IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

ISO 3297:2007 Certified ⁝ Impact Factor 8.102 ⁝ Peer-reviewed / Refereed journal ⁝ Vol. 12, Issue 5, May 2023

DOI: 10.17148/IJARCCE.2023.12595

Software Defined Radio Platforms for Wireless Technologies

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Abstract— Wireless connectivity standards have been developed by standardizing bodies to meet therequirements ofvarious applications. A wirelesstransceiver should be equipped with a Radio Frequency (RF) transceiver to support a wireless standard. Traditional RF transceivers are designed andimplemented on a radio chip or an embedded module in a System-on-a-Chip (SoC), ensuring small size, high performance, low power consumption, and cost.However, this tradition implementation design limits directly or indirectly the programmability and flexibility of the RF transceivers. This paper aims to provide a list of well-known General Purpose Processor (GPP) based SDR platforms that meet the minimum specifications of selected wireless standards. To this end, we first review the characteristics of selected wireless technologies.Then, we investigate existing SDR platform architecture and their maximal performance in terms of the frequency range, bandwidth, symbol rate, bitrate, and latency support. Finally, we intersect the wireless standard requirements with the corresponding SDR platform parameters and provide a list of GPP-based SDR platforms for some existing wireless technology implementations. All investigations related to the frequency, bandwidth, symbol rate, and bitrate parameters are supported by theoretical results, whereas latency results are obtained from experiments by benchmarking existing implementations.

I. INTRODUCTION

The number of wireless devices used by various wireless application domains such as Wireless Sensor Networks(WSNs) [1], Internet of Things (IoT) [2], cellular base stations[3], etc., has increased tremendously in the past decade. Several wireless technologies are standardized to enable the interconnection between the different wireless devices including NFC, RFID, IEEE 802.15x, IEEE 802.11x, LoRa, Sigfox, 3GPP 3G/4G/5G, etc., [3]–[5]. A wireless device can incorporate one or multiple wireless transceivers supporting distinct wireless technologies. Each transceiver performs all the physical (PHY) and a portion of the Media Access Control(MAC) layer operations through integrated analog and digital circuit blocks. Indeed, most of the PHY layer analogoperations are implemented on a dedicated and integrated analog hardware such as amplifiers, radio frequency (RF) synthesizers, filters, etc. On the other hand, some PHY layer digital baseband and time critical MAC layer functions are fully implemented on a digital hardware such as Application Specific Integrated Circuits (ASICs), a Programmable Digital Signal Processor (PDSP), Application Specific Instruction Set DSP (DSP ASIP) or a mixed solution using ASIC hardware accelerators with PDSP or with DSP ASIP [6]. This traditionalimplementation considerably limits directly or indirectly the programmability and flexibility of the transceivers for upgrading or handling multiple wireless standards.

An alternative solution to allow programmers and researchers to easily control the hardware and program the software of wireless transceivers is to use an implementation based on general-purpose processor (GPP) based Software Defined Radio (SDR) platforms,which is a reconfigurable and reprogrammable radio transceiver. In such platforms, the PHY layer digital baseband and MAC layer operations are implemented on a GPP, and the PHY layer analog RF/IF front-end operations are controlled using an analog device board supporting a wide range radio spectrum. This solution have been explored by many researchers to investigate the architecture, challenges and compare the performance of several SDR platforms [7]–[9].

In addition, as the PHY and MAC layers are performed in software by GPP host and due to thereconfigurability and reprogrammability of the radio transceiver, the SDR platform can be used to implement multiple wireless technologies. Such benefithas been exploited in many recent research works such as [10], [11]. These benefits conjugated with the continuous advancement in processing performance (hardware and software) and decreasing price of GPPs made GPP-based SDR platforms gain much attention for implementing and testing wireless technologies [12]–[16]. Moreover, it is also used to build testbeds and/or perform experimentation to study different features of communication systems and suggest performance improvement [17]–[19].Overall, the GNC architecture for drone swarm plays a crucial role in ensuring safe and coordinated operation of multipledrones.

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By integrating guidance, navigation, and control systems, drone swarms can accomplish their mission objectives while minimizing the risk of collisions and other hazards. Currently, several SDR platforms areavailable in the market and research community. To implement a desired wireless technology, an appropriate SDR platform need to be selected. Previousresearch works such as [7] and [9] have presented the challenges during SDR platform selection process and compared the performance of SDR platforms in the general context. However, they abstain from addressing the specific considerations required by SDRplatforms based on the requirement of wireless technologies.

The aim of this paper is to provide a list of possible GPP-based SDR platforms in terms of hardware components satisfying the minimum specifications of well- known wireless technologies. This is achieved by analyzingwhat a wireless technology requires at minimum in terms of frequency range, bandwidth, symbol rate, bitrate andlatency, and the performance offered by GPP-based SDR platform components. The contributions of this paper canbe summarized as: • we present a detailed study of the architecture of GPP-based SDR platforms, and analyze their capabilities in terms of the performance metrics; • we drive the minimum performance requirements of the most relevant wireless technologies.

We use these requirements to draw mapping conditions in order to determine which GPP-based SDR platform is appropriate to successfully perform a targeted wireless technology; • we identify existing wireless technology implementations from the literature that use GPP-based SDR platforms, examine theirperformance metrics, and suggest a list of other possible SDR platforms to implement the use-cases described in the literature. Thus, the in-depth analysis of selected wireless technologies and SDR platforms allows researchers from both academia and industry to easily understand required parameters, software and hardware components of SDRplatforms. We believe this paper will help researchers (SDR platform users and SDR software developers) looking for the appropriate SDR platform to implement a given wireless technology. To the best of our knowledge, this paper is the first to perform mapping several wireless technologies with GPP-based SDR platforms: This paper is organized as follows: Section II provides classification and characteristics of well-known wireless connectivity technologies. Section III discusses the architecture of GPP- based SDR platforms and provides general background on the hardware and software components. Section IV provides a detailed study on the performance parameters of GPP-based SDR platforms and presents numerical results using selected GPP-based SDR platforms. Section V presents a mapping between SDR platform performance and wireless technology requirements. Open researchchallenges and future directions are given in section VI. Finally, section VII provides conclusions to this paper.

II. WIRELESS CONNECTIVITY TECHNOLOGIES

The interconnection between different wireless devices is enabled by a wide range of wireless technologies that can cover from very short distance (in centimeter range) to several kilometers. Thus, wireless connectivity technologies can mainly be classified into three groups based on the rangethey cover [25]: i) short-range wireless technologies, ii) Wireless Local Area Networks (WLANs), and iii) Wireless Wide Area Networks (WWANs). Within each of these categories, several wireless technologies are standardized, asshown in Fig. 1. The subsequent subsections present the main PHY and MAC layer characteristics of major wireless technologies. We note that, the frequency requirement of wireless technologies stated in the tables is given based on their standard. However, the specific frequency band usedby a wireless technology depends on its allocation for globaland regional use and also countries regulation [26].

Short-range wireless technologies include proximity communication, Wireless Body Area Networks (WBANs) and Wireless Personal Area Networks (WPANs). They are mainly characterized by their short-range coverage operatingunder the unlicensed industrial, scientific and medical (ISM)frequency bands. International Organization for Standardization (ISO) International ElectrotechnicalCommission (IEC) defines the PHY and MAC layer requirements for proximity technologies, and IEEE defines for WBAN and WPANs. Some of the most prominent wireless technologies are Near Field Communication (NFC),Radio Frequency Identification (RFID), IEEE 802.15.6 (NB PHY, UWB PHY and HBC PHY), IEEE 802.15.1, and IEEE 802.15.4. IEEE also defines the PHY and MAC layer for Low-Rate WPAN to meet the limited resource requirement of IoT and WSN devices. Among thesestandards are IEEE 802.15.4 and Bluetooth Low Energy(BLE), which are developed for networks with low power consumption, low deployment cost and less complexity. Table 1 gives the PHY and MAC layer characteristics of some of the short-range wireless technologies.

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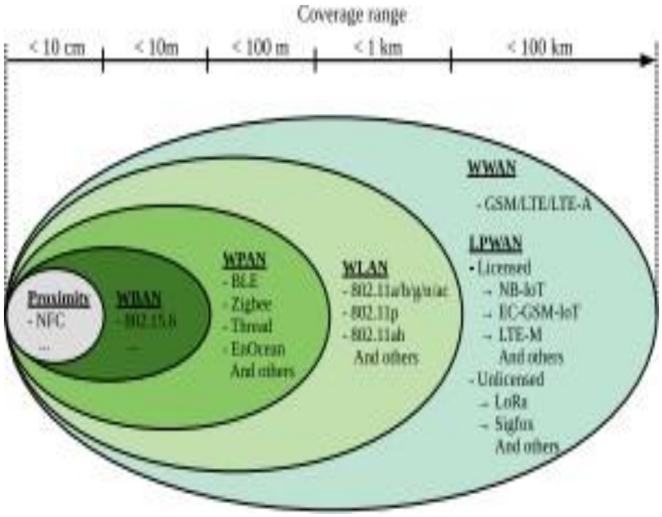

FIGURE 1: Wireless technologies

III. GPP-BASED SDR PLATFORM ARCHITECTURE

The implementation design of conventional wireless transceivers, in general, lacks reprogrammability, flexibility and scalability. Therefore, upgrading the software, changing the logic of the dedicated hardware or reusing the transceiver to implement a wireless standard other than the one the transceiverwas designed for is limited or non-existent. Moreover, conventional wireless transceivers are mostly proprietary which prevent developers and researchers from access to reprogram the assembly instruction set. An alternative solution to mitigate these limitation is using SDR platforms. In addition to the programmability feature, the SDR platform also serve as a multi-technology gateway by performing multiple wireless technologies using a common set of radio transceiver [10], [11]. It also allows to reuse software across multiple radio devices and download software over-the-air to implement new standards and fix bugs [8]. Furthermore, it is recently being used to mitigate cross-technology interference problem faced by conventional technologies [42]. An SDR platform is a class of radio transceivers which controls the analog RF/IF part using anopen-source analog device board, named SDR device, and implements all the digital part using programmable host processor. The programmable host processor can be GPP, DSP ASIP or FPGA. The scope of our study is limited to GPP-based SDR platforms due to its easy programmability using a high- level language and its flexibility for reconfiguration and handling complex algorithms [9]. The general architecture of GPP-based SDR platform is illustrated in Fig. 2. It is mainly sectioned into three parts as SDR device, communication interface and GPP host. Each component of the platform has its communication parameters that contribute to the overall performance of the SDR platform. This section investigates the GPP-based SDR platformsome of the limitations and future directions of GNC for droneswarm:

Limited Autonomy: Drone swarm GNC systems still require human intervention for mission planning, monitoring, and control. Future advancements in GNC technology should aim to increase the swarm's autonomy, enabling them to perform more complex tasks without human intervention.

Limited Range and Endurance: Drone swarm GNC systems are limited by their range and endurance, which affects their operational capability. Future GNC systems should aim toincrease the range and endurance of drone swarm, enabling them to perform long-range missions or operate in remoteareas. An SDR device is a small handheld type of devicewhich is capable of transmitting and receiving signals at different frequencies. It typically consists of software controllable analog RF/IF and digital IF front-ends. The former is called as daughterboard and the latter as motherboard. This subsection describes their respective tasks and characteristics.

IV. SDR PLATFORM PERFORMANCE ANALYSIS

To implement a wireless technology on SDR platforms or use existing implementations, it is necessary that the selected SDRplatform (SDR device, communication interface and GPP Host) performance should meet at least the requirements of thetarget wireless technology. These requirements are mainly given in terms of operating frequency band, bandwidth, symbol rate, bitrate, latency, etc. In this section, a thorough theoretical analysis of these performance parameters in GPP-based SDR platform architecture is presented along with the minimal/maximal values offered by the components. The frequency band of SDR platforms is the operating frequency range covered by the SDR device. This is determined at

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the daughterboard from the local oscillator (LO) signals generated by the frequency synthesizer, such as Phase- Locked Loop (PLL) synthesizer. Large frequency band needs large LO frequency range, and consequently wideband frequency synthesizers. The operating frequency band of SDR devices are listed by the used daughterboard's datasheet (see Table 4 for well-known daughterboards). To cover the range of frequency bands supported by daughterboards, SDR device's need to use appropriate type of antenna [74]. Each symbolgeneration/consumption requires a time duration in the baseband TX/RX path, when inverted gives the symbol rate. This duration represents the makespan (execution time) of an executable file, created after compiling the TX/RX path blocks,from generating a stream of bits to delivering the correspondingoutput symbol or from taking a symbol as input and delivering its corresponding bits.

V .CONCLUSION

Selecting SDR platform to implement and perform a wireless technology is challenging as it comprises, on one hand, to satisfy design requirements both at the hardware andsoftware level. On the other hand, previous recommendationsby researchers/developers of wireless technologies suggest tofulfill the proposed hardware and software list to successfully perform their open-source implementations. However, the proposed list is often restrictive in terms of hardware (SDR devices and GPP hosts) and doesn't take into account the use-case desired by users. This paper has reviewed and presented a large list of GPP-based SDR platforms that satisfy the minimum requirement of wireless technologies. We believe that thestudy conducted in this paper will help users to determine, fora given wireless technology, which GPP-based SDR platformconfiguration is necessary to fully or partially perform the MAC and PHY functions.

Additionally, through this study, users who already possess a GPP-based SDR platform can identify possible applications that could be implemented. To determine the candidate SDR platform, the paper first evaluated the performance of selected GPP-based SDR platforms through theoretical and experimental analysis. Then, we proposed matching conditions and created a mapping table between theminimum requirements of well-known wireless technologies and performance of GPP-based SDR platforms. Thereby, a list of candidate GPP-based SDR platforms is established for each wireless technology. This list indicates if the matchingis complete, incomplete or negative. The two latter are mainly due to the high latency of GPP hosts.

A summary of some of the existing implementations were discussed and using the mapping table we suggested other possible GPP-based SDR platforms to be used. Finally, we highlighted some of the research challenges and future directions to be considered by the research community.

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