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

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

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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.

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
μ SDR	320 mW	Yes	\$149
Galiot	350 mW	Yes	\$60
TinySDR	33 μ W	Yes	\$55
Our design	10 μ W	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

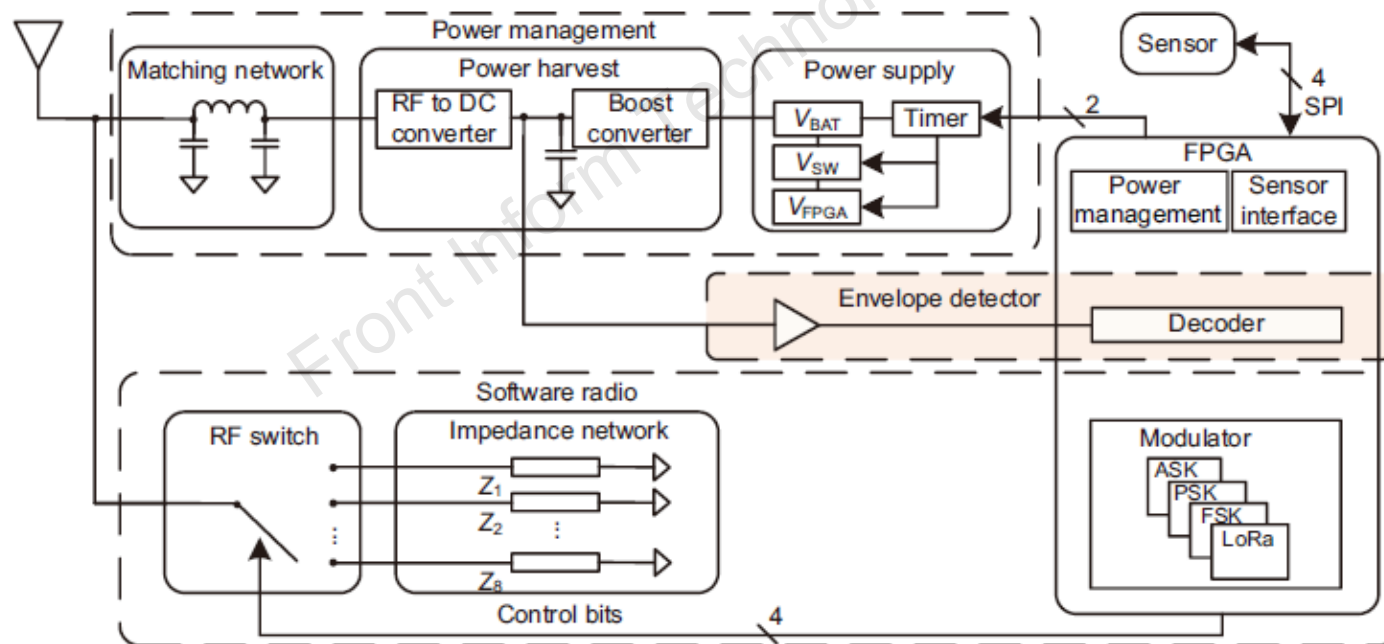


Fig. 2 Hardware system block diagram

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.

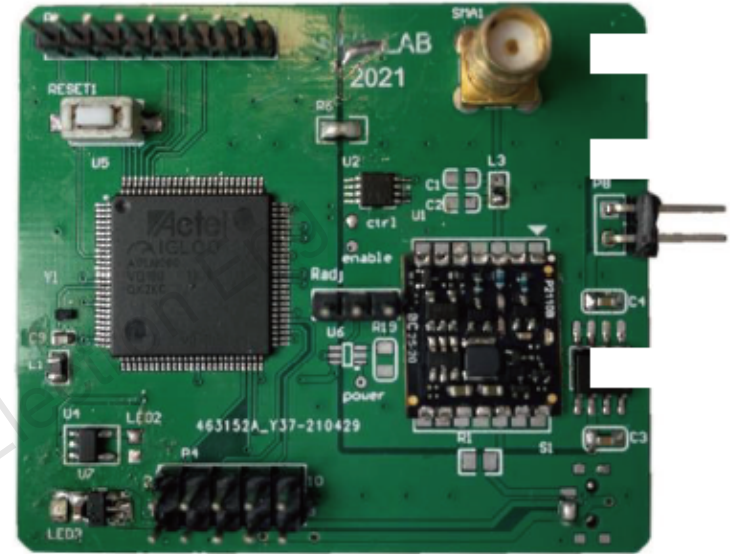


Fig. 1 Battery-free backscatter platform for IoT networks

Table 2 Bom table of the platform

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

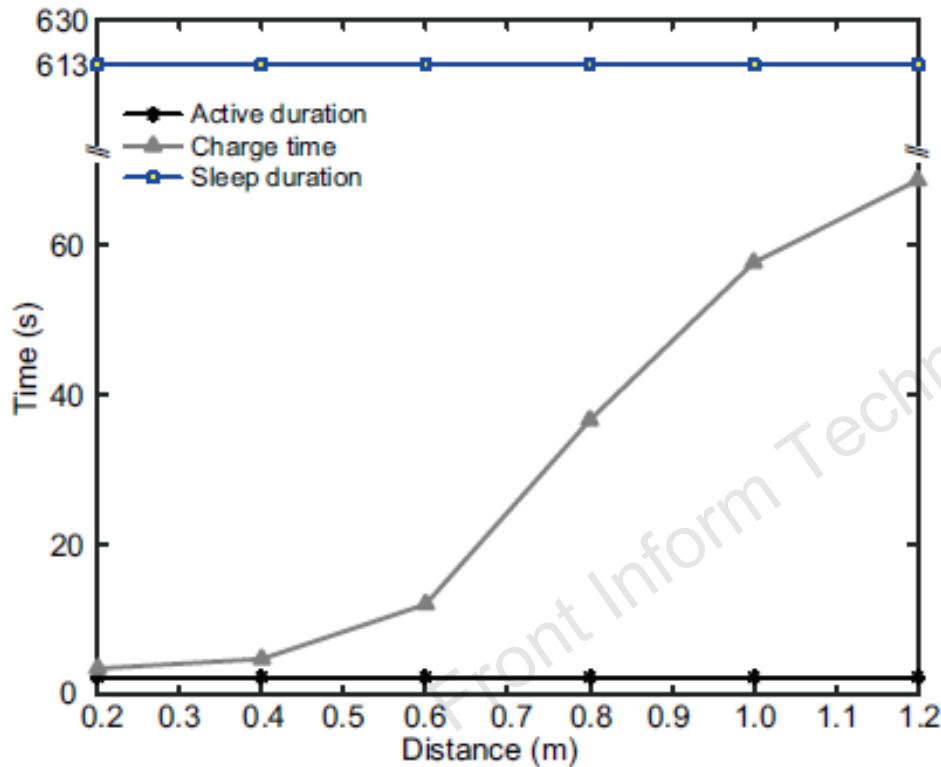


Fig. 5 Energy harvesting performance

- 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.

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.

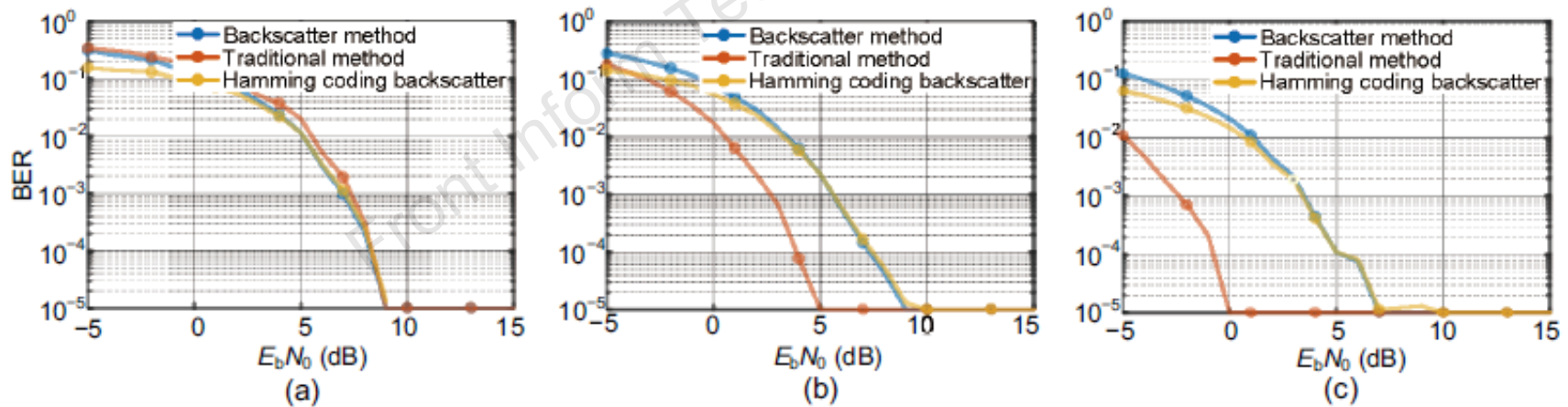


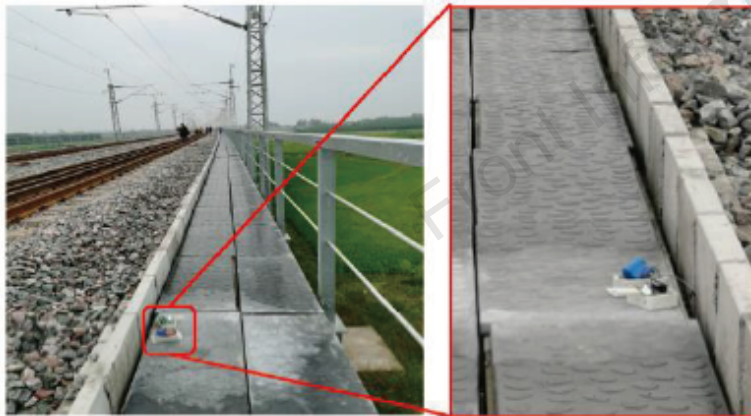
Fig. 6 Comparison of modulation results between the traditional method and backscatter-based method: (a) ASK; (b) FSK; (c) PSK

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

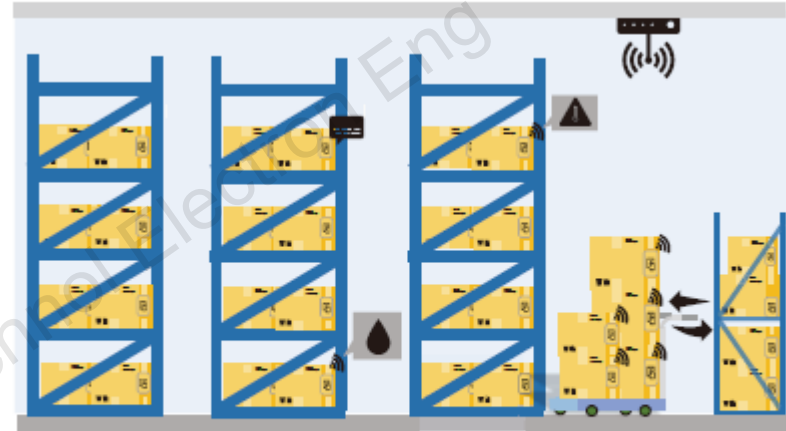


Fig. 8 Potential use of backscatter-based SDR nodes in logistics distribution systems

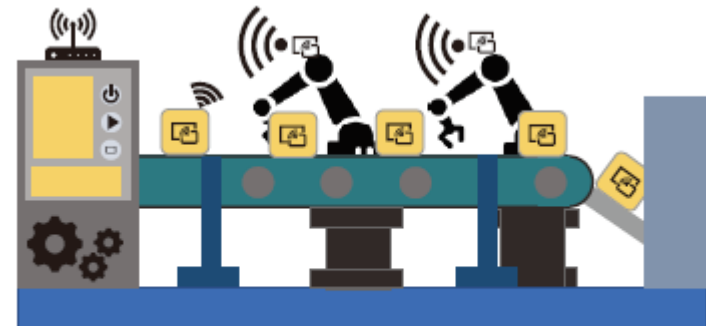


Fig. 9 Potential use of backscatter-based SDR nodes in intelligent factories

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.