Comparative analysis of wireless data exchange technologies for IoT-system realization

Alexander Denisov[1[0000-0002-8155-2573]], Anton Saveliev[1[0000-0003-1851-2699]]

[1] SPIIRAS, Laboratory of Autonomous Robotic Systems, 199178 Saint-Petersburg, 14-th line, 39, Russia
denisov@iias.spb.su

Abstract. This paper presents an analysis of the most common wireless technologies that are being used nowadays for IoT-systems' implementations in various application domains: smart home, smart city, industrial IoT, etc. The most appropriate modules for transmission of diverse types of data (multimedia, service messages) to meet consumer's requirements, were tested. Finding the optimal location of access points (AP) and deploying a wireless network using minimum resources allows to minimize the final cost of IoT-products.

Keywords: wireless technologies, IoT, data exchange.

1 Introduction

The Internet of Things (IoT) is currently one of the most popular and promising concepts in the context of the Industry 4.0 trend, which determines the priority directions of development of industrial information technologies [1]. The IoT finds its application in such domains as: service provision, consumer sector, and the real sector of economy. Smart home, smart networks, and industrial IoT are becoming a global economic powerhouse. The main advantage of such systems is rapid deployment of computer networks, as well as interface usability. Obviously, widespread implementation of IoT-systems depends on the final cost for the end consumers, so reducing it is an essential task for IoT-developers. Given such requests, the use of wireless networks while implementing the IoT concept is most preferable due to their relatively low cost and ease of deployment.

Maintaining of the data rate between modules at the certain level plays a significant role for the correct operation of the entire system in real time. In wireless networks, the data rate depends on the frequency of the connection, the transmitter power, the sensitivity of the receiver antenna and the distance between them. For example, video transmission from a surveillance camera to a server requires much higher speed than exchange of service messages, since the amount of transmitted data differs significantly.

Among the popular and easily accessible wireless technologies, Wi-Fi and Bluetooth should be mentioned first and foremost. Also, LoRa technology is gaining popularity last years [2]. Due to its high sensitivity, LoRa technology meets the requirements of low power consumption and high stability of communication over long distances.

In this paper, we compare some Wi-Fi, Bluetooth, and LoRa modules from the point of providing the required data rate for a wide range of distances. Based on this investigation, some recommendations are given for choosing the most appropriate option for IoT-system deployment in the different scales: house automation systems, building automation systems, automated process control systems for enterprises. The most popular and budget solutions presented at the market today are: combined Wi-Fi-Bluetooth modules (ESP32, ESP8266), LoRa module SX 1276, and Bluetooth modules (HC-05, HC-06).

Let us briefly consider solutions applying today for the organization of wireless networks. In [3], the principles of Wi-Fi network organization using the minimum number of Wi-Fi routers. The key problem considered by the authors is poor mobile support for Wi-Fi networks, largely due to their unplanned deployment. From practical experience, it was found that the average connection time of the link layer from each Wi-Fi access point is only 13 seconds, and the average time interval between the opening of two adjacent access points is 75 seconds. The aim of the work is to maximize the time during which users can receive Wi-Fi coverage without interruption. Also, the time during which users can receive a continuous Wi-Fi service should not be less than the preset threshold, with the minimum required number of access points.

In [4], deployment of a Wi-Fi network is considered depending on the number of users for unloading more expensive antennas of wireless networks. The authors describe the system model and set the target average throughput for each user, which the Wi-Fi network should achieve by more efficient unloading of the network of mobile operators. This target average throughput for each user is used as a criterion for finding the minimum number of Wi-Fi access points required in the overlay network. The authors use the regular hexagonal cell (RHC) architecture and three non-overlapping channels (channels 1, 6 and 11 for IEEE 802.11 WLAN in the 2.4 GHz band) for the deployment of Wi-Fi cells. The proportion of users served by Wi-Fi, designated as η, is controlled, through Wi-Fi power management. η is expressed as follows:

$$\eta = \frac{N_W}{N_{OV}} = \frac{\lambda A_W}{\lambda A_{OV}} = \frac{A_W}{A_{OV}} = \frac{KA_{AP}}{KA_{hex}} = \frac{A_{AP}}{A_{hex}}, (0 < \eta < 1) \quad (1)$$

where NOV implies users with an identical and saturated traffic demand which are uniformly distributed within the coverage AOV, NW is the number of active Wi-Fi users, λ is the active user density, AW is the overall coverage of Wi-Fi access points, Ahex is the maximum coverage area of Wi-Fi and AAP is the Wi-Fi point coverage. The value η does not depend on the number of Wi-Fi access points, K. This means that after η is fixed, the overall coverage of the access points does not change, even if the K changes. Since the throughput of Wi-Fi depends on the number of competing users in a Wi-Fi cell, one can achieve a certain level of throughput by adjusting K [3]. The authors use the Markov chain model to obtain a formula for the average bandwidth of Wi-Fi:

$$S_W^{user} = \frac{KS_W^{AP}(K,\eta,N_{OV})}{N_W} = \frac{KS_W^{AP}(K,\eta,N_{OV})}{\eta N_{OV}} \quad (2)$$

where SAPw is the normalized system throughput for a single Wi-Fi access point.

In [5], construction of mesh networks with dynamically connecting and disconnecting femtocells (low-power cellular communication stations for home use) is considered to increase the throughput of access to the Internet (i.e. access to the Internet via femtocells). Thereby, the software is developed to switch the mesh-router from one femtocell to another when the signal from the first one is lost. The idea of integrating mesh networks with femtocells is based on the fact that a mesh network with one or more Internet gateways (IGW) does not have enough capacity to support real-time streaming applications such as VoIP calls, multimedia data and etc.

In [6], the theoretical aspects of the wireless networks designing are discussed. The authors present an analytical model that combines industrial modeling tools with the ability to scale and analyze the impact of various design parameters and optimize the performance of a Wi-Fi network in the real world. The model takes into account all central system parameters including channelization, power allocation, load balancing, advanced PHY techniques (physical layer) (single-mode and multi-user MIMO (multiple-input and multiple-output), and joint transmission from multiple access points), topological characteristics and protocol overhead. The accuracy of the model is verified by multiple simulations. The model is developed to study a wide range of real-world scenarios, providing recommendations for processing the impact of various design parameters on performance.

In smart home systems, as well as in the IoT-systems, it is necessary to provide exchanging not only service messages but also multimedia data, which will allow creating highly loaded user systems while maintaining energy consumption and the cost of the final product at a low level.

In [7], a detailed study and analysis of the problems of interaction between wireless data transmission systems and mitigation solutions consequences in WBAN technologies (wireless body area network). Three main wireless WBAN technologies were considered: Zigbee, IEEE 802.15.6 and Low-power Wi-Fi (LP-WiFi). A thorough review of modern studies on the coexistence of WBAN has been conducted. The coexistence of wireless technologies in WBAN was mathematically analyzed and formulas were obtained for the probability of successful access to the channel in the event of interference from neighboring networks. To evaluate the interaction of WBAN IEEE 802.15.6 with Wi-Fi networks and WBAN LP-WiFi performance, the authors conducted a series of simulations using OPNET. The authors presented the results of mathematical analysis and modeling, and also analyzed the influence of the interference network on various wireless technologies. The results showed that the interfering Wi-Fi network affects the performance of WBAN and can disrupt its operation. Therefore, the use of LP-WiFi for WBAN is an acceptable and promising option in comparison with the Zigbee and IEEE 802.15.6 standards. That is, the LP-WiFi showed higher resistance to interference from Wi-Fi. In addition, the ability of LP-WiFi to interact with Wi-Fi opens the way for the integration of WBAN with a network cloud.

[8] discusses cross-domain protocols for wireless networks (ETSI 2013, IERC 2013), networks Wireless Network (WMN) (Fleisch 2013), Ad Hoc Networks (AHNs) (Marry 2013) for use in the IoT systems. The authors of the paper come to the conclusion that these technologies cannot be used in IoT systems for several reasons. First, the heterogeneity of IoT due to the fact that basically there are heterogeneous hardware

configurations, QoS requirements (QoS - quality of service, the ability of the network to provide the necessary service to a given traffic within a certain technological framework), functionality and goals. On the other hand, nodes in WSN usually have similar hardware specifications, similar communication requirements and a common goal. Secondly, the Internet participates in the IoT system, from which it inherits a centralized and hierarchical architecture. For comparison: WSN, WMN and AHN have relatively flat network architectures: nodes in these networks exchange data in a multi-move mode, and the Internet is not involved.

[9] provides an overview of the literature on economic analysis and pricing models for data collection and wireless communication in IoT. Wireless sensor networks (WSNs) are the main component of IoT that collect data from the environment and transmit data to the receiver nodes. For long service time and low maintenance costs, WSNs require adaptive and reliable designs to solve many problems, e.g., data collection, topology formation, packet forwarding, resource and power optimization, coverage optimization, efficient task allocation and security. On these issues, sensors should make optimal decisions from existing capabilities and available strategies to achieve the desired goals. The authors consider various applications of economic and price models for the development of adaptive algorithms and protocols for WSN, presented the general architecture of the IoT system, including its components and services.

The work [10] provides an overview of the technologies, protocols and application problems in IoT. The authors of the article aim to provide a more detailed summary of the most relevant protocols and application problems that will allow researchers and application developers to understand the process of negotiating different protocols to provide the desired functionality without the need for specification of standards. The authors study the relationship between IoT and other new technologies, including large data analytics cloud computing and foggy computing. The authors provide detailed examples of the use of services to illustrate how the various protocols presented in the work fit each other to deliver the desired IoT services.

The authors of [11] present a fuzzy logic mechanism to improve the life of devices in IoT systems. The authors of the work carried out an analysis of wireless communication protocols and received results on which Bluetooth Low Energy (BLE) has potential to become an important technology for the Internet of things, because one of its main advantages is its low power consumption. The aim of this work was to dynamically change the sleep time of BLE modules to increase their battery duration. The simulation results are very promising and demonstrate that using the proposed fuzzy logic controller, a significant reduction in power consumption is achieved compared to simulations performed with a fixed sleep time. The reference values for imitations are obtained from the data sheets of two finished devices, i.e. Microchip micro-controller (16 bits of the MCU PIC24F family - PIC24FJ256GB108) and the Bluegiga radio transceiver (BLE121LR Bluetooth Low Energy).

2 Testing modules for building a smart house system

To create systems that combine ability to exchange both service messages and multimedia data, one need to determine the actual data transfer rate between the modules, as well as the optimal location of the communication modules to ensure the declared functionality. To accomplish this task, the wireless modules mentioned in the previous section were mathematically and physically tested for maintaining the maximum range at a certain data rate. To calculate the data transmission and reception distance for the discussed wireless technologies, the following formula is used [11]:

$$D = 10^{\left(\frac{FSL}{20} - \frac{33}{20} - \lg(F)\right)} \quad (3)$$

$$FSL = P_t - P_{sen} - SOM \quad (4)$$

where D is the required distance between the receiver and transmitter for the given technology, F is the data rate, FSL is the Free Space Loss, SOM (System Operating Margin) is the radio power reserve, Pt is the transmitter power, and Psen is the receiver sensitivity.

Let us give the calculation of the data transmission distance for Wi-Fi-modules. Table 1 shows the values of the ESP-32 and ESP-8266 module parameters from the datasheet for Wi-Fi technology.

Table 1. Parameters of Wi-Fi for modules ESP-32 and ESP-8266.

F, MHz	SOM, dB	Pt, dBm	Psen	
2412	20	16,5	Speed, Mbps	Sensitivity, dBm
			72	-71
			54	-75
			32	-79.5
			11	-91
			6	-93
			1	-98

Table 2. Calculation results for Wi-Fi technology of modules ESP-32 and ESP-8266.

Speed, Mbps	72	54	32	11	6	1
Distance, m	22	34	58,5	220	277	492

Table 3 shows the datasheet of the module SX 1276 for the LoRa technology.

Table 3. Datasheet of LoRa technology for module SX 1276.

F, MHz	SOM, dB	Pt, dBm	Psen	
625	20	13	Speed, kbps	Sensitivity, dBm
			1.2	-121
			4.8	-117
			38.4	-108
			250	-95

Table 4. Calculation results for LoRa module SX 1276.

Speed, kbps	1.2	4.8	38.4	250
Distance, km	21,37	13.48	4.78	1.07

Table 5 shows the values of variables from the datasheet of the ESP-32 module for the Bluetooth technology.

Table 5. Technical specification for ESP-32 and ESP-8266 Bluetooth module.

F, MHz	SOM, dB	P_t, dBm	P_{sen}	
2412	20	4	Speed, Mbps	Sensitivity, dBm
			3	-84
			2	-98

Table 6. Results of calculation of range ESP-32 and ESP-8266 Bluetooth.

Speed, Mbps	3	2
Distance, m	23	116

Table 7 shows the values of variables from the technical specification for the Bluetooth modules HC-05 and HC-06.

Table 7. Parameters of HC-05 and HC-06 modules.

F, MHz	SOM, dB	P_t, dBm	P_{sen}	
2412	20	4	Speed, Mbps	Sensitivity, dBm
			2	-80

Table 8. Calculation results for Bluetooth technology of modules HC-05 and HC-06.

Speed, Mbps	2
Distance, m	14

To test the actual data transfer rate over Wi-Fi, we have applied a ready-made solution for throughput testing using TCP [12] for the ESP-32 module and a sketch from the standard Arduino IDE library for the ESP-8266 module. The experiment was hend indoors in direct line of sight from the transmitter module to the receiver module.

The results of testing the ESP-32 and ESP-8266 modules with a channel width 40MHz are presented in Table 9.

Table 9. Testing results for Wi-Fi modules ESP-32 and ESP-8266.

Speed, Mbps	5	4	3	2	1
ESP-32					
Distance, m	10	15	20	30	40
ESP-8266					
Distance, m	7	12	15	20	27

To test the speed of data transmission using LoRa technology, the ready-made software provided with the SX 1276 module was used. The testing results of the SX 1276 module are shown in Table 10.

Table 10. Testing results for LoRa module SX 1276.

Speed, kbps	37	25	15	5	1
Distance, km	0,1	0,4	0,76	1,29	3,59

To test the speed of data transmission using Bluetooth technology, we have implemented a ready-made solution based on the Arduino IDE libraries for ESP-32, ESP-8266, HC-05, and HC-06 modules. The testing took place in a room where the transmitter and receiver module were in direct line of sight. Based on the results of testing the Bluetooth technology, the following data presented in Table 11 were obtained.

Table 11. Results of testing the Bluetooth modules.

Speed. Mbps	3	2	1
ESP-32 Bluetooth			
Distance, m	3	5.5	13
ESP-8266 Bluetooth			
Distance, m	3	5	10.5
HC-05 Bluetooth			
Distance, m	3.5	6	12
HC-06 Bluetooth			
Distance, m	3.5	6	12

Based on the research results, it can be concluded that the theoretical computation of the range of propagation of radio waves differs from the practical realisation. All the modules of the considered technologies have both beneficial and negative impacts. The main advantages of Wi-Fi modules include high throughput, long range, low cost, and high security, the main disadvantages are high load in the frequency range of Wi-Fi, which can lead to loss of data packets. The advantage of LoRa modules is large coverage area of low-frequency radio waves, which allows to send data over a distance of more than 1 km, but the shortcomings include a low data rate, which is also explained by low-frequency data transmission. The main advantage of Bluetooth modules is low cost and, relatively to LoRa, high data transmission speed. At the same time, they are characterized by a small range, which does not allow them to be used in large industrial premises.

3 Conclusion

Realization of an IoT system needs efficient resource consumption and effective use of existing infrastructure, making the final cost of product as minimum as possible. Therefore, it is recommended to use LoRa modules when there is a need to transmit a small amount of data, usually control information, for example, in industrial production with a large territory. For home use or in office environments, Bluetooth and Wi-Fi modules are more suitable due to their high data transmission rates. In further work, we are planning to use the results of this study to develop a technique for indoor data transmission rate mapping that meets certain requirements for maintaining the constant signal level and speed of data transmission. This will allow to arrange wireless modules within some smart space with the most effective signal level in the optimal way.

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