# A Measurement Study of Adalm-PLUTO Software Defined Radio with IEEE 802.15.4

Yonghan Kwon, Mingyu Park, and Jeongyeup Paek
Department of Computer Science & Engineering
Chung-Ang University
Seoul, Republic of Korea
{yh3155, hello0922, jpaek}@cau.ac.kr

***Abstract*—Software Defined Radio (SDR) enables a general purpose computer to generate, manipulate, and process various kinds of radio signals using software. It is receiving great interest from scientists and engineers to design novel communication and networking technologies without manufacturing dedicated radio chips. While USRP being the most popular one, Adalm-PLUTO is one of the most affordable SDR among those produced by several different companies. However, Adalm-PLUTO has hardly been used in research work to the best of our knowledge. In this paper, we measure the performance of Adalm-PLUTO SDR as an IEEE 802.15.4 radio, with and against a commercial off-the-shelf device, to verify that Adalm-PLUTO is capable of running IEEE 802.15.4 technology at 250 kbps datarate, at least on the radio side. Evaluation results show that Adalm-PLUTO can achieve over 95% reliability without CSMA nor retransmissions.**

***Index Terms*—Software Defined Radio (SDR), IEEE 802.15.4, Adalm-PLUTO**

## I. Introduction

Various wireless technologies such as Wi-Fi, Bluetooth, and Zigbee are being used in everyday life to connect our laptops, tablets, headsets, and home IoT devices just to name a few. As wireless is becoming pervasive and universal, scientists and engineers are striving to enhance performance and resolve problems that were unforeseen in the past. However, commercial off-the-shelf (COTS) radio devices are hard to manipulate; i.e. it is difficult to try out new protocols and radio signals on COTS devices. In this regard, *software defined radio* (SDR) is receiving interest to apply and test new communication and networking ideas. SDR enables a general purpose computer to generate, manipulate, and process various kinds of wireless signals using software. SDR can be used by scientists and engineers to design and implement novel wireless technology before manufacturing dedicated radio chips.

There are several producers that develop SDR devices. For example, Universal Software Radio Peripheral (USRP) [1], [2] and RTL-SDR [3] have been used in a lot of recent studies to evaluate their proposed communication models. However, *Adalm-PLUTO* [4], one of the most inexpensive SDR in the market, has hardly been considered. We searched research publications that can be found on IEEE Xplorer and ACM Digital Library from 2018. IEEE Xplorer and ACM Digital Library returned only 11 and 6 publications for Adalm-PLUTO respectively, which is far less compared to USRP (578, 470) and RTL-SDR (65, 42)[1]. In addition, there were only two publications [5], [6] that have used IEEE 802.15.4 as their communication technology; Gvozdenovic *et al.* [5] considered a security issue, and Benitez *et al.* [6] experimented IEEE 802.15.4 communication between two Adalm-PLUTO devices. However, there was no study that measures Adalm-PLUTO's performance with and against COTS 15.4 device.

TABLE I: Adalm-PLUTO hardware specification

| **Specifications** | **Typical** |
|---|---|
| ADC/DAC sample rate | up to 61.44 MSPS |
| ADC/DAC resolution | 12 bits |
| Frequency accuracy | $\pm$25 ppm |
| RF tuning range | 325 MHz to 3800 MHz |
| Tx power output | 7 dBm |
| Rx noise figure | $<$3.5 dB |
| Host bus | USB 2.0 |
| Core | Single ARM Cortex-A9 @ 667 MHz |

It is very important to verify whether an SDR device is compatible with COTS devices before amending specific communication technology. Based on this observation, this work builds IEEE 802.15.4 communication module in SDR and measures the performance of Adalm-PLUTO with and against TelosB [7], a COTS IEEE 802.15.4 device. The module is implemented on *GNU Radio software* [8], and we conduct real experiments on a testbed. Each node transmitted 1000 packets per run, while increasing packet length for each directional scenario. We measure packet reception ratio (PRR) as an evaluation metric. Evaluation results show that Adalm-PLUTO can achieve high throughput and reliability over 95% without CSMA and ACK/retransmissions.

The remainder of this paper is structured as follows. We first present a brief background on SDR and the design of our communication modules in Section II. Then, we evaluate the performance of Adalm-PLUTO through real implementation and experiments in Section III. We conclude the paper in Section IV.

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2022R1A4A5034130 & No. 2021R1A2C1008840).

[1]We searched with keywords 'USRP', 'RTL-SDR', and 'Adalm-PLUTO', and counted the number of publications

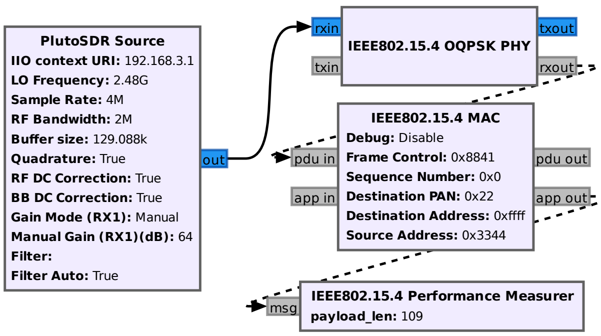



Fig. 1: An IEEE 802.15.4 receiver implementation

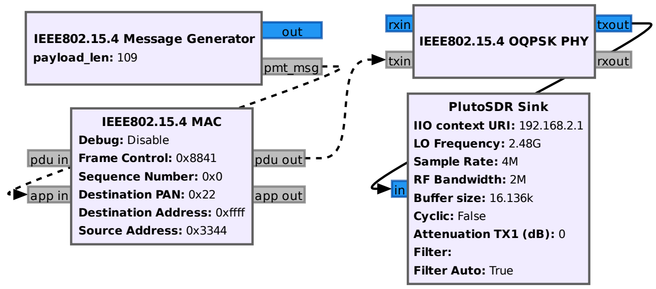
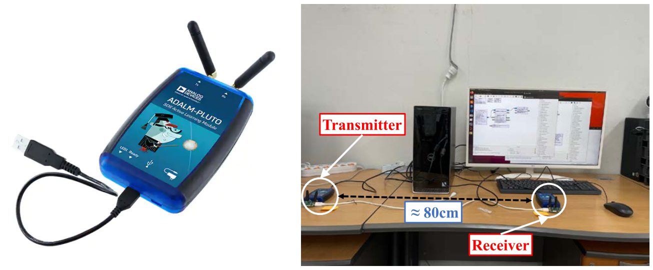



Fig. 2: An IEEE 802.15.4 transmitter implementation




(a) An Adalm-PLUTO device (b) A testbed implementation

Fig. 3: Testbed setup

The contributions of this paper are three folds;

- we implement communication module on GNU Radio that can communicate with COTS IEEE 802.15.4 devices.
- we provide some benchmarks of Adalm-PLUTO when it communicates with a commercial device over IEEE 802.15.4.
- we reveal the potential to apply IEEE 802.15.4 technology on Adalm-PLUTO devices.

## II. Background and Implementation

This section introduces Adalm-PLUTO and GNU Radio tools, and describe the design of our GNU Radio module to communicate with commercial IEEE 802.15.4 devices.

### A. Tools for Software Defined Radio

Adalm-PLUTO is an SDR hardware available from Analog Devices Inc. (ADI) that can be used to test and develop fundamentals of SDR or radio frequency (RF) communication. It offers one receive channel and one transmit channel which can operate in full duplex, capable of generating or measuring RF analog signals. Table. I lists detailed specifications.

Adalm-PLUTO supports variety of software packages such as MATLAB, simulink, GNU Radio or custom C, C++, Python environments to interact with RF signals. In this study, we implement our design on the GNU Radio software. GNU Radio is a free and open-source software development tool that provides signal processing blocks to implement software radios. It can be used to create SDR with an external RF hardware or a simulation-like environment without hardware. Engineers can implement and test their algorithm designs readily just by connecting function blocks.

### B. Module Implementation

Fig. 1 presents an implementation of IEEE 802.15.4 receiver to measure performance of Adalm-PLUTO when communicating from TelosB to Adalm-PLUTO. The implementation adopts open-software IEEE 802.15.4 O-QPSK transceiver modules[2] [10] to demodulate and decode IEEE 802.15.4 signals. The signal comes from a 'PlutoSDR Source' block and passes through an 'IEEE 802.15.4 OQPSK PHY' block. The decoded data is translated to a frame by an 'IEEE802.15.4 MAC' block. An 'IEEE 802.15.4 Performance Measurer', our implementation, records sequence numbers it receives. The measurer prints entire received messages after the end of transmissions to avoid delay caused by *print function*.

Fig. 2 depicts an implementation of IEEE 802.15.4 transmitter to generate IEEE 802.15.4 packets for communicating from Adalm-PLUTO to TelosB mote. It also adopts IEEE 802.15.4 O-QPSK transceiver modules to encode and modulate IEEE 802.15.4 signals. Our 'IEEE802.15.4 Message Generator' generates specific length of packets periodically. The message is encapsulated into a frame passing through an 'IEEE802.15.4 MAC' block. The frame is encoded and modulated to IEEE 802.15.4 signal by an 'IEEE802.15.4 OQPSK PHY' block, and then transmitted through a 'PlutoSDR Sink' block.

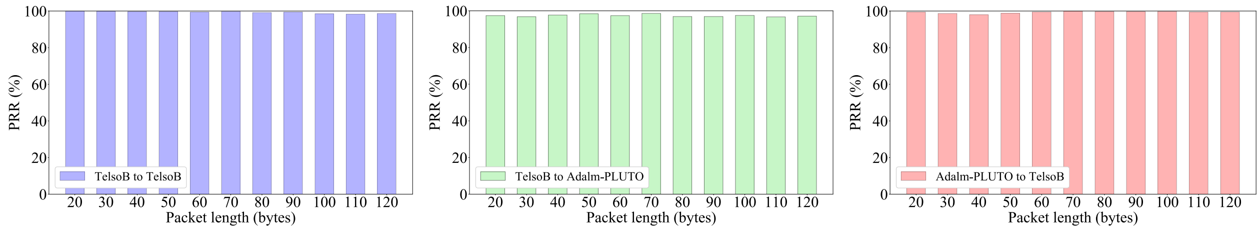
## III. Evaluation

In this section, we describe detailed experiment setup and evaluate Adalm-PLUTO with a TelosB device. TelosB [7] is an IEEE 802.15.4 mote widely used in the wireless sensor network literature. Its performance has been proved in a vast number of prior research works. Therefore we use TelosB mote in the experiments as a comparison device. Fig. 3 shows our testbed setup in an office room for experiments. The devices are 80cm apart from each other.

### A. Evaluation setup

Three communication setups are considered to measure performance. 'TelosB-to-TelosB' communication is experimented first to measure the baseline performance of IEEE 802.15.4 commercial devices. Then, we conduct experiments for 'Adalm-PLUTO-to-TelosB' and vice versa to measure the performance of Adalm-PLUTO when operating with a

[2]https://github.com/bastibl/gr-ieee802-15-4 [9]




(a) TelosB to TelosB

(b) TelosB to Adalm-PLUTO

(c) Adalm-PLUTO to TelosB

Fig. 4: Evaluation results

commercial device. We switch devices to appropriate ones for each experiment from the testbed presented in the Fig. 3.

Experiment parameters are set as follows. CSMA, ACK, and retransmission are disabled to derive pure PHY hardware performance of each device. Communication occurs in channel 26 (2.48 GHz) with 2 MHz bandwidth. A transmitter generates 1,000 messages with 20 millisecond intervals. We count the number of received messages and print out the result after all transmissions are finished. The experiments are conducted 11 times with varying PHY payload length (from 20 to 120 bytes). Buffer size of both PLUTO 'source' and 'sink' blocks (in Figs. 1 and 2) are set to appropriate values according to the PHY payload length because Adalm-PLUTO stores data into a buffer and does not transmit until the length of data exceeds a certain threshold[3].

### B. Evaluation result

Fig. 4 presents evaluation results for each scenario. As shown in Fig. 4a, baseline performance in 'TelosB-to-TelosB' achieves approximately 99% reliability without any enhancement schemes such as CSMA and retransmission. The performance with Adalm-PLUTO is almost the same as well as shown in Figs. 4b and 4c. The performance trends do not change even when the payload length increases, maintaining over 99% reliability.

An interest observation is that frame losses occur slightly more frequently when an Adalm-PLUTO device is the receiver. The performance decreases to approximately 95% while it can maintain 99% reliability when it operates as a transmitter. This is because of the buffer issue of Adalm-PLUTO. It stores data into a buffer until a certain threshold length. When the Adalm-PLUTO is a transmitter, this is not a problem because the host forwards *fixed length* data into the buffer which does not cut a message. However, signals including background noise are injected continuously into Adalm-PLUTO's buffer when the Adalm-PLUTO operates as a receiver. Therefore, the length of received bytes of a signal cannot be deterministic, and a message may be chopped by the buffer if the message arrives at the end of the buffer. In this case, the first chunk will be forwarded to the host-side directly while the second chunk is held and delayed by the buffer that leads to loss. This problem degrades the performance of Adalm-PLUTO, but it is tolerable ($\approx$ 3% when the buffer size is 8 times of transmitted samples).

[3]Adalm-PLUTO is an SDR that is oblivious of 'framing' concept in higher layers. In addition, host sample rate ($\approx$ 6 MHz) and ADC/DAC sample rate ($\approx$ 60 MHz) of Adalm-PLUTO are different, leading to a bottleneck issue. Therefore, it buffers data to avoid ambiguity of technology and bottleneck.

## IV. Conclusion

Adalm-PLUTO supports SDR functionally which enables a general purpose computer to generate, manipulate, and process various kinds of radio signals using software. However, it has hardly been used in research work to the best of our knowledge. In addition, there was no research to investigate compatibility of Adalm-PLUTO with commercial IEEE 802.15.4 devices. Therefore, we evaluated performance of Adalm-PLUTO in terms of PRR to reveal its capability to apply IEEE 802.15.4 technology. TelosB mote was used as a comparison device and the evaluation results showed that Adalm-PLUTO can operate with commercial IEEE 802.15.4 devices achieving more than 95% reliability without CSMA, ACK and retransmission scheme. Based on the result, we remain developing novel IEEE 802.15.4 communication model on the Adalm-PLUTO device and re-evaluating its performance with enabling CSMA, ACK and retransmission as our future works.

## References

[1] "Engineer Ambitiously - NI," 2022, [last accessed Aug. 2022]. [Online]. Available: https://www.ni.com

[2] "Ettus Research - The leader in Software Defined Radio (SDR) — Ettus Research, a National Instruments Brand — The leader in Software Defined Radio (SDR)," 2022, [last accessed Aug. 2022]. [Online]. Available: https://www.ettus.com

[3] "RTL-SDR.com," 2022, [last accessed Aug. 2022]. [Online]. Available: https://www.rtl-sdr.com

[4] "PlutoSDR - PlutoSDR Software," 2022, [last accessed Aug. 2022]. [Online]. Available: https://plutosdr.org

[5] S. Gvozdenovic, J. K. Becker, J. Mikulskis, and D. Starobinski, "Truncate after preamble: PHY-based starvation attacks on IoT networks," in *Proceedings of the 13th ACM Conference on Security and Privacy in Wireless and Mobile Networks*, 2020, pp. 89–98.

[6] H. K. Benitez, C. H. Cabuso, M. T. De Leon, J. R. Hizon, and M. Rosales, "Implementation of a physical layer wireless sensor network testbed using software defined radios," in *International Symposium on Multimedia and Communication Technology (ISMAC)*. IEEE, 2019, pp. 1–6.

[7] J. Polastre, R. Szewczyk, and D. Culler, "Telos: Enabling Ultra-Low Power Wireless Research," in *Proceedings of IPSN/SPOTS*, Apr. 2005.

[8] E. Blossom, "GNU radio: tools for exploring the radio frequency spectrum," *Linux journal*, vol. 2004, no. 122, p. 4, 2004.

[9] B. Bloessl, "bastibl/gr-ieee802-15-4: IEEE 802.15.4 ZigBee Transceiver," 2021, [last accessed Aug. 2022]. [Online]. Available: https://github.com/bastibl/gr-ieee802-15-4

[10] B. Bloessl, C. Leitner, F. Dressler, and C. Sommer, "A GNU radio-based IEEE 802.15. 4 testbed," *12. GI/ITG KuVS Fachgespräch Drahtlose Sensornetze (FGSN 2013)*, pp. 37–40, 2013.