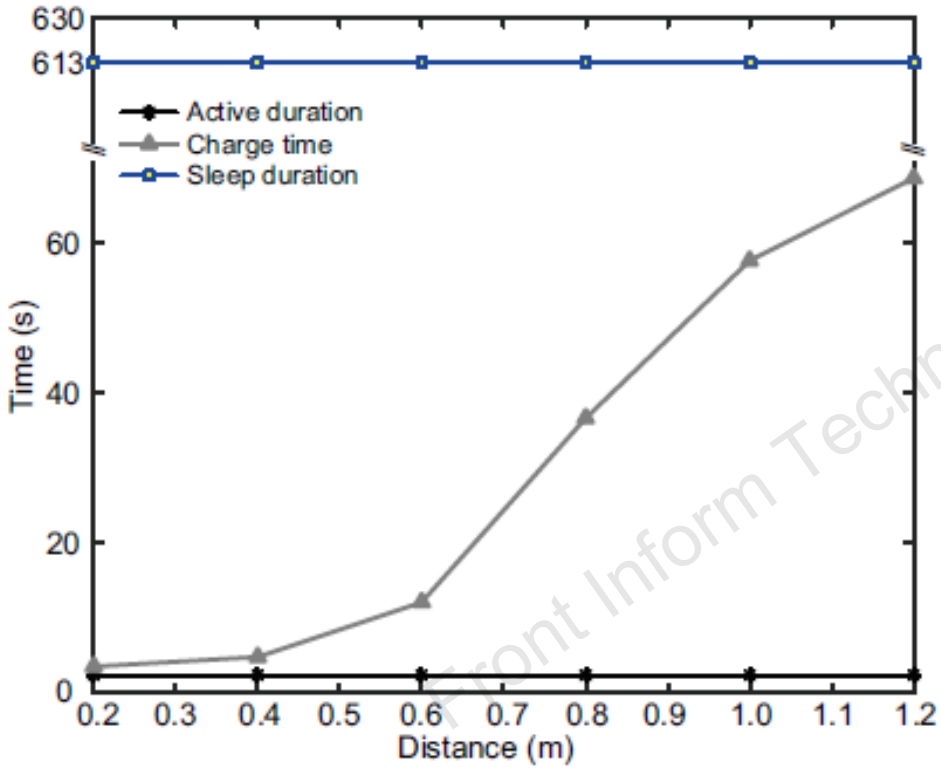

Fig. 5 Energy harvesting performance

- A 100-mF super-capacitor is used for energy storage.
- The capacitor can be fully charged in 60 s at a distance of 1 m.
- In sleep mode, the energy stored in the capacitor can support our platform for 613 s.
- In active mode, the energy stored in the capacitor can support our platform for 2.38 s.

Front Inform Technol Electron Eng

Evaluation results

- In ASK modulation, the traditional modulation and backscatter-based modulation have a similar effect.
- In FSK and PSK modulations, the traditional modulation is better than the backscatter-based modulation at a low signal-to-noise ratio (SNR).
- Backscatter-based modulation using Hamming(7,4) code has some improvement at a low SNR.

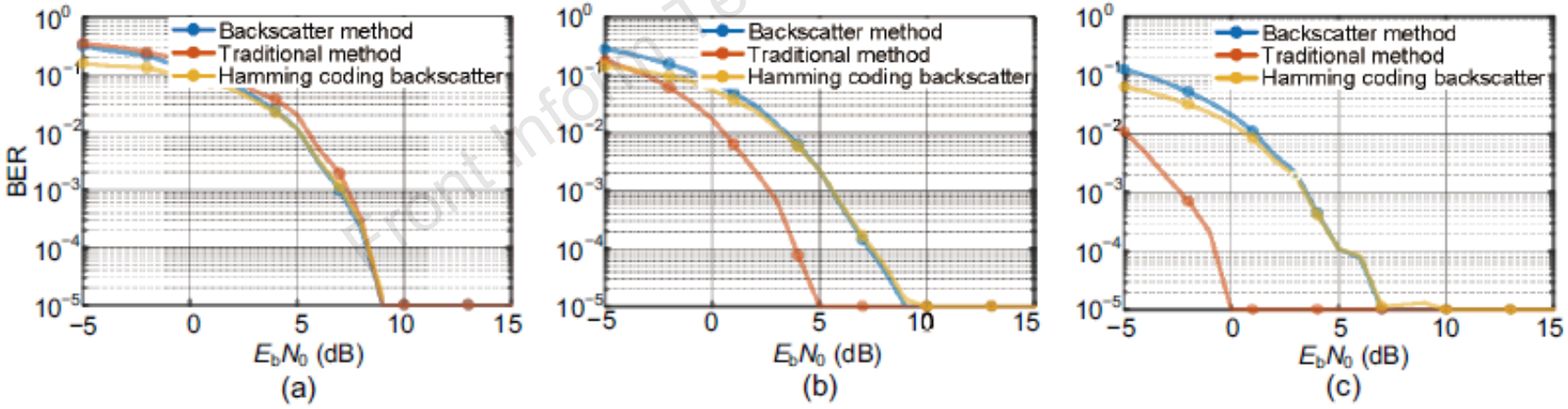

Fig. 6 Comparison of modulation results between the traditional method and backscatter-based method: (a) ASK; (b) FSK; (c) PSK

Potential applications

- Railway monitoring (achieved)
- Logistics distribution
- Intelligent factories

(a)

(b)

Fig. 7 Case study on railway monitoring: (a) railway sensor monitoring system; (b) deployment test on railway

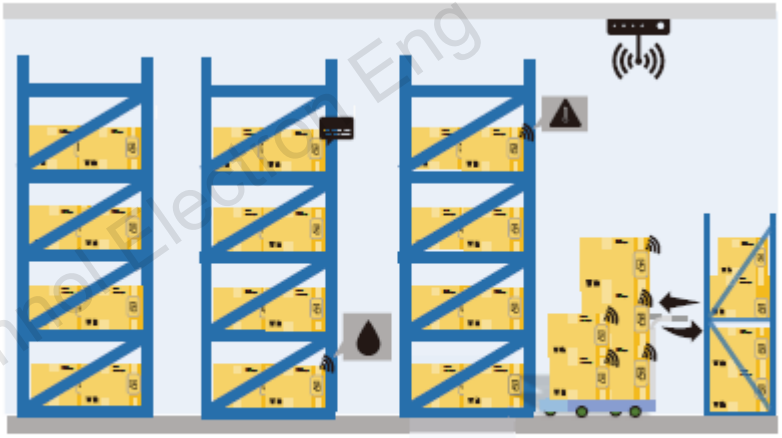

Fig. 8 Potential use of backscatter-based SDR nodes in logistics distribution systems

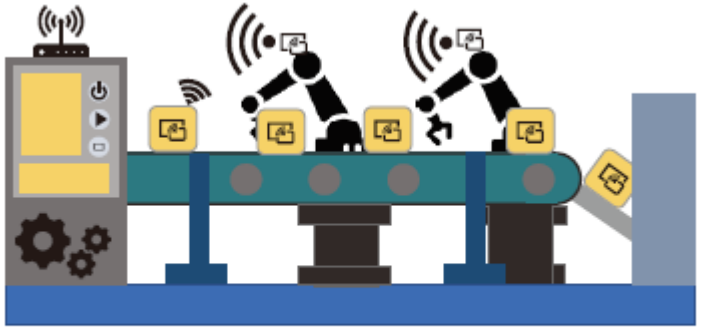

Fig. 9 Potential use of backscatter-based SDR nodes in intelligent factories

Conclusions and future directions

Conclusions:

- This study takes the first step toward SDR design by employing μW-level backscatter technology for battery-free IoT nodes, and provides a prototype for verification.

Future directions:

- Energy efficiency management during communication, which can improve the performance of the platform.
- Large-scale passive backscatter network management, which is necessary in an extensible passive network.
- Concurrent communication and sensing in passive backscatter networks, which is important in factories and logistics with a large amount of goods.

Front Inform Technol Electron Eng