Throughput and Reliability Trade-Offs of 6LoWPAN in Low-Power IoT and Smart Systems

Krzysztof Tokarz[1][0000-0002-0139-3753], Paweł Buczyński[1], and Dariusz Mrozek[1][0000-0001-6764-6656]

Silesian University of Technology, Gliwice, Poland
`krzysztof.tokarz@polsl.pl` `pawel.r.buczynski@gmail.com`
`dariusz.mrozek@polsl.pl`
http://www.polsl.pl

Abstract. The Internet of Things (IoT) has become a key enabling technology for modern smart systems, where reliable and efficient data transmission is essential for both operational safety and user satisfaction. Wireless communication is widely adopted in IoT deployments due to its ease of installation, device mobility, and flexibility; however, battery-powered operation imposes strict constraints on energy consumption, processing capability, and network parameters such as transmission range and packet size. While short data frames reduce radio activity and power usage, they also introduce challenges related to the interoperability of low-power wireless protocols with IP-based networks. To address these limitations, the Internet Engineering Task Force introduced the 6LoWPAN adaptation layer, enabling IPv6 communication over IEEE 802.15.4 links. This paper presents an experimental evaluation of the 6LoWPAN protocol implemented on the nRF52840 system-on-chip (SoC), focusing on its impact on throughput and communication reliability. In addition, the communication range of the IEEE 802.15.4 radio link was assessed using the nRF52840 USB dongle development platform. The results demonstrate that protocol overhead introduced by 6LoWPAN reduces achievable network throughput compared to native IP communication, while header compression mechanisms partially mitigate this effect by improving application-layer efficiency.

Keywords: 6LoWPAN · Internet of Things · Wireless networks · Sensor networks.

1 Introduction

The constant development of computer technology, electronics, and telecommunications leads to the emergence of newer communication methods, protocols, and network standards. Technological developments over the following years have led to the definition of a subset of computer networks describing the PAN (Personal Area Network), consisting of devices located in close proximity to their users or directly on them [1]. Devices that fit this definition include smartphones,

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: 10.1007/978-3-032-29918-5_25

tablets, smartwatches, electronic readers, and all kinds of wearable devices. Currently, the most popular wireless PAN (WPAN) protocol used in such networks is Bluetooth with its low energy version (BLE). Another type of network used in industrial and consumer electronics, usually covering a single location, enabling interconnection between many nodes, are sensor networks. Protocols used for low-power, short-range communication sensor networks include ZigBee [23], WirelessHart [20], Matter [21], Thread [22] and others. The mentioned protocols are efficient in terms of power consumption mainly due to high transmission power optimisation, short data packets that reduce radio transmission time, and reduced packet processing complexity, which lowers the computational power required to implement the protocol. Additionally, integrated circuit producers implement portions of the functionality of the protocols in hardware, significantly reducing the operation time of the processor. The miniaturisation of microprocessors and the development of low-power data transmission methods have contributed to the emergence of the Internet of Things (IoT), which has been continuously expanding its reach since its inception. The IoT concept assumes the connection of all devices to the global Internet network, which has increased demand to expand the pool of available IP (Internet Protocol) addresses and widen the use of the IPv6 version with a 128-bit address field [24]. The issue is the lack of compatibility between popular WPAN and sensor networks protocols and IP addressing schemes, as well as differences in packet sizes between IoT and IP networks [25]. For example, the standard IPv6 packet size is 1280 bytes, while the maximum Bluetooth packet size is only 251 bytes, and Zigbee is even shorter - 128 bytes. As the answer to the issue, the Internet Engineering Task Force (IETF) has published an RFC [2] describing a new protocol called 6LoWPAN, which acts as an intermediary layer between the IEEE 802.15.4 physical layer and the IP network layer. However, despite the widespread adoption of 6LoWPAN in IoT systems, there is still a lack of detailed experimental analyses quantifying its protocol overhead and practical performance limitations when implemented on commercially available, low-cost system-on-chip platforms. This study addresses this gap by providing an in-depth evaluation of the 6LoWPAN adaptation layer operating on the nRF52840 SoC, complemented by empirical measurements of radio link range under real-world conditions. The use of an additional intermediary device that operates on two physical layers (IEEE 802.15.4 and Wi-Fi) enables the transport of packets from WPAN devices to IP-addressable networks. This work focuses on a detailed analysis of the operation of a communication stack using the 6LoWPAN protocol implemented in the nRF52840 system on chip. We also investigated the radio range parameters achieved by the nRF52840 USB dongle development board.

2 Background and Related Works

The 6LoWPAN protocol can be implemented with a variety of hardware platforms and operating systems. The most popular microcontrollers include Texas Instruments CC2650 [6], CC2652 [7], STMicroelectronics STM32 [10] processors,

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: 10.1007/978-3-032-29918-5_25

Nordic Semiconductor nRF52 family of SoCs, Raspberry PI [11] and others. According to [9], IoT-targeted embedded operating systems implementing 6LoWPAN include Contiki, TinyOS, Riot, OpenWSN, Mbed OS, and Zephyr. There are also open-source implementations of the 6LoWPAN stack with uIP-Contiki, SICSlowpan, 6lowpancli, B6LoWPAN, BLIP, NanoStack and others. They are comprehensively analysed and compared in [8].

2.1 IPv6 protocol

IP is a protocol of the network layer of the OSI model. It defines methods and a number of rules for addressing and sending packets over the network infrastructure of the Internet. With the increasing popularity of the global network, new challenges have emerged. The pool of addresses provided by the IP standard in version 4 has begun to be exhausted [4]. This required rebuilding the packets for the new addressing. The older standard operates on 32-bit addresses, translating into a pool of 4,294,967,296 addresses. The new standard allocates as many as 128 bits to the address, which, in practice, ensures an inexhaustible amount. IPv6 has not yet de facto replaced the IP in version 4. The reason is the great economy in managing available addresses by IANA (Internet Assigned Numbers Authority). Unused addresses are reintroduced into circulation. The undoubted advantage of the newer version is the uniqueness of the address.

2.2 6LoWPAN protocol

The main task of the 6LoWPAN layer is to enable the use of the higher IPv6 protocol by the devices with an incompatible IEEE802.15.4 physical layer [5]. The 6LoWPAN itself is an intermediate layer that enables the conversion of packets between the IPv6 network layer and the IEEE 802.15.4 link layer, as shown in Fig. 1. Due to its application, it is called an adaptation layer. Creating the specification from the beginning caused many problems due to the incompatibility of the aforementioned physical layer with the requirements of the IPv6

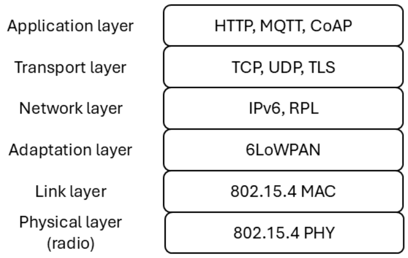

Fig. 1. Network layers with 6LoWPAN adaptation layer.

protocol. Most of the challenges were described in the RFC 4919 document [3]. The 6LoWPAN adaptation layer serves three primary functions.

- Packet fragmentation and reassembly
- Compression and decompression of headers
- Routing, mainly to implement mesh networking

2.3 Packet fragmentation and reassembly

The IEEE802.15.4 protocol was created to support constrained devices, so the maximum frame size is 127 bytes. For comparison, the minimum IPv6 packet size is 1280 bytes. 6LoWPAN enables interoperability by dividing large IPv6 packets into several smaller IEEE802.15.4 physical layer packets. An additional fragmentation header, composed of the datagram length, tag, and offset, is added. The datagram length represents the actual length of the datagram when it is not fragmented. The datagram fragmentation tag is added to link all frames containing the fragmented datagram. The datagram offset holds the relative position of the fragment so that the receiver can reorganise and assemble fragments in proper positions [15].

2.4 Header compression and decompression

The MAC layer frame of the IEEE802.15.4 has a length of 127 bytes, and the maximum payload is 102 bytes. In comparison, only the packet header of IPv6 is 40 bytes, which would consume almost a third of the frame. 6LoWPAN uses the corresponding packet header compression technology [26], which can effectively reduce the size of the packet to improve transmission efficiency and save memory and node energy.

2.5 Similar research

In the paper [13], Bai and Zhang presented the results of the performance evaluation focusing on the 6LoWPAN gateway used in the real network built with devices working under control of the Contiki operating system. They measured the round-trip times (RTT), delay variance, packet loss, and average throughput. The authors of [14] presented the research on the effects of the interference resulting from the coexistence of 6LoWPAN and WiFi networks in the same environment. Performance measurements were based on the varying size of the payload and the distance between the sensor node and the gateway. The SoC used in the testbed was Texas Instruments CC2431. In the paper [18], the authors presented an extensive 6LoWPAN-based network simulated in OPNET modeller. Some papers focus on the routing protocol RPL and its version HRPL, which reduces the redundant retransmissions that would cause the routing overhead. In [16], Mohd Yusoff et al. used the Cooja simulation for the Contiki operating system to determine control traffic overhead, latency, and energy consumption for this

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: 10.1007/978-3-032-29918-5_25

routing protocol. In [17], the same authors extended the research with an experiment on Texas Instruments CC2538 microcontrollers. Research by Khattak et al. [19] presents the performance analysis of OpenThread network implementation with the use of nRF52840 USB dongles connected to the Raspberry PI 4 model B. Analysing the mentioned literature, we decided to perform complementary research to [14], [17] in terms of using SoCs from another vendor, to the [13], [16] in terms of using the Zephyr operating system instead of Contiki and to [19] by focusing at the 6LoWPAN layer instead of the Thread protocol. According to our best knowledge, none of the works were focused directly on the parameters of the Zephyr implementation of the 6LoWPAN protocol and the transmission range of nRF52840 USB dongles. We decided to conduct the measurements using real equipment rather than a simulator, which makes the results even more realistic.

3 Research methodology

Among the many possible parameters for the experiments, we decided to select those that can serve as a useful source of information in the context of the 6LoWPAN protocol and the nRF52840 environment. These experiments cover:

- Measurements of the range of transmission
- Measurements of the number of received packets per second with different delays between packets
- Measurements of the communication throughput between network nodes

3.1 Measurements of the transmission range

The measurement of effective network range requires a pair of devices. The first acts as a transmitter, and the second plays the role of a receiver. The receiving device must be capable of archiving received data and saving it for further analysis. The requirements of the transmitting device include the capability to precisely specify the data sent to ensure repeatability. The nRF52840 USB dongle is equipped with the RF antenna of the meander type. Typical antenna radiation pattern studies [27], [28], [29] were referred to precisely position the devices in space to achieve the highest possible part of the radiation power reaching the receiver. Both devices were configured as PCs with a Linux operating system with an nRF52840 USB dongle with 6LoWPAN implementation as shown in Fig. 2. The measurements were taken in an area away from buildings to avoid possible interference from other wireless transmission systems. During the tests, the systems were always within the optical line of sight. One station remained stationary while the other moved away, and a transmission attempt was made every two meters. The test was continued until the communication between the devices was lost. One device sent the packets while the other received them and stored the packet payload.

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: 10.1007/978-3-032-29918-5_25

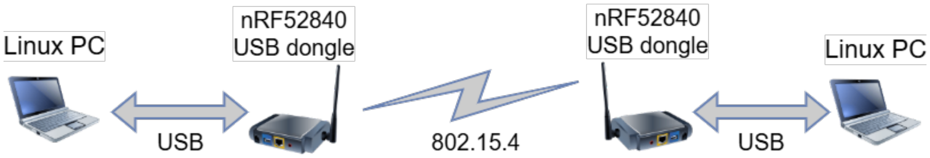

Fig. 2. Configuration of the measurement environment.

3.2 Measurements of the number of received packets and throughput

The throughput measurements were conducted by transmitting packets between two nRF52840 USB dongles. The connection to the computer, although physically done with USB, is performed as a UART, which significantly limits the maximum possible transmission speed. Because of this, connections to PCs were used to start, stop, and gather the results of the measurements instead of transmitting the content of the packets. Devices were programmed with the application written for the Zephyr operating system, which prepares the transmission by executing the following steps:

- initialise the Zephyr Operating System
- set up the network ID and IP addresses of devices
- use of the Neighbourhood Discovery protocol to establish a connection between devices

Devices were placed at a close distance of around 30 cm, ensuring a stable and reliable link. The application executed on the sending device generated the data packets, whilst the receiver gathered the packets and sent the number of properly received packets per second to the PC. Network performance can be presented in several ways; thus, we decided to conduct two measurement scenarios.

- Scenario 1. The maximum number of received packets per second with different delays between packets.
- Scenario 2. Measurement of the throughput for different data sizes in the application layer.

4 Results of experiments

4.1 Range measurements

Maintaining a low number of packet losses is crucial to ensuring network reliability. It can be assumed that about 10% is an acceptable value that allows for predictable network behaviour. Measurements were taken at distances from 2 meters up to 112 meters. For each distance, we collected the percentage of successful transmissions and RSSI (Received Signal Strength Indicator). The results are presented in Figs. 3 and 4, respectively. At a range of up to 50 meters at

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: 10.1007/978-3-032-29918-5_25

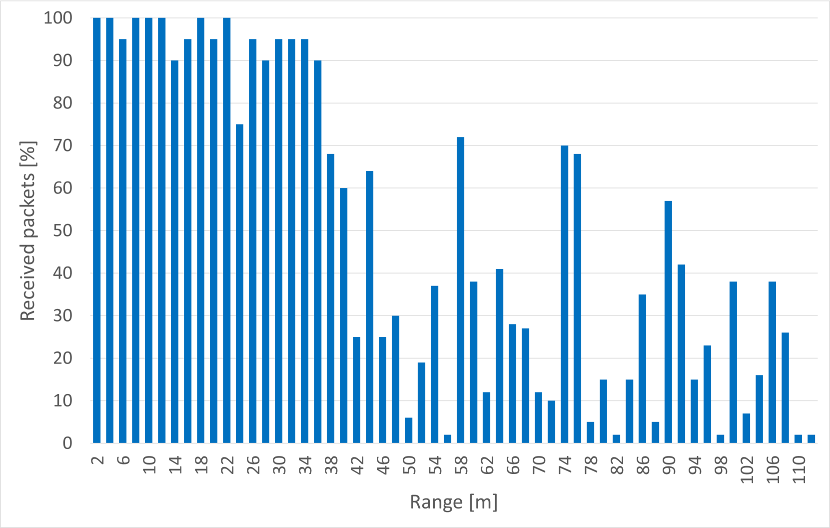

Fig. 3. Percentage of successfully received packets depending on distance.

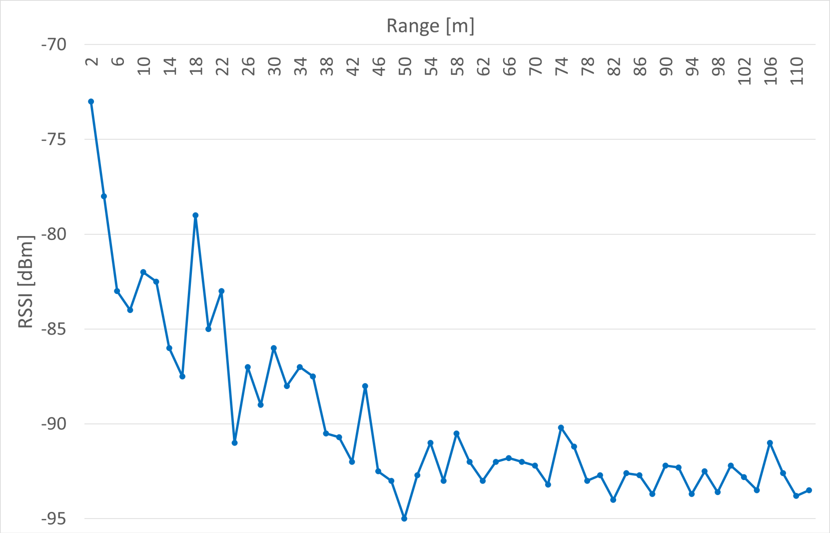

Fig. 4. Results of the RSSI measurements.

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: 10.1007/978-3-032-29918-5_25

each distance, 20 packets were sent. At distances up to 36 meters, the number of packet losses does not exceed the aforementioned 10% limit. With each additional meter, packet reception began to deteriorate rapidly. Due to significant packet reception randomness at distances greater than 50, 72, and 98 meters, the number of frames sent was increased to 100, 400, and 1000, respectively, which allowed us to calculate the percentage of successfully received packets. Variability in packet loss may be due to the multipath loss and slight changes in antenna orientation when manually shifting the distance. This can cause significant instability when receiving a signal near the sensitivity threshold.

The maximum value of the RSSI was -72.8 dBm, whilst the minimum value was -95 dBm. Comparing the measurements presented in Fig. 3 with those in Fig. 4, we can conclude that the probability of receiving a signal with RSSI below -93 dBm is very low, not exceeding a few per cent. On the other hand, signals above -88 dBm are correctly received with a probability of at least 90%.

The 112-meter range was the furthest distance at which the packets were received. It can be observed that the most reliable transmission can be achieved at distances up to 40 meters in line-of-sight conditions. At longer distances, the packet loss ratio increases, so successful data transfer requires packet retransmissions, which significantly limit the overall throughput of the network.

4.2 Measurement of number of received packets and throughput

The physical limit of the IEEE802.15.4 link transmission speed is 250 kb/s. Considering the maximum packet size of 127 bytes, the theoretically largest number of packets sent without any delays between them could reach the value of 246 per second. The measurements in two scenarios were performed to answer the question of the throughput achieved in real conditions.

Scenario 1 - the number of received packets per second. In real WPAN applications, transmission takes place sporadically. For this reason, we decided to simulate different delays between successive transmissions. Six series of measurements were performed with 500 packets sent between devices. The delay between packets was set at 100, 50, 25, 10, 5 and 0 ms. The results of the measurements presented in Fig. 5 show the number of packets sent at specific periods of 1-second length and the time of sending all 500 packets. It is visible that for shorter delays, the number of packets sent in one-second periods is higher, while the maximum achievable number of packets in one second is achieved for zero-delay time between packets (the red line in Fig. 5). The zero-delay scenario represents the maximum possible throughput achieved by the link. With 200 packets per second, it is nearly 20% less than the theoretical one. This observation allowed us to calculate the processing time of the packet by the transmitter and receiver. The transmission time of one packet was 4.064 ms. Packets were sent effectively every 5 ms. The difference gave the processing time equal to 0.936 ms.

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: 10.1007/978-3-032-29918-5_25

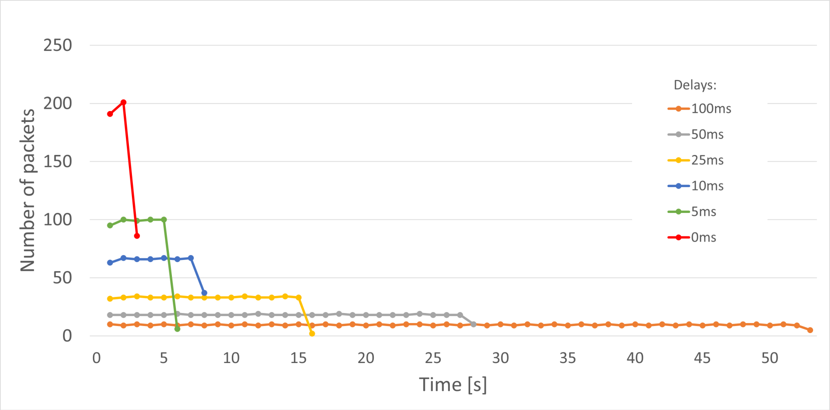

Fig. 5. The number of packets sent per second with various delays. 500 packets in total

Scenario 2 - throughput measurement. The purpose of the second scenario was to measure the maximum throughput of the 6LoWPAN protocol. In the first test, to ensure the best data-to-protocol overhead ratio, the IEEE802.15.4 frame length was set to the maximum allowable 127 bytes. This means that in a 127-byte packet, 63 bytes were allocated for the user payload. It should be noted that the extended addresses defined in IEEE802.15.4 were used in the first test, which increased the protocol overhead. The additional overhead was added by the CRC mechanism, which consumes the last two bytes of the frame to verify the correctness of the data. The maximum throughput achieved was 161 kbps, while the application layer throughput reached 79.866 kbps. To measure the impact of the fragmentation mechanism, the transmission of longer packets was tested with the header compression mechanism enabled. Compression mechanisms had no noticeable effect on the total network throughput. The maximum recorded value was 158.4 kbps. As expected, the application layer throughput was higher with the header compression mechanism enabled. The results obtained for the data sizes of 128 and 256 bytes reach 92.160 kbps and 99.768 kbps, respectively. The average throughput obtained in different conditions is presented in Fig. 6.

5 Discussion

Our experimental results provide important practical implications. They demonstrate the real-world performance limits of IPv6-based communication in low-power IEEE 802.15.4 networks. They also show that, while the nRF52840 platform enables stable and predictable data transmission in typical line-of-sight IoT scenarios, network reliability rapidly degrades once signal conditions approach the sensitivity threshold. This behaviour demonstrates that, in constrained WPAN environments, link quality rather than nominal transmission range becomes the dominant factor determining usable communication distance.

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: 10.1007/978-3-032-29918-5_25

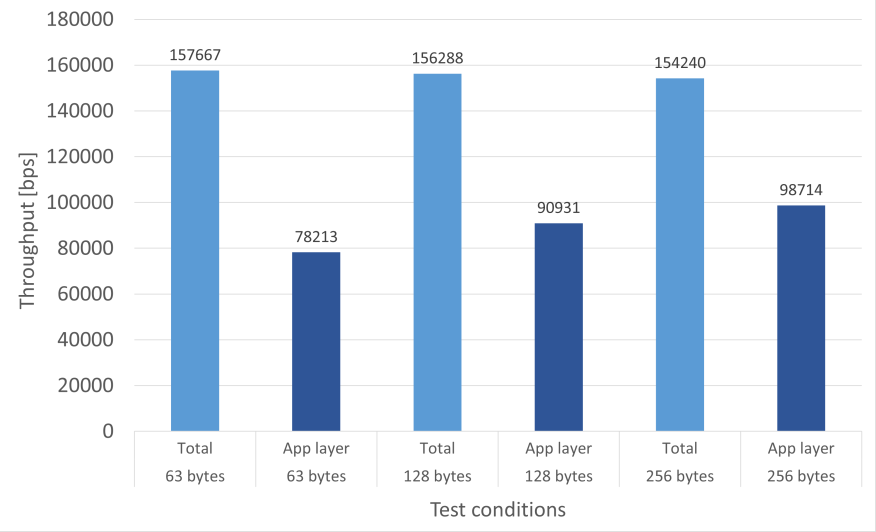

Fig. 6. The average results of throughput measurements.

Consequently, system designers should prioritise deployment conditions that ensure stable RSSI margins, as occasional long-range connectivity offers limited practical value when packet losses necessitate frequent retransmissions. It should be noted that the line-of-sight measurement represents the best-case scenario, rather uncommon in real applications. In indoor environments, signals can suffer interference, multipath fading, and attenuation due to obstacles, including walls, furniture and equipment.

The throughput analysis highlights the fundamental trade-offs introduced by the 6LoWPAN adaptation layer. Although 6LoWPAN enables seamless integration of low-power devices with IPv6 networks, this interoperability comes at the cost of additional protocol overhead and processing latency, which reduces effective application-layer throughput. Header compression improves payload efficiency but does not eliminate the throughput limitations imposed by the physical layer and packet processing constraints. These results emphasise the need to balance interoperability, energy efficiency, and data rate when designing IoT systems. In applications where low power consumption and global IP connectivity are prioritised, the observed performance penalties are acceptable, whereas throughput-intensive use cases may require alternative communication technologies or architectural optimisations.

These observations are consistent with prior studies on IEEE 802.15.4 and 6LoWPAN-based networks presented in [19] showing similar maximum network throughput. The throughput values measured by authors of [13] present much lower values, which can result from limitations introduced by the UART connection between the Linux-based gateway and USB stick. The use of up-to-date electronic elements, equipped with fast processor cores and hardware accelera-

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: 10.1007/978-3-032-29918-5_25

tors for local wired and remote radio communication, significantly shortens the processing time of data packets. In our research, it was estimated at less than 1ms. The range measurements show that the nRF52840 USB dongle achieves a higher range of transmission in comparison to the module presented in the work [14]. In the mentioned article, results show that the system the authors used achieves the same range of RSSI values, ensuring stable transmission, but reaches a maximum range of 7 meters, while the USB dongle we tested allows for stable transmission up to 40 m and the signal is lost above 100 m. This demonstrates that advances in sensor networks and communication systems enable significantly improved transmission distances. Our observations present that the use of modern electronic elements allows for the development of fast and reliable solutions, for example, for V2V technology.

6 Conclusions

The conducted research shows that the maximum range of the network using the IEEE802.15.4 protocol implemented using nRF52840 systems, allowing for reliable data transmission, is about 40 meters. The most advantageous arrangement of antennas relative to each other, in direct visibility, and packet loss not exceeding 10% was assumed. One should expect frequent retransmissions at more considerable distances, which significantly reduces the network throughput. The maximum transmission range achieved for nRF52840 systems was about 100m. Throughput studies have shown that the 6LoWPAN protocol, together with the IEEE802.15.4 link layer protocol, uses about 50% of the link bandwidth. It can also be observed that header compression has a small but positive influence on the effective network throughput. This is especially important for longer IPv6 data packets that must be divided into many short IEEE802.15.4 protocol frames. Like the IPv6 protocol, the 6LoWPAN protocol is currently being implemented more and more often in IoT devices. It can be expected that with the withdrawal of the IPv4 protocol and its replacement by the more modern and capacious IPv6, the popularity of 6LoWPAN will increase. It has also been implemented as an element of broader solutions such as OpenThread. It is, therefore, important to thoroughly understand the principles of its operation and reliably assess its impact on the functioning of networks operating in the IoT segment, including network throughput. Knowledge of network parameters, such as range, transmission speed, and packet fragmentation rules, allows for conscious design of the network topology and layout of key network elements to achieve the best possible performance and reliability. The presented results of measurements not only show the maximum throughput of the 6LoWPAN protocol but also can serve as useful guidance for optimising the network's performance under various traffic conditions.

Acknowledgments. This research was partially supported by Statutory Research funds of the Department of Graphics, Computer Vision and Digital Systems and the Department of Applied Informatics, Silesian University of Technology, Gliwice, Poland.

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: 10.1007/978-3-032-29918-5_25

This paper was partially supported by the Reactive Too project that has received funding from the European Union's Horizon 2020 Research, Innovation, and Staff Exchange Programme under the Marie Skłodowska-Curie Action (Grant Agreement No. 871163). Scientific work published as part of an international project co-financed by the program of the Minister of Science and Higher Education entitled "PMW" in the years 2021 - 2025; contract no. 5169/H2020/2020/2.

Disclosure of Interests. The authors do not declare a conflict of interest.

References

1. Grzesik, P., Mrozek, D.: Comparative Analysis of Time Series Databases in the Context of Edge Computing for Low Power Sensor Networks. In: Krzhizhanovskaya, V.V., et al. Computational Science – ICCS 2020. ICCS 2020. Lecture Notes in Computer Science(), vol 12141. Springer, Cham (2020) https://doi.org/10.1007/978-3-030-50426-7_28
2. Montenegro, G., Kushalnagar, N., Hui, J., and D. Culler.: Transmission of IPv6 Packets over IEEE 802.15.4 Networks, RFC 4944, 2007, https://doi.org/DOI 10.17487/RFC4944
3. Kushalnagar, N., Montenegro, G., and C. Schumacher, "IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs): Overview, Assumptions, Problem Statement, and Goals", RFC 4919, 2007, https://doi.org/DOI 10.17487/RFC4919
4. J. Beeharry and B. Nowbutsing.: Forecasting IPv4 exhaustion and IPv6 migration, 2016 IEEE International Conference on Emerging Technologies and Innovative Business Practices for the Transformation of Societies (EmergiTech), Balaclava, Mauritius, 2016, pp. 336-340, https://doi.org/ 10.1109/EmergiTech.2016.7737362
5. Zach Shelby, Crstern Bormann.: 6LoWPAN: The Wireless Embedded Internet, Wiley Telecom 2009, ISBN: 9780470686225
6. TAMARIZ-FLORES, Edna Iliana, TORREALBA-MELÉNDEZ, Richard, BALBUENA-AGUILAR, Arturo and LÓPEZ-LÓPEZ, Mario.: Temperature monitoring indoor based on a 6LoWPAN network. Journal of Scientific and Technical Applications. 2020. 6-18:1-6, https://doi.org/ 10.35429/JSTA.2020.18.6.1.6
7. Shen, Bin and Zhang, Guiqing and Wang, Ming and Li, Chengdong.: Internet of Building Equipment System Based on Thread Network and Methods for Managing End Devices. 2018 IEEE 4th International Conference on Computer and Communications (ICCC), 2018, pp. 987-991. https://doi.org/10.1109/CompComm.2018.8780616
8. C. Yibo et al.: 6LoWPAN Stacks: A Survey. 2011 7th International Conference on Wireless Communications, Networking and Mobile Computing, Wuhan, China, 2011, pp. 1-4. https://doi.org/10.1109/wicom.2011.6040344
9. A. M. Abood, W. K. Hasan and H. Khaled.: 6LoWPAN - Technical Features and Challenges in IoT: A Review. 2024 IEEE 4th International Maghreb Meeting of the Conference on Sciences and Techniques of Automatic Control and Computer Engineering (MI-STA), Tripoli, Libya, 2024, pp. 476-481. https://doi.org/10.1109/MI-STA61267.2024.10599740
10. Alaerjan, A. Towards Sustainable Distributed Sensor Networks: An Approach for Addressing Power Limitation Issues in WSNs. Sensors 2023, 23, 975. https://doi.org/https://doi.org/10.3390/s23020975

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: 10.1007/978-3-032-29918-5_25

11. E. S. Pramukantoro, F. Andri Bakhtiar, B. Aji and R. Pratama.: Middleware for Network Interoperability in IoT. 2018 5th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI), Malang, Indonesia, 2018, pp. 499-502. https://doi.org/10.1109/EECSI.2018.8752917
12. Olsson, Jonas. "6LoWPAN demystified." Texas Instruments 13 (2014): 1-13.
13. E. Bai and X. Zhang.: Performance Evaluation of 6LoWPAN Gateway Used in Actual Network Environment. 2012 International Conference on Control Engineering and Communication Technology, Shenyang, China, 2012, pp. 1036-1039. https://doi.org/10.1109/ICCECT.2012.196
14. R. Khoshdelniat, G. R. Sinniah, K. A. Bakar, M. H. M. Shaharil, Z. Suryady and U. Sarwar.: Performance evaluation of IEEE802.15.4 6LoWPAN gateway. The 17th Asia Pacific Conference on Communications, Sabah, Malaysia, 2011, pp. 253-258. https://doi.org/10.1109/APCC.2011.6152814
15. L. Zhao and G. Wang.: Research Status of 6LoWPAN in the Field of Internet of Things. 2020 5th International Conference on Automation, Control and Robotics Engineering (CACRE), Dalian, China, 2020, pp. 739-743. https://doi.org/10.1109/CACRE50138.2020.9230293
16. N. H. Mohd Yusoff, N. A. Zakaria, A. Sikora and J. Sebastian E.: 6LoWPAN Protocol in Fixed Environment: A Performance Assessment Analysis. 2019 10th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS), Metz, France, 2019, pp. 1142-1147. https://doi.org/10.1109/IDAACS.2019.8924283
17. N. H. M. Yusoff, N. A. Zakaria, A. Sikora and E. Jubin Sebastian.: HRPL Protocol for 6LoWPAN Smart Home System: A Performance Assessment Analysis. 2020 IEEE 5th International Symposium on Smart and Wireless Systems within the Conferences on Intelligent Data Acquisition and Advanced Computing Systems (IDAACS-SWS), Dortmund, Germany, 2020, pp. 1-5. https://doi.org/10.1109/IDAACS-SWS50031.2020.9297079
18. D. Chen, J. Brown and J. Y. Khan.: Performance analysis of a distributed 6LoWPAN network for the Smart Grid applications. 2014 IEEE Ninth International Conference on Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP), Singapore, 2014, pp. 1-6, https://doi.org/10.1109/ISSNIP.2014.6827646
19. S.B.A. Khattak, M.M. Nasralla, H. Farman and N. Choudhury.: Performance Evaluation of an IEEE 802.15.4-Based Thread Network for Efficient Internet of Things Communications in Smart Cities. Appl. Sci. 2023, 13, 7745. https://doi.org/https://doi.org/10.3390/app13137745
20. J. Song et al.: WirelessHART: Applying Wireless Technology in Real-Time Industrial Process Control, 2008 IEEE Real-Time and Embedded Technology and Applications Symposium, St. Louis, MO, USA, 2008, pp. 377-386, https://doi.org/10.1109/RTAS.2008.15
21. W. Zegeye, A. Jemal and K. Kornegay, "Connected Smart Home over Matter Protocol," 2023 IEEE International Conference on Consumer Electronics (ICCE), Las Vegas, NV, USA, 2023, pp. 1-7, https://doi.org/10.1109/ICCE56470.2023.10043520
22. I. Unwala, Z. Taqvi and J. Lu, "Thread: An IoT Protocol," 2018 IEEE Green Technologies Conference (GreenTech), Austin, TX, USA, 2018, pp. 161-167, https://doi.org/doi: 10.1109/GreenTech.2018.00037
23. Pan, Meng-Shiuan, and Yu-Chee Tseng. "ZigBee and their applications." Sensor networks and configuration: Fundamentals, standards, platforms, and applications. Berlin, Heidelberg: Springer Berlin Heidelberg, 2007. 349-368.

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: 10.1007/978-3-032-29918-5_25

24. P. Wu, Y. Cui, J. Wu, J. Liu and C. Metz, "Transition from IPv4 to IPv6: A State-of-the-Art Survey," in IEEE Communications Surveys & Tutorials, vol. 15, no. 3, pp. 1407-1424, Third Quarter 2013, https://doi.org/10.1109/SURV.2012.110112.00200
25. Jayavardhana Gubbi, Rajkumar Buyya, Slaven Marusic, Marimuthu Palaniswami,: Internet of Things (IoT): A vision, architectural elements, and future directions, Future Generation Computer Systems, Volume 29, Issue 7, 2013, Pages 1645-1660, ISSN 0167-739X, https://doi.org/10.1016/j.future.2013.01.010
26. Syed Rameem Zahra, Mohammad Ahsan Chishti,: Packet Header Compression in the Internet of Things, Procedia Computer Science, Volume 173, 2020, Pages 64-69, ISSN 1877-0509, https://doi.org/10.1016/j.procs.2020.06.009
27. M. Shahidul Islam, M. T. Islam, M. A. Ullah, G. Kok Beng, N. Amin and N. Misran,: "A Modified Meander Line Microstrip Patch Antenna With Enhanced Bandwidth for 2.4 GHz ISM-Band Internet of Things (IoT) Applications," in IEEE Access, vol. 7, pp. 127850-127861, 2019, https://doi.org/10.1109/ACCESS.2019.2940049
28. Elabdi, Abdellah, Moussa Elayachi, and Mohammed Rahmoun. "Meander-Shaped Miniature Antenna for 2.4 GHz IoT Applications." International Conference on Smart Medical, IoT & Artificial Intelligence. Cham: Springer Nature Switzerland, 2024.
29. Mamati, Mehmet Selim, Şeref Keser, and M. A. Alsunaidi. "A Compact Flexible High-bandwidth Meander Line Patch Antenna for IoT Applications." 2025 21st International Conference on Synthesis, Modeling, Analysis and Simulation Methods, and Applications to Circuits Design (SMACD). IEEE, 2025.

ICCS Camera Ready Version 2026
To cite this paper please use the final published version:
DOI: 10.1007/978-3-032-29918-5_25