Bartlomiej KAWA[1], Piotr BORKOWSKI[1]

Department of Electrical Apparatus, Technical University of Lodz (1)

doi:10.15199/48.2021.02.28

Data analysis of the latency in the building with using telecommunication technology

***Abstract**. This article analyses the latency data that occur during data transmission using the actual telecommunications network in the building. This study is aimed at checking the possibility of using telecommunications as an alternative to the currently used communications in intelligent buildings in order to ultimately move as many elements as possible to the cloud or disperse the system across all building devices. The delay study allows you to determine what delays the system will work with, which is necessary in real-time systems.*

***Streszczenie.** Ten artykuł przedstawia analizę danych opóźnień występujących podczas transmisji danych z wykorzystaniem rzeczywistej sieci telekomunikacyjnej w budynku. Badanie to ma na celu sprawdzenie możliwości wykorzystania telekomunikacji jako alternatywę obecnie wykorzystywanych łączności w inteligentnych budynkach aby docelowo przenieść jak najwięcej elementów do chmury lub rozproszyć system po wszystkich urządzeniach budynkowych. Badanie opóźnień pozwala określić z jakimi opóźnieniami będzie pracował system co jest niezbędne w systemach czasu rzeczywistego. (**Analiza danych opóźnień występujących w budynkach podczas transmisji danych z wykorzystaniem rzeczywistej sieci telekomunikacyjnej**)*

Keywords: Latency, Telecommunication, Data analyses
Słowa kluczowe: Opóźnienia, Telekomunikacja, Analiza danych

Introduction

Data transmission is one of the most developing research of science. Many scientists and companies work on the development of communication. This is very clearly visible when we look at the development of telecommunications networks, from 2G (GSM) to the currently developing 5G standard. This development consists in improving the parameters of data exchange [1].

Communication is one of the key elements in intelligent buildings, many scientists emphasize this aspect in their work. The concept of Smart Building, which is described in many publications, is extremely important for improving the quality of people's lives. Smart buildings currently focus mainly on diagnostics and control. One of the aspects of our interests is the use of the telecommunications network for building applications. In this publication, we have checked what delays occur in the real telecommunications network in an example apartment block. Ultimately, we want to use telecommunications connectivity to improve the quality of living conditions in cattle, so that the possible delays between sensors and actuators should be as small as possible [2].

Many researchers are working on improving building control systems by reducing installation costs, e.g. using Raspberry Pi-based systems. Wireless connection is becoming more and more common standard, on the example of Xiaomi, which produces many sensors for home automation, now all use wireless connectivity [3-4].

Our vision in the study is to reduce physical connections and replace them as much as possible with wireless connectivity with the highest connection quality. Due to many methods of communication, the most reliable and sure way is telecommunications, which from decade to decade achieves better and better results of connection speeds and decreasing latency. The use of non-ionized radio bands causes that the signals are subject to high uncertainty and susceptibility to interference. For example, the popular WiFi in many studies shows the instability of the link, which is not visible in the case of cellular communication [2, 5-7].

Standards describing the generation of mobile telephony define many parameters, including latency. Companies providing equipment are working on their improvement, but they focus mainly on calculate occurring in network nodes, e.g. on the X2 interface between eNodeBs in fourth and fifth generation networks. The best way to measure latency is through end-to-end testing to determine the true latency of the data link in the building [8].

Why are we talking about latency? The delay is the time difference between the transmission of a signal and its reception. The expectations of modern intelligent building systems mean that we want to control the building in real time, to be able to achieve it, we need the lowest possible delays, or at least the knowledge of possible delays. Of course, many sensors are located outside buildings and therefore they do not struggle with the problems of reducing the signal strength that occur in buildings.

The current trends show moving as many management units as possible to the cloud and communication of individual devices directly through the cloud using the Internet. To make it possible, WiFi networks are used in wireless communication, which means that we must have coverage in the entire area where we want to place devices. In order not to cover the entire area, it is possible to use the telecommunications network which in many cases covers nearly 100% of Poland's area and over 95% of the world population is within the range of telecommunications networks. Data transfer can also take place in a distributed system, where each device can act as a central unit. Regardless of the method of communication, the best and most reliable way of communication is to use the telecommunications network. In this research, we focused on checking what delays we have to take into account in different types of telecommunications connections in two connection methods, TCP / IP and SMS. From the reports presented by Ericsson, the leader in telecommunications equipment, we know that currently LTE is one of the most popular types of data and signal transmission and is constantly growing. In our research we used GSM, WCDMA and LTE, we were not able to test the 5G network due to the lack of sprint and range [9-10].

Building management systems (BMS) use various methods of communication between devices. There are two basic ways: wired and wireless. Wired communication systems are very popular due to the simplicity of communication, eg LCN [11]. However, they cannot be used e.g. in mobile devices or with a considerable distance. However, wireless systems can help. The parameter of choosing the appropriate wireless communication method, example: distance, mobility, amount of data, connection quality, delays, integrity. An example of such communication can be LoRa, WiFi, Bluetooth [12]. A new trend that is emerging is the use of commercial radio frequencies reserved for telecommunications. Not dependent on the radio band, wireless communication is characterized by many parameters, the most important of them:

- Radio Band type, licensed or not
- Frequency
- The distance between devices
- Data transmission speed
- Delay

In the current systems of intelligent building management, an important aspect is the exchange of data with the lowest possible delay so as not to waste time on the system's reactions and taking appropriate action. Examples of data in the system: electricity consumption, heat consumption and others [13-15]. Very important topic about control in the building is increase air quality. Currently, many countries in the world are struggling with the problem of smog, Poland is one of the few countries in the European Union where we note an increase in CO2 emissions. Dusts below 2.5 ppm are often found in the air and are harmful to health. The future of intelligent buildings is not only to ensure easy control and low energy consumption, but also to provide the best living conditions in the building [16-19].

Many building systems use the cloud for many tasks such as data storage and, increasingly, for control. An example of a cloud management system is proposed by Intel [20].

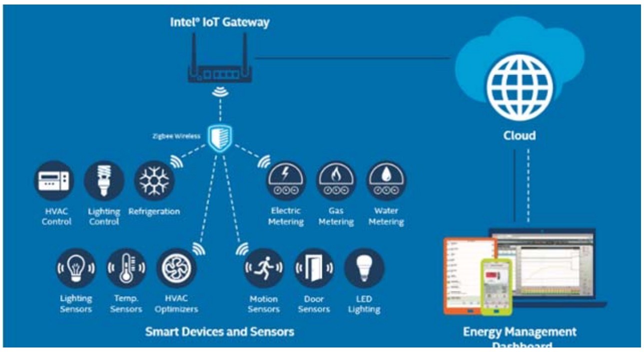

Fig. 1 BMS proposed by Intel company [20]

Our proposal is to replace traditional wireless connectivity with cellular connectivity. The use of this type of connection allows many ways of communication, such as the use of the cloud, direct communication between devices. An exemplary application is presented in Figure 2.

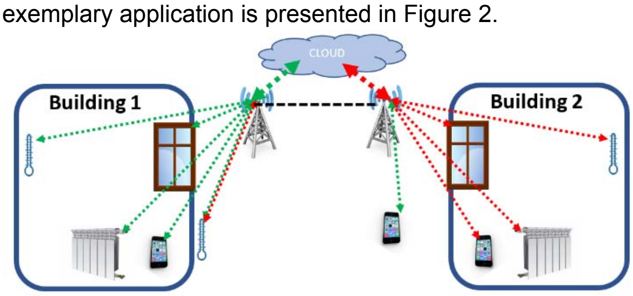

Fig. 2 Concept of using telecommunications in the BMS

The above diagram allows for unlimited distance between devices and, as research shows, a fairly stable method of communication. On the example of communication in building 1 marked with a green dashed line, we can see that the system communicates with the cloud, and the control devices, i.e. the telephone, can be located in a completely different place without additional programming or hardware devices. Red dashed lines show signals in building 2. An example of sharing sensors is also marked, which can be seen on the temperature sensor that sends data to both building 1 and 2. Such sharing of resources (devices) between buildings allows you to significantly reduce installation costs. By using BMS in the building we can also reduce energy consumption by better management of devices.

In telecommunications applications, we can use various methods of communication: GSM, WCDMA, LTe, 5G, NB-IoT, LTE-M and E-GSM. All of these technologies work on commercial frequency bands. The above system allows communication from anywhere in the world and can work in real time [21-25]. The proposed method of communication may ultimately:

- Reduce energy costs and reduce the building's CO2 production
- Reduce installation and equipment costs
- Reliability of transmission compared to non-commercial radio bands due to standardized by 3GPP organization the details of transmission

Measuring system

In building applications in which we use telecommunications networks, we have tested SMS and TCP/IP technology. The research in this article allows for a confirmed choice of such a method as the main communication medium in buildings. All measurements were taken inside the building to best reflect the possible future working environment. The building in which all the measurements were made is made of large slabs. The material from which the building is made can influence the quality of the connection, as shown by research [26]. Such a building is very popular in Central and Eastern Europe and, of course, including Lodz. We did not investigate the effect of the building material on the lags in the research. The device that simulated an example of home devices is the SIMCOM7600E module, shown in Figure 3. We chose the device because of its low cost and easy integration with other modules.

Fig. 3 SIMCOM7600E used in the research [27]

The measuring system consists of two main parts. The first is the module mentioned above as a mirror of the device. The second part is the computer on which the measuring application is running. The module is connected to the computer by means of the COM serial port. The module described above supports 4G, 3G and 2G. It is compatible with the CAT4 standard, which, for example, means that we can get speeds up to 150Mbps for LTE. The measurement application was made in C # technology in which all technologies for both SMS and ICMP were tested.

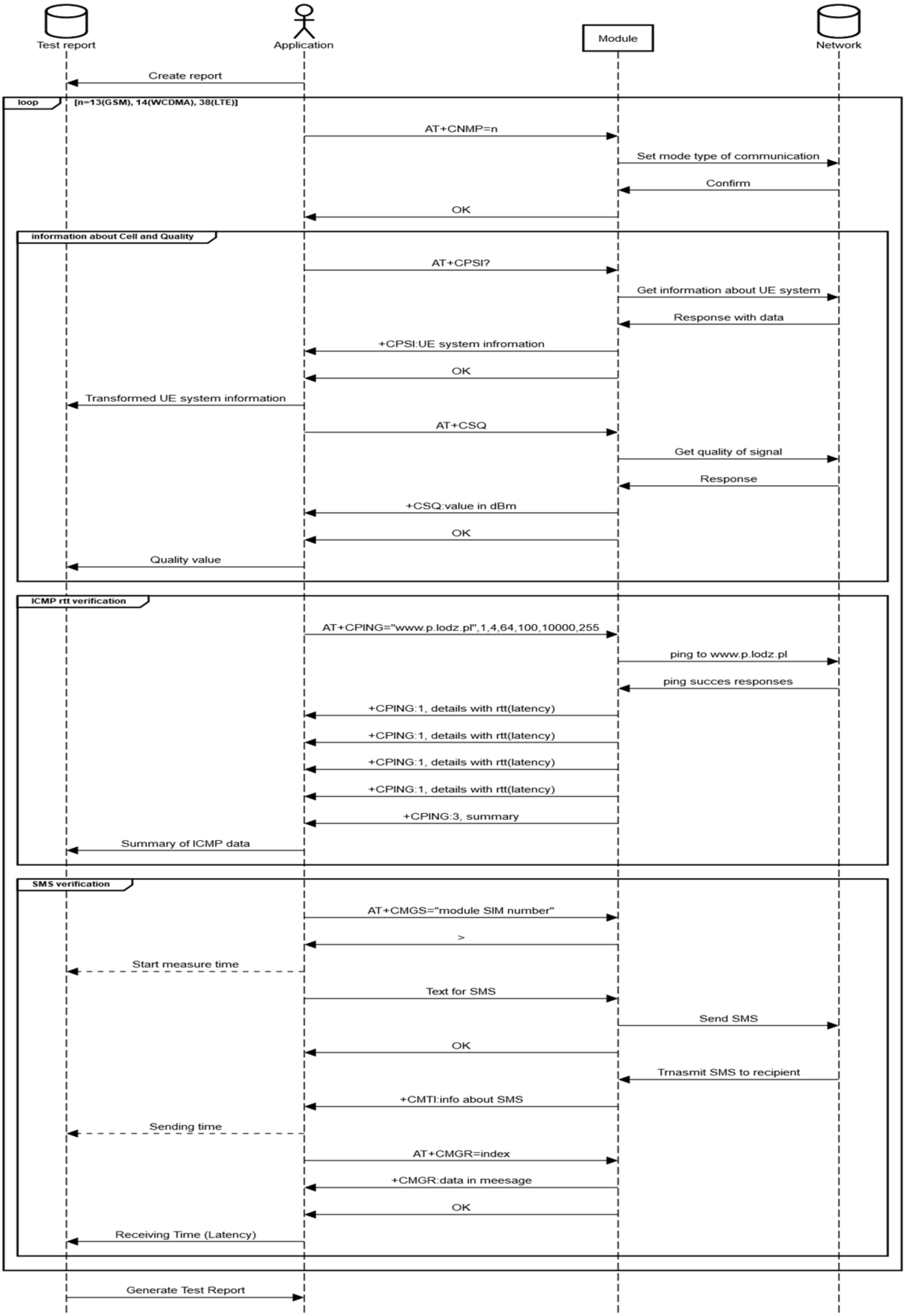

Fig. 4. Schema 0f measuring system

The measurement scheme is shown in Figure 4, which is divided into 3 groups:

- Information about CELL with which we connect
- RTT study for ICMP
- SMS research

In the first group we storage information about Cell and quality of signal. In this block We storage all information in the test report (TR). Information from AT+CPSI and AT+CSQ exist in the TR.

The AT+CPSI return information about inquiring system information. The response of this function is depended to mode of communication.

Example outputs of CPSI:

+CPSI: GSM,Online,260-02,0xe69b,8497,24 EGSM 900,-83,0,23-23

GSM – means that module using GSM technology to the communication.

Online – this a status of module in the network.

260-2 – PLMN (Public Land Mobile Network) this value contains MCC (Mobile Country Code), for Poland is 260 and MNC (Mobile Network Code), the value describe which operator network module is connected, for T-Mobile network is 02.

0xe69b – Location Area Code (LAC) describe area of the vendor network is unique for one vendor. LAC grouped Cel connected to the Mobile Switching Centre (MSC).

8497 – Cell Id, unique value of Cell in the Network.

PLMN, LAC and Cell Id is necessary to define which Cell will be using in the communication.

24 EGSM 900 – this is a definition which band, frequencies will be using. The frequency for uplink is set on 894,8 MHz and for downlink is set 939,8 MHz.

-83 – this a value in dBm and represents received signal strength. Good signal is above -95dBm.

The AT+CSQ function return information about received signal strength and also bit error rate.

Example output of AT+CSQ:

+CSQ: 17,99

In this example value 17 means -79dBm and value 99 means bit error rate unknown.

Next group of test flow called by ICMP rtt verification. In this block is verify communication in the TCP/IP type. Is using ICMP protocol to check latency between send and receive packets. Function CPING is using to that. We tested connection between module and server of Technical University of Lodz (www.p.lodz.pl). The function CPING needs 7 parameters:

1. Address IP of using for ICMP communication.
2. Type of address family, 1 for IPv4 and 2 for IPv6.
3. The number of times the ping request.
4. Data byte size of the ping packet, it is possible send packet between 4 and 188 bytes.
5. Interval between each ping. Unit of this parameter is milliseconds. We can use value between 1000 and 10000.
6. Time out for Ping function.
7. Time-To-Live (TTL) value for the IP packet over which the ping.

In the summary of CPING, function return summary of sending PING request to the server, example of CPING summary:

+CPING: 3,64,63,1,218,556,223

3 – this value means summary of response CPING. Value 1 is using for each of ping send with success. Value 2 is using similar as 1 but with time out.

64 – number of sending packets.

63 – number of receiving packets.

1 – number of packets without response.

218 – minimum value of Round Trip Time (RTT) is time between sending and receive packet.

556 – maximum value of RTT.

223 – average value of RTT.

The last block is responsible for SMS verification. In this block is sending and receiving SMS. To sending data by SMS is using CMGS function. Next step is waiting for CMTI which inform module about incoming message. The last step is receive message by using CMGR function.

The CMGS function contains two parameters. First is destination address and second is text of message. In the CMTI indicator we get information about index into ME. This index will be using in the function CMGR to download message from the storage. Example of using CMGR for text Mode of SMS:

AT+CMGR=0
+CMGR: "REC UNREAD","+48696279891","","19/08/22,21:12:37+08"
Example of message
OK

"REC UNREAD" – status of received message, that means received unread message.

"+48696279891" – this is a destination address of SMS.

"19/08/22,21:12:37+08" – this data of receive message by server.

Data analyses for SMS

SMS is very popular system of using to transfer data with using of telecommunications. Currently a lot of system using that to communicate information to central station.

Table 1. Data analysis for SMS type communication

		GSM	WCDMA	LTE
Count of samples		38	20	31
Cell	Location	Lodz, Tomaszowska 53 (T-Mobile)	Lodz, Zakladowa 61 (T-Mobile)	Lodz, Zakladowa 61 (T-Mobile)
	MCC	260	260	260
	MNC	02	02	02
	LAC	59030	59030	59031
	Cell ID	23145	41473626	74474296
	Band [MHz]	900	2100	1800
	Distance [m]	3472	2000	2000
Latency [ms]	Arithmetic average	3852	2675	668
	Minimum value	3604	2534	555
	Maximum value	5144	3261	2533
	First quartile	3717	2569	592
	Second quartile (median)	3777	2568	608
	Third quartile	3838	2691	616
Signal strength	Minimum [dBm]	-95	-107	-107
	Maximum [dBm]	-85	-91	-51
	Arithmetic average [dBm]	-90	-100	-82
	Quality	Good	Accepted	Very good

The measurement was doing on the one cell in the each of technology. All data are stored in the table 1. The data is grouped in the three main groups: Cell information, Latency and Signal strength.

The location of the cell originates from website btsearch.pl and distance was calculated with using google maps. The rest data originates from output of the commands. Latency analysis was calculated on the data storage during the tests. Signal quality are also from the research. Quality of the signal is a subjective opinion based on signal values.

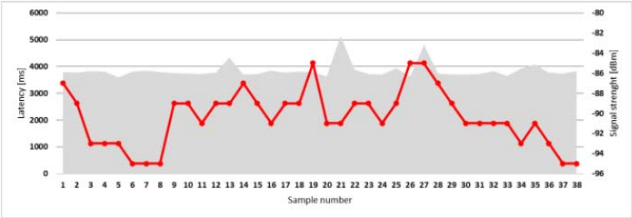

Fig. 5 Latency characteristic for SMS in GSM

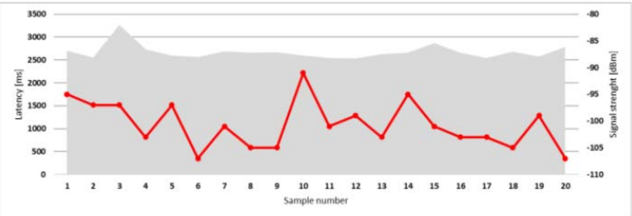

Fig.e 6 Latency characteristic for SMS in WCDMA

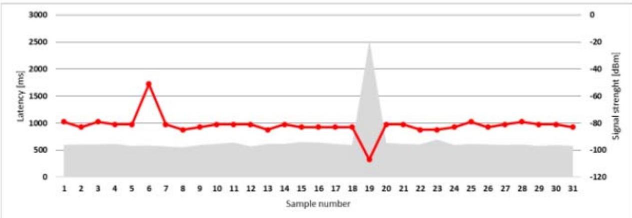

Fig. 7 Latency characteristic for SMS in LTE

The latency and signal strength are presented on the figures 5-6. The grey area chart represent latency during research. The red line chart present Signal strength.

In our research data analysis is focused on the latency values between first and third quartiles due to ignore signal pick as minimum and maximum but of course is analysed too.

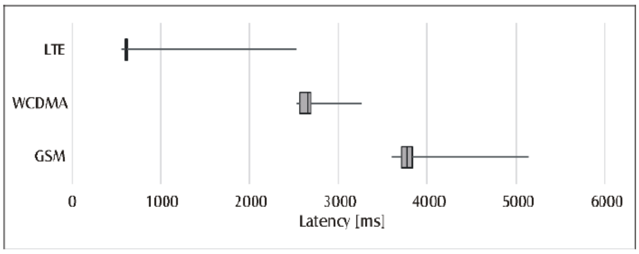

Fig. 8 Compere analysis of SMS communication

On the figure 8 we see the quartiles analyses. All technologies are very stable because difference between quartile 1 and quartile 3 is very small. It is very important in the IBMS with the real time. We can expect that all message sending by SMS will be in the delivered in the specified time. For LTE the quarter deviation is 12 ms it means that 50% sample have been handled in time between (592-616) ms. For WCDMA the quarter deviation is 61 ms and for GSM is very similar because it is 60 ms.

In the sampling of LTE exists one very extremal high latency, probably network was more occupant, because Signal strength in the time when latency has been very high, the signal strength was good.

From above data, LTE is the best choice to sent SMS because it is very stable, latency has small range and value of latency is the smallest for all technologies. If module can connect with LTE other devises which can need data from that can expect information with delay between from 592 ms to 616 ms with 50% probability. The both of rest technology should be using when module can't connect to LTE, in this case probably module connect with GSM network due to coverage of world by this technology. For WCDMA the system will be expect signal with delay between 2569 ms to 2691 ms and for GSM between 3717 ms to 3838 ms. GSM signal strength is the most stable because values are between -95 dBm to -85 dBm. WCDMA is also stable with values between -107 dBm to -91 dBm. LTE is table but during the test existed one pick of the signal strength. Quality in this point increased to the -51 dBm. Increased value of the strength signal had not big impact on the latency because in this point the delay is 590 ms.

Data analyses for PING

PING is using for verification communication between device and server. Value of latency in this research is time between sending and receiving packet. In this test have been used server of main page of Technical University of Lodz. The test of each technology was doing on the same radio cell station as for SMS.

Table 2. Data analysis for PING type communication

		GSM	WCDMA	LTE
Count of samples		35	37	33
Latency [ms]	Arithmetic average	246	122	77
	Minimum value	171	81	62
	Maximum value	597	438	233
	First quartile	187	97	64
	Second quartile (median)	234	107	71
	Third quartile	262	113	78
Signal strength	Minimum [dBm]	-97	-113	-89
	Maximum [dBm]	-81	-93	-77
	Arithmetic average [dBm]	-90	-99	-82
	Quality	Good	Accepted	Very good

Latency of the communications between two IP device in the network with using ICMP protocol is presented on the figure 9-11. Red line chart present signal strength in dBm. Grey area chart present range of latency in the research. Blue line chart is the average of the latency.

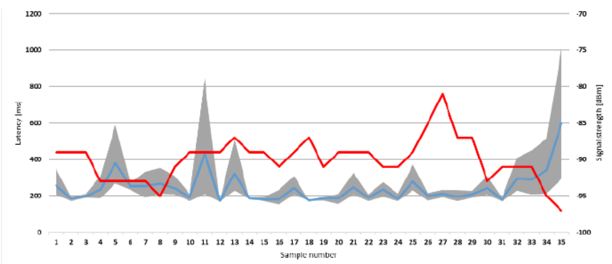

Fig. 9 RTT characteristic for PING in GSM

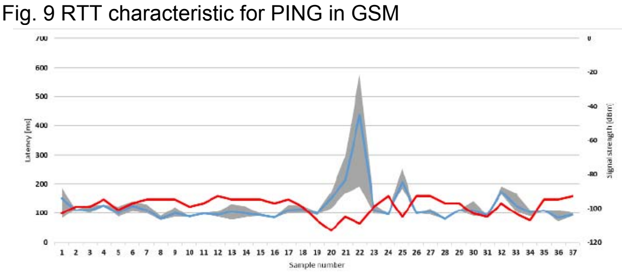

Fig. 10 RTT characteristic for PING in WCDMA

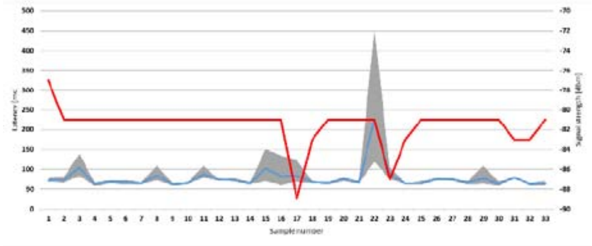

Fig. 11 RTT characteristic for PING in LTE

The result for all technologies is included on the figure 12. The chart presents the quartiles analyses for 3 technologies of telecommunications. In the grey are block is mark time between first and third quartile. It means that 50% of samples are in this block.

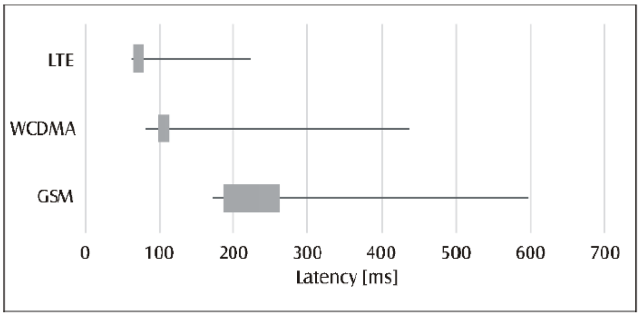

Fig. 12 Compere analysis of PING communication

Summary analysis for SMS and PING

For ICMP type of protocol (PING) we have very small deviation for LTE and WCDMA but for GSM this buffer is longer. For LTE deviation time is 16 ms. This deviation is bigger than for SMS (12 ms). Range of buffer for 50% samples is between 64 ms and 78 ms. This values are lower than for SMS about 7-9 times. Communication with using Ethernet protocol is more stable than for SMS because maximum value for PING test in the LTE communication is 233 ms. The maximum latency of LTE is the reason of only one pick on the chart, presented on the figure 11. It means that LTE technology is very stable because figure 7 for SMS in the LTE is also stable. Very stable was also signal strength for PING. During 14 samples signal strength had the same value (-83 dBm).

The same value of deviation between first and third quartile exists for WCDMA, it is also 16 ms. Of course in the WCDMA we have different range. Samples in that quartiles are between 97 ms and 113 ms. In this technology tests was very stable. Maximum value of latency is 438 ms. On the figure 10 is presented only one big pick when latency increased to the maximum value. Without one maximum value, latency for this technology is also very stable. The range and deviation is very close to LTE. The both technology is the best choice during fit for IBMS when system working in the real time. The last technology has worse result of latency.

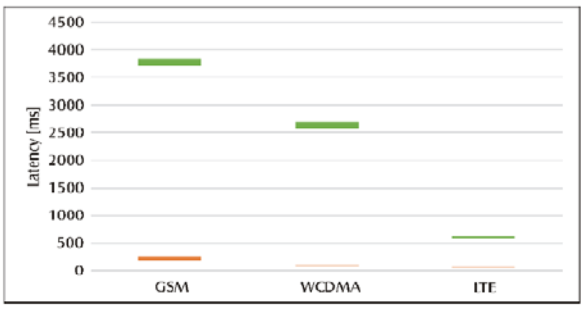

Fig. 13 Third quartiles for communication

In the GSM technology result of latency is worse. The deviation of latency in the quartiles is 75 ms. It is better than for SMS (121 ms). The latency in this technology is less stable. On the figure 8 latency has some more picks than one (for LTE and WCDMA exist mainly one pick of latency). The maximum value of Latency in the GSM is 597 ms.

Generally protocol of TCP/IP is more stable and latency have less deviation. All latencies between first and third quartiles are presented on the figure 13. Green blocks present latency for SMS, orange blocks present latency in the ping test.

Latency for LTE has small difference between SMS and ping. In the other technologies differences between SMS and ping is significantly larger.

Analyse impact signal strength on the latency

On the latency in the each technology can affect signal quality.

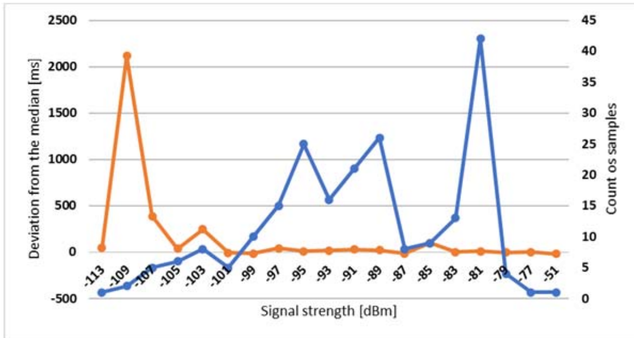

Fig. 14 Analyze impact signal strength on the latency

On the figure 14 the relationship between signal strength and deviation from the median is presented, this relationship is presented on the orange line chart. The figure 14 present also count of samples in the ach signal strength, it is present on the blue line chart.

The signal strength effect on the latency. Generally all signals bellow -100 dBm can be marked as poor quality. In the our research quality was in the range between -100 dBm and -51 dBm. Deviation of latency from the median is very low, bellow 100 ms in the one pick (-85 dBm). When signal has poor quality, bellow -100 dBm, deviation extremally increase. In the one pick value of deviation is 2115ms. If signal quality is good, We mean above -100 dBm, it is not affect much on the latency. The measurements were taken in the morning (between 3:00 and 7:00) due to the lowest traffic in the telecommunications network, as shown in the Ericsson article [28]. Samples were run approximately every 5 minutes. On the Latency can affect other factors, for example: mobile network traffic, number of switches during transmission.

Summary

In the research from this article, we verified the latency parameters and the relationship with the signal strength in the building, using the telecommunications network. The study allowed for the verification of the parameters of the transmission medium (telecommunications) for building applications. When creating future building systems in which we would like to use telecommunication networks, we have to plan possible delays, which may depend on the connection mode and communication method. The research also shows that the delays are variable within a narrow range, which allows for a fairly precise planning of real-time systems. Based on the research, it can be concluded that the tested communication method can be used for both distributed and cloud-based building solutions. Checking livestock latencies allows adaptation to network parameters in new management systems, and the location in the building influenced the measurement samples.

The use of telecommunications networks to manage the market as the main communication medium allows an unlimited range of access. For example, smog sensors can be placed on cars and smog values can be measured. Sensor data is transmitted over the telecommunications network and then used by BMS to improve indoor air quality [29].

In the future, when we can use the 5G network that is already being launched on the territory of Poland with high coverage, we will be able to communicate with many more devices within the range of one antenna. Modern building systems will be able to use this potential of the network to increase many control parameters, which will be the next stage of our research, due to the launch of the 5G accelerator in the area of the Lodz University of Technology. According to equipment manufacturers, the latency may be below 1ms for medium frequencies (3.5 GHz) [30]. Such low delay values will allow to build dispersive by-day systems without the preparation of complicated communication installations. We believe that it will be the best choice for building systems in the future.

The next step for us is to create a fully functional system in the building in real time and communicating with the use of 5G telecommunications technology. This is the next step along with artificial intelligence (AI) for use in the building. This system will be very convenient for users and easy to manage. Likewise, the system has a positive effect on people's health thanks to faster building control and very reliable. Work is also underway on the 6G system, which can be even more adapted for building purposes, with the announcement that THz waves and delays below 100us are to be used there [31-32].

***Authors**: mgr inż. Bartłomiej Kawa, Politechnika Łódzka, Katedra Aparatów Elektrycznych, Stefanowskiego 18/22, 90-537 Łódź, E-mail: bartlomiej.kawa@dokt.p.lodz.pl; prof. dr hab. inż. Piotr Borkowski, Politechnika Łódzka, Katedra Aparatów Elektrycznych, Stefanowskiego 18/22, 90-537 Łódź, E-mail: piotr.borkowski@p.lodz.pl.*

REFERENCES

[1] Korzeniewska E., Krawczyk A., Łada E., Plewako J., 5G technology as a stage of development of wireless communication, *Przeglad Elektrotechniczny,* 2019, 144-147
[2] Powroznik P., Kusmierek D., The practical aspect of estimating the range between wireless devices in building management systems, *Przeglad Elektrotechniczny,* 2018, 67-71
[3] Guy H.D., Deploying Raspberry Pi in the Classroom, *Apress*, 2017, 1-16
[4] Xiaomi, https://mi-home.pl/inteligentne-urzadzenia, list of intelligent devices
[5] Długosz M. and others, Bezprzewodowy system automatyki domowej pracujący w standardzie sieci Z-Wave, *Pomiary Automatyka Robotyka*, 17 (2013), nr 7-8, 100 - 106
[6] Łukaszewski R., Prus A., Winiecki W., Rozproszony system pomiarowy z transmisją bezprzewodową Wi-Fi i GSM z wykorzystaniem modułu FieldPoint, *Pomiary Automatyka Robotyka*, 7-8 (2004), 85 – 89
[7] Sinopoli B., Smart Building Systems for Architects, Owners and Builders, *Butterworth-Heinemann*, 2009, 1st Edition, 1-30
[8] 3GPP, TS 38.420, Xn general aspects and principles, Release 15, 2018
[9] Ericsson company, Ericsson Mobility report, 2019
[10] O'Brien L., What is a distributed control system (DCS)?, *ARC Advisory Group*, 2017
[11] Horynski M., Syla S., Intelligent control for HVAC devices in LCN system, *Teka Commision of Motorization and Power Industry in Agriculture*, 2013, 57-64
[12] Vangelista L., Long-Range IoT Technologies: The Dawn of LoRa TM, *Conference Infrastructures*, 2015, 51-58
[13] Tadeusiewicz R., Selected problems resulting from the use of internet for teaching purposes, *Bull. Pol. Ac.:Tech*, 2008, 406
[14] Ler E.L., Intelligent building automation system, *Faculty of Engineering and Surveying, 1-52*
[15] Rasool Z., Building Management System for IQRA University, *Asian Journal of Engineering, Sciences & Technology*, 2012, 106-109
[16] Zhao D., Chen H., Yu E., Luo T., PM2.5/PM10 Ratios in Eight Economic Regions and Their Relationship with Meteorology in China, *Hindawi Advances in Meteorology,* 2018, 1-15
[17] Stieb D., Pengelly D., Arron N., Taylor M., Raizenne M., Health effects of air pollution in Canada: Expert panel findings for The Canadian Smog Advisory Program, *Hindawi Canadian Repository Journal,* 1995, 155-160
[18] Czerwinska J., Wielgosinski G., Szymanska O., Is the Polish smog a new type of smog?, *Sciendo DOI: 10.1515/eces-2019-0035,* 2019, 465-474
[19] UK GBC, Climate Change, *https://www.ukgbc.org/climate-change*
[20] Intel company, Save on Energy and Streamline Operations with Incenergy and Intel, 2017
[21] Lehnert J.S., Borth D.E., Stark W.E., Telecommunication, *Britannica*
[22] Soproni L., Bodog S.A., Telecommunication systems, indispensable for world wide communication, *Fascicle of Management and Technological Engineering*, 2007, 2346-2350
[23] 3GPP, TS 45.005, GSM/EDGE Radio transmission and reception, 2016
[24] 3GPP, TS 05.05, Radio Transmission and Reception, 2016
[25] 3GPP, TS 21.905, Vocabulary for 3GPP Specifications, 2015
[26] Postel J., Internet control message protocol, *Network Working Group*, 1981
[27] Waveshare company, SIM7600E-H 4G HAT
[28] Ericsson company, A technical look at 5G energy consumption and performance, 2019
[29] Tudose D.S., Patrascu T. A., Voinescu A., Tataroiu R., Ţapus N., *Mobile sensors in air pollution measurement*, 2011 8th Workshop on Positioning, Navigation and Communication
[30] Ericsson company, 5G ultra-low latency, 2019
[31] Dang S., Amin O., Shihada B., Alouini M., What should 6G be?, *Nature Electronics,* 2020, 20-29
[32] David K., Berndt H., 6G Vision and Requirements: Is There Any Need for Beyond 5G?, *IEEE Vehicular Technology Magazine,* 2018, 72-80