Transmission of Biomedical Data from BIOSIP Modules in a Wireless Personal Area Network with Synchronous Measurements, and the Future Use in the Internet of Things

Barbara Szuster, Zbigniew Szczurek, Paweł Kowalski, Bartłomiej Kubik, Andrzej Michnik, Rafał Wiśniowski, and Katarzyna Świda

***Abstract*—The paper aims to present the organizational concept of the wireless personal area network (WPAN network) transmitting biomedical data, used in the BioSip system. The network transmits data from recording modules arranged on the subject's body to a collective node (data integrator). At the same time, all the necessary properties are maintained, i.e. low power consumption of the modules, increased resistance of the network to artefacts, the required transmission speed and signal delays. The options to synchronize measurements in various modules have also been presented, along with the resulting benefits. The wireless personal area network of BioSip modules may be based on various communication protocols, such as Bluetooth Smart or ANT. The BioSip network builds on its own protocol based on transmission mechanisms by Nordic. The software of BioSip modules may be adapted for operation in the Internet of Things through network protocol layers made available by Nordic.**

***Index Terms*—body sensor networks, wireless medicine, low power, personal area network, Bluetooth Smart, ANT, BioSip, WPAN – Wireless Personal Area Network, Body Area Network, Internet of Things - IoT, IPv6 - Internet Protocol version 6**

I. Introduction

It is more and more often that medicine benefits from concurrent examinations of many different physiological parameters. Such examinations require the use of numerous interoperable sensors and/or devices, which involves a number of connecting cables in typical solutions. The examinations were mainly performed in healthcare facilities because the patient required long-lasting preparation – the cables and electrodes had to be connected, the subject secured so as to prevent them from falling off, and the electrodes placed in specific locations on the subject's body. Comfort is offered by eliminating redundant cables connecting sensor groups and using a personal area network for communication. The system can also be adapted to specific needs. There is an available range of tests, and a specific set may be selected, such as ECG, SPO2, EMG, GSR, respiration, temperature or spatial orientation. The set will contain all the elements that are necessary for a specific examination. If complex connections between modules are eliminated, the system is easier to use at home. If a personal area network is used, significant cost reduction may be achieved, related to securing the connecting cables. The comfort of the examination is also improved. Maintenance of the personal area network entails some problems when it comes to its effective organization and security of the transmitted data. No part of the data sent to the central unit may be lost. Interruptions in transmissions may cause losses of certain material data. As a result, the course of the examination may be affected or unwanted artefacts may be introduced that are likely to have an adverse impact on the final evaluation of the examination.

B. Szuster, Z. Szczurek, P. Kowalski, B. Kubik, A. Michnik, R. Wiśniowski and K. Świda are with Institute of Medical Technology and Equipment, 118 Roosevelt St., 41-800 Zabrze, Poland (e-mails: barbara.szuster@itam.zabrze.pl, zbigniew.szczurek@itam.zabrze.pl, pawel.kowalski@itam.zabrze.pl, bartlomiej.kubik@itam.zabrze.pl, andrzej.michnik@itam.zabrze.pl, rafal.wisniowski@itam.zabrze.pl, katarzyna.swida@itam.zabrze.pl

II. BIOSIP System Architecture

A. Description of the BIOSIP system

BIOSIP system architecture has been presented in Fig. 1. BIOSIP is made up of a central node, an integrator which gathers data from other modules, and a number of small devices dealing with the measurements of specific biomedical and environmental parameters. The cables which connect the electrodes and the measurement device can be significantly shorter as a result of this division. BioSip system modules are divided into:

1) *BIOSIP-1:* this module allows for the measurement of ECG or respiration and may also participate in the measurement of spatial orientation.
2) *BIOSIP-2:* this module is similar to module BIOSIP-1 and additionally permits simultaneous measurement of ECG i respiration.
3) *BIOSIP-3:* this module plays the role of the integrator, and collects measurement data from other, smaller modules, and retransmits them to the central unit. It also enables the measurement of ECG and respiration, may take part in the measurements of spatial orientation, and is equipped with a GPS tracking unit.
4) *BIOSIP-4:* this module measures skin resistance to evaluate the level of stress (GSR) and determine the spatial orientation.

ISSN 2080-8755

5) *BIOSIP-5:* this module measures the external body temperature.

6) *BIOSIP-6*: this module takes part in spatial orientation measurements.

7) *BIOSIP pulse module:* this module makes it possible to record the pulse wave, as well as take GSR, temperature, and spatial orientation measurements.

The all modules have a software mechanism for detect abnormalities e.g. when the contact with electrode is bad during the measuring GSR or ECG. When the state of health patients has been deterioration. All of the problems are signalized via alarm (sounds).

The BIOSIP system may be configured freely according to the profile of the conducted examination, and may be adapted to the patient's requirements. The number of the modules in the system is conditional upon the transmitted parameters. If a single module needs to be used, the software stack Bluetooth LE or ANT/ANT+ may be uploaded to the module to provide communication with commonly available mobile devices, e.g. a smartphone or tablet. This simple configuration makes it possible to adapt the system for home use, in outpatient clinics or in hospitals. The modules also work with other wireless medical monitoring systems.

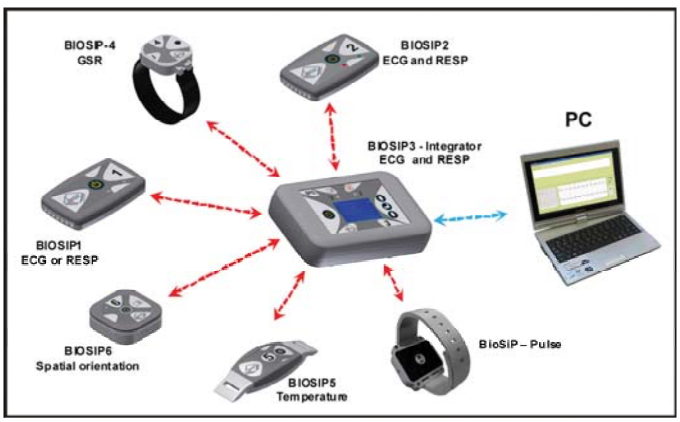

Fig. 1. BIOSIP system architecture.

III. ORGANIZATION OF A PERSONAL AREA NETWORK

B. Personal area network - hardware

The personal area network consists of a BioSoc solution nRF51822 [7] by Nordic Semiconductor, equipped with a microcontroller with the processor Cortex-M0. The system has a built-in 2.4GHz transceiver conforming to the IEEE802.15.1 standard[1]. This system can provide a basis for a Bluetooth LE and ANT/ANT+ network or the user's own protocol may be used, adapted in the best possible way to the operation of the BioSip system network. The system microcontroller is equipped with peripheral mapped IO. As a result, the PCB print can be created in a much simpler way because the main element that must be paid attention to is the radio part RF and the ADC converter. The other peripherals, e.g. I2C, SPI, UART, may be assigned to any GPIO pins. Fig. 2 demonstrates a simplified block diagram of connections for the BIOSIP-2 module.

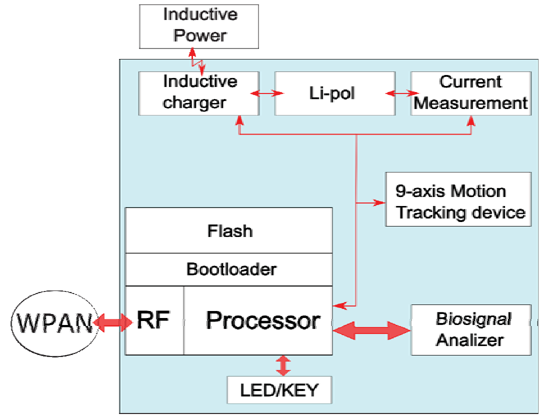

Fig. 2. BIOSIP-2 module architecture.

The module consists of the following main functional components:

1) *Processor:* The BioSoc nRF51422 kit including a microcontroller, controlling the entire module, with a built-in transceiver. A bootloader allows for the software update of the kit or even a complete replacement, e.g. for a different protocol, such as Bluetooth or ANT/ANT+.

2) *Biosignal Analyzer*: this functional element gathers biomedical signals and analyzes them in due time. The analysis of the PQRST complex will be added to this element in the future; data will also be optimized for transmission.

3) *9-axis Motion tracking device:* the module is responsible for collecting and processing information from accelerometric, gyroscopic and magnetometric sensors. Processing consists in the computing of all data to obtain instantaneous angular velocities (roll, pitch, yaw).

4) *Current measurement:* this module measures power consumption and evaluates the condition of the battery.

5) *Inductive charger:* this element is used for wireless charging of the BioSip module battery. Owing to wireless battery charging, the examination may be continued without an interruption to take the battery out and recharge it. What is more, the whole device is tightly locked, and therefore safer and resilient to most environmental conditions which affect the operation of electronics.

C. Topology of a personal area network

The topology of a personal area network depends on the number of modules which are registered within the network, and their data transmission reliability. A few scenarios can be worked out, which has been demonstrated in Fig. 2.:

1) *BROADCAST:* used when each module has to receive the same information, e.g. change of network settings, change of channels, resynchronization with the modules.

2) *PEER-TO-PEER:* used when there is only one module, and one receiving station (integrator) in the network. The frames may be sent with an ACK confirmation or without a confirmation; in this way, the next frames can be sent faster.

3) *STAR:* This is the main network topology which provides a basis for the concept of the personal area network. Topology is required when the network contains more modules. By analogy with a PEER-TO-PEER solution, the frames may be sent with or without an ACK confirmation.

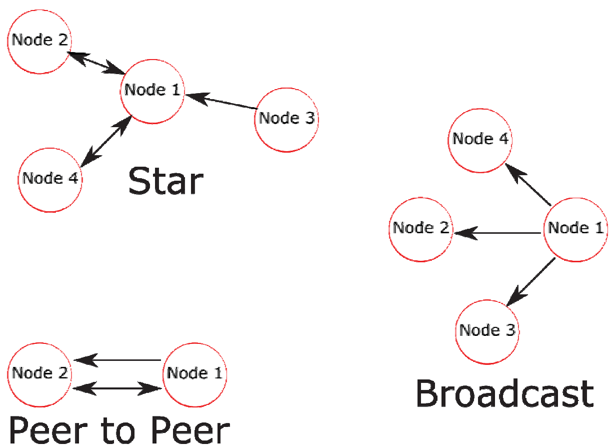

Fig. 3. Network topologies used in the BioSip system.

D. Parameters sent in the network

Table I shows the parameters that are sent in the BioSip system in relation to the criteria required for the broadcast data. It can be seen that the main biomedical parameter is the ECG signal. This parameter provides a basis for the evaluation of the patient's condition.

TABLE I
SELECTION CRITERIA FOR THE TRANSMITTED BIOMEDICAL PARAMETERS

Measurement	Selection criteria for the transmitted biomedical parameters			
	Throughput	*Delay*	*Impact of transmission errors*	*Priority*
ECG	High	Low	High	1
EMG	Medium	Low	Medium	2
Respiration	Low	Medium	Low	3
Spatial orientation	Medium	Low	High	4
GSR temperature	Low	High	Low	5

Let us assume that there is a system which requires a 16-bit, dual-channel ECG with a 250Hz sampling rate. Such a signal, sent in real time, requires the throughput of 8000bits/s. Besides, the ECG signal delays must be very small, and the transmission errors are very impactful. An interrupted ECG signal may lead to data losses, indicating that the patient is in serious condition, or to poor and erroneous analytics. In case of less resistant QRS algorithms, the biomedical parameters may be incorrectly calculated.

Another significant parameter, critically affected by transmission errors and delays between the frames, is spatial orientation. Three basic sensors are used to calcuate spatial orientation – the accelerometer, magnetometer and gyroscope. If the data from the sensors were not recalculated, but sent directly unprocessed, a transmission of 11440Bps would be required for three such 16-bit sensors and for data transmitted 10 times per second. It is mandatory for energy savings that data should be recalculated immediately in the modules in which they are gathered. The transmission speed can then be reduced by 960Bps. Hence, a data stream of 480Bps is sent when transmitting only the computed instantaneous angular rotation (Pitch, Roll, Yaw), while maintaining the exactitude of 16 bits.

The other parameters, such as respiration, GSR and temperature, are slowly changing signals and do not require very frequent updates. Also, single errors in transmission only slightly affect the evaluation of the patient's condition.

E. Security and resistance to artefacts of a personal area network

Data security can be divided into the following groups:

1) *Data encryption*: The basic security measure is the encryption of the transmitted data. A transmission can be handled in such a way that the transmission decryption key is provided during synchronization, and changed with each subsequent synchronization for better data protection [2]. There is a disadvantage to a changing key; an attack and subsequent interception can happen while the key is being sent, next data may be intercepted until the next synchronization change of the key. Faster security algorithms are an advantage of this solution; the algorithms require less computing, while a frequent change of the key prevents the transmission from unauthorized disclosure of only a certain part of the data. Another method consists in determining one unchanging security key, yet it is less safe in the longer run. This security measure entails a risk of breaking the key. If the key is broken, all the transmitted data will be decrypted immediately. Such transmissions involve encryption algorithms which require a significant amount of computing. Consequently, they become slower, although much more difficult to break.
2) *Frequency Hopping Spread Spectrum FHSS [4]:* FHSS is a method which secures the transmission from artefacts and attempts to intercept data, and consists in changing the carrier frequency according to a certain "hopping" pattern and a set algorithm, at regular time intervals. Failing data transmission at a particular frequency is repeated at a different frequency after the channel is changed. In this transmission type, the signal spectrum is spread within the whole accessible transmission band, and its strength is uniformly averaged. If the interception device has no "knowledge" of the frequency changing sequence in the transmitter, it cannot decrypt the data. The network transmission and reception nodes must be synchronized in the method used e.g. in the Bluetooth transmission, which involves high energy consumption.
3) *Mixed methods:* The security method used in BioSip is a combination of several security measures. The first one consists in the encryption of data sent with a variable key. The second method builds on the FHSS method and the "hopping" pattern to other frequencies as soon as artefacts are detected (Fig. 4). After the artefacts in the

channel are detected, the network nodes search for a different frequency according to a set pattern. After a different frequency is found, data exchange continues until another artefact appears.

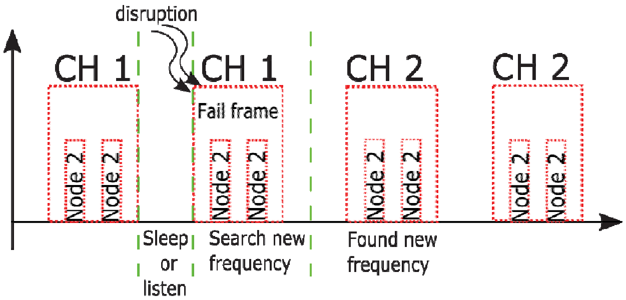

Fig. 4. Security measures used in the BIOSIP system.

F. Organization of the personal area network – software

Organization of the personal area network stack can be divided into three main parts:

1) *Network initialization*: It is possible to initiate the personal area network stack in two ways. The first method is to keep the initial settings. The network automatically selects optimal parameters. Modules are added automatically or at the user's request. The second way is initialization according to predetermined configuration. It is the user who decides which modules the network should connect to, how many modules can be connected to the network, if the transmission requires confirmation or not, how long the frames will be for individual modules, if artefact monitoring should be activated, or if "hopping" to a different channel should be possible to improve the quality of the transmission.
2) *Adding new modules 5:* by sending the Broadcast frame. At the next stage, the modules which have received such a frame contact the initiation module to specify network parameters or receive parameters from the primary module.
3) *Transmitting and receiving secured data 6:* For each module, the integrator determines time windows in which the modules are able to communicate. After the decision about time windows is made, the channel can be changed to communicate with other modules or the channel remains the same if it offers more modules for communication.

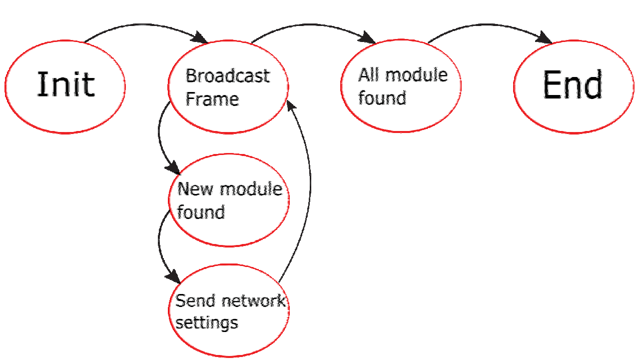

Fig. 5. A simplified block diagram of the stack for adding new modules to the network.

Once the integrator has completed data reception, and is waiting for a longer time for the next broadcast, the reception module of the integrator can be toggled into two modes. In the listening mode, the integrator "listens" to the channel traffic to see if the channel is busy and possibly "hop" to a different channel to improve the reliability of the broadcast. In the second mode the radio receiver is deactivated to save energy.

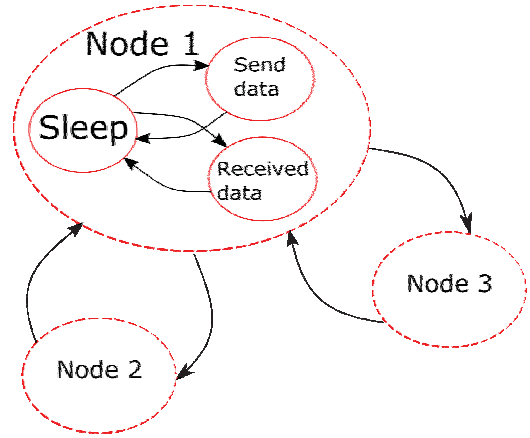

Fig. 6. A simplified block diagram of the stack for data transmission and reception.

G. Comparison of Bluetooth LE, ANT/ANT+, ZigBee protocols and the transmission protocol BioSip/ITAM

Table II compares the protocols that can be used in a personal area network.

TABLE II
COMPARISON OF COMMUNICATION PROTOCOLS

Parameter	**Comparison of communication protocols**			
	ANT/ANT+	***Bluetooth LE***	***ZigBee***	***BIOSIP System***
Over the air transmission rate (kbit/s)	1000	1000	250	250, 500, 1000, 2000
Protocol	ANT/ANT+	Bluetooth LE	ZigBee	ANT/ANT+, Bluetooth LE, own BioSip stack
Standard	Proprietary	802.15.1	802.15.4	802.15.1
Required PCB area (mm^2)	125	Depends on architecture	Depends on architecture	Depends on architecture
Range (metres)	1 to 30	1 to 10+	1 to 100+	1 to 10+
Min. node configuration	Transmitter only or transceiver	Transceiver	Transceiver	Transmitter, receiver or transceiver
Max. network size (nodes)	2^{32}	7	2^{64}	Depends on stack software

We can see that each protocol has its benefits and drawbacks. Still, the protocol used in the BioSip system has some additional advantages. Since the BioSip system was designed at ITAM, it can be tailored to suit the individual needs of the designed network, optimized for energy savings, effective data transmission speed, and selection of the format for the transmitted data. On the other hand, personal area network modules which operate in accordance with the

BioSip/ITAM protocol are designed in a way rendering them interoperable with other individual personal area networks using ANT/ANT+ or Bluetooth LE standards, and for instance enabling them to work with the existing systems. Moreover, the modules may be offered as independent devices for operation in the Bluetooth LE standard, e.g. in connection with a mobile device, such as a smartphone or tablet.

IV. Synchronization of the Measurements in the Network

A system of BioSip modules operating in a network enables measurements of physiological quantities in a convenient way for the patient, and in an optimal way for the measurements because the sensors are placed on the most appropriate parts of the body. The fact that the measurements are made independently of one another and are only slightly related in time might be some kind of disadvantage of this solution. This does not really matter for the measurements handled by the basic BioSip module set, yet it may be of some importance for the measurements of some quantities in the system. PTT, pulse transit time, and PWV, pulse wave velocity, are some of these measurements. These quantities must be measured because in this way arterial stiffness can be evaluated as an indicator of the progressing ischemic heart disease, mortality caused by cardiovascular disease and strokes [5]. Owing to close correlation between PWV and systolic blood pressure, changes in the pressure can be monitored on a permanent basis [6].

The measurement of the pulse transit time requires the moment when the wave begins propagation to be defined, and the moment when it approaches one distant part of the body or moments when it approaches two distant parts of the body. This entails the need to measure the presence of the pulse wave in two different places of the body. If BioSip modules are applied, the ECG module (BioSip-1, BioSip-2 or BioSip-3) can be deployed to detect the R wave of the ECG curve as the beginning of the pulse transit, as well as a module to record the arrival of the pulse at the upper limb. The module has been developed as an addition to the basic version of the BioSip system owing to its open structure. It enables photoplethysmographic recording of the pulse wave. Modules in the BioSip network are able to detect moments that are important for the measurement: the appearance of the R wave and the arrival of the head of the pulse wave independently. However, the measurement of the pulse transit time requires a precise definition of these moments on the time axis, and thus close synchronization of local module clocks. The pulse transit time to the upper limb in an adult ranges from 110 to 470ms, so, in order to follow the changes of this parameter, the measurement precision should be single miliseconds. Synchronization of measurement module clocks should be as precise as that.

The microcontroller of control and transmission BioSip nRF51822 modules is equipped with a real time clock which permits the synchronization of the measurements with the required precision. However, synchronization between RTC clocks of the modules is an issue. This can be done with the use of the BioSip system's own communication protocol. The network must be initiated in accordance with the assumed configuration. The initiation module sends a short, (32-bite) “broadcast frame” with a slight delay, and with the RTC status of the initiation module. After the broadcast frame is received, the modules are capable of synchronizing their clocks. During normal operation of the network, the secondary modules send measurement data to the primary module, and receive a confirmation (also a 32-bite broadcast frame) which also contains the RTC status of the primary module. Hence, synchronization may be adjusted. The transmission time of the initiation and confirmation frames for the basic network transmission speed of 1Mbit/s amounts to 256μs, which is sufficient for precise synchronization of the clocks.

Synchronous ECG and pulse recording with the photoplethysmographic method made after module clocks are set, and with high sampling frequency (~1000/s) allows for a precise PTT measurement, and for determining PWV.

V. BioSip Modules as IoT Elements

BioSip modules have been developed for use in local systems which monitor biomedical parameters. In systems of this kind, all acquired data is transferred to the operator's workstation which enables the operator to monitor on an ongoing basis the condition of the monitored person, and which collects the data that is necessary for future use. Broad access to this data was not taken into account. Such access was only possible via the operator's workstation if permitted by the software, and outside the structure of the system and BioSip modules. A question arises if BioSip modules could be used as universally accessible autonomous data sources. In other words, a question arises if they can become part of the Internet of Smart Objects, i.a. Internet of Things. If so, which conditions need to be satisfied? If such a solution were feasible, each module could be used to provide data for Internet platforms, and to monitor the patients on a global scale. Although this option may raise concerns and legal doubts, it also offers numerous benefits, such as lower costs of healthcare and higher security of the monitored persons.

As was mentioned before, BioSip modules communicate with their environment via a radio transmission based on nRF51822 SoC (System on Chip) modules by Nordic [8]. The module makes it possible to use in communication i.a. the Bluetooth LE protocol, in its latest version known as Bluetooth Smart. Nordic offers a software development kit (SDK) which connects to the Internet of Things the devices based on the nRF51 hardware platform deployed in BioSip modules, and on its latest version nRF52. The general idea behind the connection is demonstrated in Fig. 7. The idea builds on the connection of the modules equipped with nRF51 modules with the network (“Cloud”) via a dedicated IoT Router. Communication with the router is enabled by means of the Internet Protocol Suite located on the Bluetooth Smart protocol being the network interface layer protocol which provides a basis for the physical performance of the transmission. The router is connected to the network in a standard manner, e.g. via wire (Ethernet) or wirelessly (Wi-Fi or GSM).

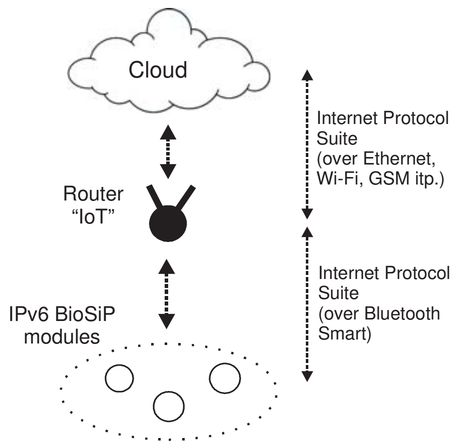

Fig. 7. BioSip modules as IoT elements via Bluetooth Smart.

The Internet Protocol Suite offered by Nordic is based on standard Internet protocol layers. This is the "application layer", with protocols directly interoperable with user software of the devices. "Transport layer" with protocols responsible for the transmission of the datagrams. "Network layer" – the actual Internet protocol; for IoT, this is the IPv6 protocol owing to its extensive address space and "network interface layers" with protocols contacting directly the physical transport medium being the radio broadcast, band 2.4GHz, for nRF51 modules.

Fig. 8 demonstrates the software structure of BioSip modules, which makes it possible to include them in the Internet of Things. The most external software for this structure is the user application of the module responsible for its operation, measurements, processing and preparing the data for transmission.

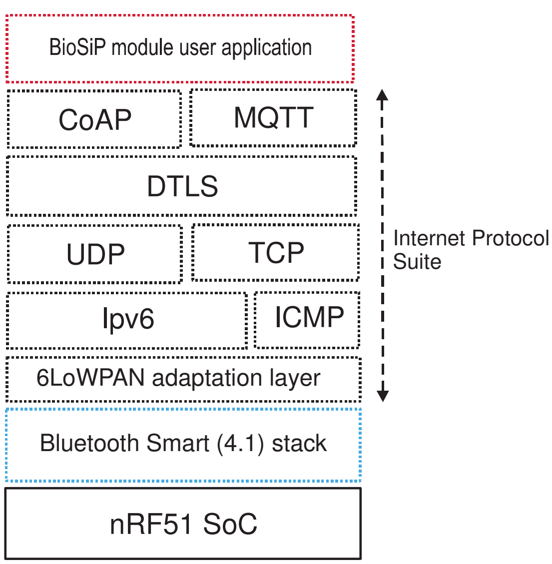

Fig. 8. Software architecture of BioSip modules being elements of IoT.

The user application uses application layer protocols of the Internet Protocol Suite for communication with the Internet. The use of standard protocols used in this layer, such as HTTP or FTP, for small devices based on the nRF51 module, and for limited data sets that we are dealing with is inefficient and difficult to implement owing to limited hardware resources. Hence, "light" protocols are proposed, adapted to the Internet of Things.

MQTT (Message Queueing Telemetry Transport) is one of them; this is a simple and light protocol based on the template "publication – subscription" [9]. This is a protocol which works for the connections: machine – machine, and in the Internet of Things. Another suggested alternative protocol for this layer is CoAP (Constrained Application Protocol), an active communication protocol developed for simple and small devices [10]. As an addition to the application layer protocols, Nordic delivers DTLS (Datagram Transport Layer Security), a protocol which ensures communication security by preventing forgery and interception of the transmitted information.

A UDP (User Datagram Protocol) is a transport layer protocol – a protocol without transmission control mechanisms, used mainly by the CoAP protocol or TCP (Transmission Control Protocol), a commonly used Internet transport layer protocol with the transmission control mechanisms.

As was mentioned before, the network layer protocol is IPv6 (Internet Protocol version 6) – a protocol with increased available address space (a 128-bit address) compared with the traditional IPv4. Owing to the network layer protocol, several small devices such as the BioSip modules, are directly addressed in the global network. This layer also provides for the operation of ICMP (Internet Control Message Protocol).

Communication would not be possible via the Smart Bluetooth protocol without the protocol stack for nRF51 modules in 6LoWPAN (IPv6 over Low power Wireless) – compression which allows for IPv6 sets to be sent via simple wireless networks. 6LoWPAN has been developed for networks based on the IEEE 802.14.4 standard to be interoperable with IoT (the IEEE 802.14.4 standard is a basis for the operation of wireless networks with the ZigBee protocol), but has been adapted by Nordic to work with Bluetooth Smart networks. The physical data transfer in the SoC nRF51 module is performed by the software stack for wireless radio communication Bluetooth Smart (Bluetooth Low Power 4.1).

The BioSip module is equipped with this software, and the deployed MQTT protocol would be capable of transmitting ("publishing") the measured parameters to MQTT "broker" (the MQTT client server, e.g. the popular Mosquitto, RabbitaMQ or HiveMQ). The data might be subscribed in the "broker" by IT devices or systems using the data to oversee the monitored person, to provide early warning or to carry out a treatment.

The use of BioSip modules in the Internet of Things requires an IoT router which enables communication by transferring data from the local Bluetooth Smart network to the global network. This is an issue because at present servers of this kind are not commercially available. Nordic has presented a concept how to make such a server based on the single-board computer module Raspberry Pi. Fig. 9 demonstrates the software architecture of such a server.

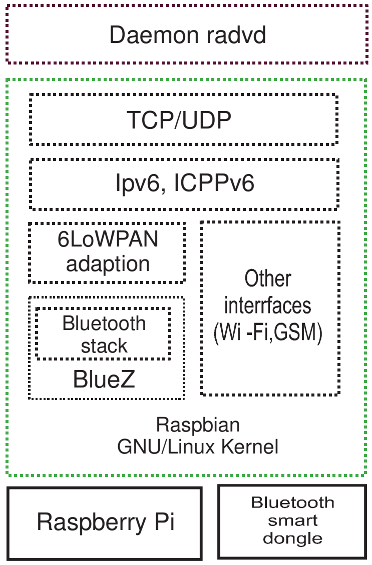

Fig. 9. IoT router based on a Raspberry Pi module.

The router uses open-source radvd (Router Advertisement Daemon) software based on Linux to process the transmission of IPv6 packages. Data from the Bluetooth Smart network is sent to the global network via standard Wi-Fi interfaces, Ethernet or via GSM.

BioSip modules may be used as elements of the Internet of Things provided that software is adapted by implementing universally accessible network protocols or those delivered by Nordic. They will be available in the network on condition that they are in an environment containing an IoT router. Such a router can be constructed with the use of guidelines and software from Nordic. The hardware for the IoT router, and first of all its relatively high power consumption (~3W) requires connection to the mains, which contradicts the idea of the modules being wireless. In order to fully utilize the wireless modules, such as BioSip in the Internet of Things, a dedicated wireless IoT router must be made, e.g. by adapting the integrator (the BioSip-3 module). It may as well be possible to implement the IoT router in the software of the mobile devices which are usually equipped with sufficient hardware for this purpose (Bluetooth Smart, Wi-Fi interfaces, GSM - LTE, HSPA+ communication).

VI. Summary

The BioSip system, building on a personal area network and the BioSip/ITAM protocol, may be used in medical and in other applications alike; all those which require individual monitoring of physiological parameters and the patient's behaviour. The BioSip system modules, whose communication system is based on the SoC Nordic nRF51422 solution, have numerous benefits and configuration options. They can operate in a personal area network, designed in order to create the BioSip system, and in the dedicated information exchange protocol or, using standards like Bluetooth LE, Ant/Ant+, they can be integrated with other networks and monitoring systems. BioSip modules permit synchronous measurements of biomedical parameters, hence they may be deployed in new areas of research. The modules may be used as elements of Internet of Things by installing Internet protocols based on IPv6, and by using Bluetooth Smart as the communication interface.

If we focus on one transmission type, we limit ourselves to a certain part of the market. On the other hand, implementing all transmission types that are available on the market to make a versatile device is not the optimal solution in terms of economy. The use of the nRF51422 system has allowed for a compromise because a standardized transmission medium has been created, which is easy to use in everyday work and also easy to be tailored to the demands of the potential consumer. The presented solution proposes a developed measurement platform which can be adapted to market requirements at low cost and with little time investment, solely by changing the software. Hence, a versatile solution has been obtained that can satisfy the needs of a large part of the market.

Acknowledgments

The paper provides a description of system concepts and their modules operating within personal area networks developed at the Institute of Medical Technology and Equipment in Zabrze, under a project partially financed by the National Centre for Research and Development (NCBiR) under program PBS1/B3/13/2012 and STRATEGMED 1/233221/3/NCBR/3/2014. The solution is patented (No. P.414460).

Thanks are due to all members of the project consortium: Warsaw University of Technology, Military Institute of Aviation Medicine, Institute of Electron Technology, the Silesian Center for Heart Diseases in Zabrze, Kardio-Med Silesia and the Polish-Japanese Academy of Information Technology.

References

[1] https://www.nordicsemi.com

[2] „Security of bluetooth systems and devices updated guide issued by the internal institute of standards and technologu (NIST)", Radack S. Itl bulletin for august 2012,

[3] Texas Instruments Wiki "Low Power RF Solutionsp - ZigBee Security".

[4] DigiKey: „Bluetooth and Wi-Fi Coexistence Originally Published: November 2011 Updated: October 2012"

[5] „Assessment of Arterial Distensibility by Automatic Pulse Wave Velocity Measurement" Roland Asmar, Athanase Benetos, Jirar Topouchian, Pierre Laurent, Bruno Pannier, Anne-Marie Brisac, Ralph Target, Bernard I. Levy; Hypertension vol 26, No 3 September 1995

[6] „Continuous Blood Pressure Monitoring using Pulse Wave Transit Time" Gu-Young Jeong, Kee-Ho Yu and Nam-Gyun Kim; ICCAS2005 International conference on Control, Automation and systems, June 2-5 2005 in KINTEX, Gyeong Gi, Korea

[7] PROD BRIEF nRF51822.pdf, Nordic Semiconductors

[8] PROD BRIEF nRF51 IoT SDK v1.0.pdf, Nordic Semiconductors

[9] mqtt-v3.1.1-os.pdf, http://docs.oasis-open.org/mqtt/mqtt/v3.1.1/csprd02/mqtt-v3.1.1-csprd02.pdf

[10] CoAP.pdf, https://tools.ietf.org/html/rfc7252

Barbara Szuster was born in Mikołów, Poland, in 1989. She received the B.Sc degrees from the Silesian University of Technology in Biomedical Engineering in 2012 and M.Sc in Electronic and Telecommunication (specialization biomedical electronics) in 2013.
Currently employed at the Institute of Medical Technology and Equipment ITAM as a constructor electronics and assistant. She is a member of telemedical systems department. She has been working on electronic design and programming embedded systems and test benches.
Her main field of study are medical electronic, processing and analysis of bioelectric signals used for the create the systems based on a personal body area network.

Zbigniew Szczurek received the M.Sc. degrees from Silesian University of Technology of Gliwice Poland in 1976. Since 1976 till now he is employed in Institute of Medical Technology and Equipment ITAM in Zabrze. He is designer of modern equipment for diagnostics, therapy and medical rehabilitation. He is interested in designing systems for remote monitoring of vital parameters and telemedical care.

Paweł Kowalski received the M.Sc degrees from the Silesian University of Technology in Automatics and Robotics in 2003. He is currently pursuing the Ph.D. degree in mechanics at the Silesian University of Technology. From to 2004-2012 he was a constructor electronics and assistant in the department of telemedical systems in the Institute of Medical Technology and Equipment ITAM in Zabrze. Currently employed as a manager in department of telemedical systems. He has been working on electronic design and programming embedded systems and test benches and oversee a lot of projects realized in Institute. His main field of study are medical electronic, processing and analysis of bioelectric signals used for the create the systems based on a personal body area network, system to monitor the treatment of burn wounds and systems for the cardiac rehabilitation and special applications.

Batłomiej Kubik received the M.Sc degrees from the Silesian University of Technology in automatics and electrical metrology in 2011. From to 2010-2016 he was a constructor and programmer electronics in the department of telemedical systems in the Institute of Medical Technology and Equipment ITAM in Zabrze. He has been working on electronic design and programming embedded systems and test benches and oversee a lot of projects e.g. *BIO-SIP, MICROS, Revitus-T, Monitel-HF, Rengo, IR-Diagnostics*. His main field of study are medical electronic, systems based on a personal body area network, system to monitor the treatment of burn wounds and systems for the special applications.

Andrzej Michnik was born in Bytom, Poland, in 1976. He received the M.Sc degrees from the Silesian University of Technology in Electronic and Telecommunication (specialization: electronic equipment) in 2001.
Currently employed at the Institute of Medical Technology and Equipment ITAM as a constructor electronic and assistant. He is a member of telemedical systems department. He has been working on electronic design and programming embedded systems.
His main field of study are medical electronic, mechatronics in rehabilitation and wireless communications.