Network Supplemented by Wireless Sensors. 2. Realisation.

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Abstract. In recent years, digital facilities have been accepted a new potential solution to support wireless sensors networks. Sometimes, latency, minimum power dissipation are not limitations of hardware. Most algorithms become the innovative reasons that are being deployed in structures of Zigbee communication. Exciting things happen when removed standard MAC commands, implemented hops methods in 802.15.4 stack. Based on this research, new multi-sensors in wireless sensors network is significant ability for business.

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Introduction

Review of possibilities and realization of wireless sensors network is presented in previous publication [1].

The objective of this work is to design and construct multifunctional sensor, which would organize wireless sensor network all by itself. One of the essential requirements is the automatic self-reconfiguration of the network when the infrastructure, parameters or position of the network are changing. From the viewpoint of innovation, the sensor performs collection, procession and transmission of all physical parameters, subject to ensuring energy minimization and independence in the network. When using semiconductor electronic components and high-level algorithms, the achieved result must reflect electronic device, which has no analogues in the market - sensor, which will solve the deficiencies of IEEE 802.15.4 standard wireless networks, ensure overall security of data transmission and idealize the conceptual self-expression via inclusive capabilities of smart phone.

The purpose of application could be formulated as follow: a) new concept of smart house's security systems and b) flexible degree of integration in other systems.

1. Design of smart sensor

After the analysis of market segment, global practice and several theses, the multifunctional smart sensor designing was selected. It is multifunctional since the sensor is designed to identify or measure more than one process or parameter. Another important feature is to determine which parameters are the most important to human needs. Having considered the increasing demand of smart houses, energy consumption minimization priority by using physical parameters and commercial premisses maintenance trends, motion, electric field, carbon monoxide, temperature, humidity and lighting sensors were joined into a single sensor network. All sensor network parameters that are identified are important to smart house systems.

Traditionally for the motion detection the PIR sensor is selected, which is designed into single sensor network together with an identical pair, so that the design result would comply with three dimension coverage zone. That means that no matter in which location of the space the sensor will be used, it will be able to detect the motion not only in front, bellow and above it but also on its left and on its right side. Such solution gives the mobility to the electronic device. The other condition of mobility is formed using vacuum technology due to which a smart sensor can be used but the surface should be sufficiently even. In order for the sensor to conform to the definition of "smart", the microcontroller must be used. It performs the following important functions to manage processe the information, control the processes and communicate with network elements.

CORTEX M0 architecture microcontroller LPC1115XL [2] made by "NXP" company is chosen because the energy demand can be minimized to 840 μA not during the 'stand-by' mode. As it was discussed in Ref. [1], the semiconductor device MRF24J40 was selected which is proper for the execution of Zigbee protocol. The Zigbee element is installed on the housing of the installation board MRF24J40MB, in order to increase the network radius up to 10 times, since the

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formed chain strengthens the relayed signal by 20 dBm with 56 dB range energy control, and the sensitivity during the reception of the signal is increased to 102 dBm with the maximum input level of 23dB. It is necessary to note that such electronic component requires sufficiently high values of current while beeing in the active state; however, in the stand-by mode in which it will spend the most of its time the needs drop to 5 μA. Power supply circuit plays a very important role, it has to ensure proper operation of sensors, microcontroller and Zigbee chip. And finally, to utilize solar cell with battery in order not only to ensure the uninterruptible energy supply, but also to minimize the consumer's problem - the energy needs. Solar batteries also work as an illuminance meter, since when the illuminance changes the generated voltage changes as well. Depending on the solar cells, the value of the outlet voltage due to the illuminance scale.

1.1. LPC1115XL microcontroller

CORTEX-M0 microcontrollers made by "NPX" company [2] are the smallest, with the least energy consumption and most energy efficient ARM architecture microcontroller in the market. These semiconductor devices are especially valuable in auxiliary and monitoring processes where energy needs play an important role. The energy needs of such semiconductor device are lower than 85 μW/MHz (0.085 mW). At the beginning of the design, the electric power circuit of LPC1115XL microcontroller is joined together. At each outlet where power supply is connected, 0.1 μF capacitors, that work as the electric charge containers are used, due to it, their placement is designed as close to the outlets of the microcontrolle as possible, in order to instantly compensate the sudden need of the current. As in all other devices the USB port is provided to uploade the program code or to supply the power to the sensor if there is a considerable demand. Program code of interface goes through the UART bus. The "reset" button designed by the outlet of the microcontroller is to reset the programme of the microcontroller and, the one by the outlet of the PI0.1 is not only to upload the programme but also to select the uploading method: via the USB bus, when the button is not pressed and the high level falls on the outlet, or via the UART interface, in this case via our designed micro USB port when the button is pressed and the low level falls on the outlet, since the circuit is grounded by the push of the button.

The next important task is to incorporate the sensor network next to the microcontroller. For that purpose, the ADC changer circuits are used. First of all, smart house systems must have a security function, which is perfectly fulfilled by "MURATA" analogue PIR sensors. The design of such sensors is not complex, only the voltage value at the outlet must be monitored after connecting the power supply. This function is performed by the microcontroller outlets PIO1.1 and PIO0.11 that check the voltage value generated by the emitted radiation volume of moving body. In order to ensure the scope of three dimension detection, two such sensors are used. In another case, the Fresnel lens is not able to collect the radiation from the visibility zone. Smoke and gas sensor is another important element of sensor network. Such sensor is vital for fast identification of fire and gas leak in real time. The designing of the selected sensor is identical to the PIR sensor, only the value of the voltage is set on PIO1.2 outlet. Such sensor could detect the CO particles concentration from 20 to 2000 ppm. The temperature sensor is no less important. The temperature setting is vital for many processes. The TMP112 silicon based sensor was used. The tolerance of such sensor is only 0.5 ^{o}C, and this is a high result in smart house systems. This sensor is more modern since it may be controlled and transfers temperature values via I^2C data transfer interface. The design is not complex; you only have to properly connect the I^2C busses to the microcontroller outlets (PIO0.4 AND PIO0.5). Necessary requirement is not to forget to use the pull up resistors.

HIH-5030 the most expensive humidity sensor, which is gaining popularity fast, is a capacitive polymeric humidity sensor. Such sensors are characterized by a low temperature coefficient, full recovery after condensation and the resistance to chemical pollution and quick response time. The usual tolerance of such sensors is about $\pm 2\%$, when the relative humidity is between 5% and 95%. Capacitive sensor can not be designed far away from the microcontroller, since the tracks or wires cause additional capacity which affects the results. The design of the sensor itself is not complicated as the relative value of humidity depends on voltage, the value of which is obtained after measuring the voltage value at the outlet of PIO1.1 microcontroller. The infra-red ray communication is also provided as additional function, i. e. the outlet of PIO2.0 microcontroller can generate the needed signal form which is implemented through the simplest npn BC817 transistor. High level at the base opens the transistor, the infra-red light diode circuit is shortened and the light signal is generated. The transistor opening speed reaches 1 MHz; therefore, the communication of such type is easily implemented, since the only sufficient condition is the commutation speed of approximately 10 kHz.

1.2. MRF24J40MB module

According to the instructions, MRF24J40MB Zigbee module is placed near the microcontroller and is connected via SPI bus for the exchange of data and commands. Due to the expanded functionality three additional outlets - "reset" by the PIO3.4, "int" by the PIO2.5, "wake" by the PIO2.4 are formed by the microcontroller. Designing the SPI bus, you should not forget that the microcontroller data reception and transmission outlets must be switched with the outlets of the chip that is being connected, so there was a logic interaction - see Fig. 1. MRF24J40MB module connected to the microcont-

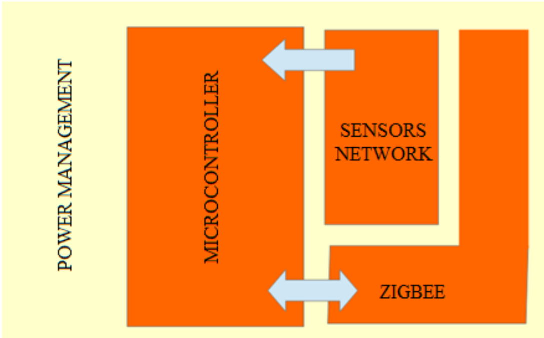

Fig. 1. Simplified topology of smart sensor.

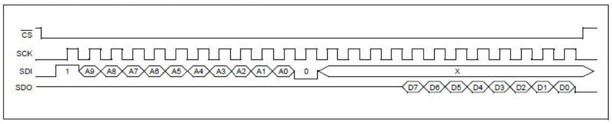

Fig. 2. Time diagram of long reading register

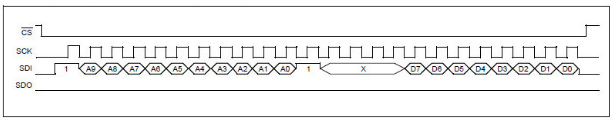

Fig. 3. Time diagram of long writing register.

roller according to the time charts is controlled by the functions.

The module control design was fulfilled; the functions were formed according to the module control features. There are two types of functions:

```
reading (unsigned int  spi_read_long_addr (unsigned int addr))
writing (        void spi_write_long_addr (unsigned int addr,
                                           unsigned int val))
```

and there are two models of functions - to manage short and long registries.

```
unsigned int spi_read_long_addr(unsigned int addr)
{
    unsigned int res;
PinClear(PIN_CS);
SSP_ReadWrite(0,((addr >> 3) & 0x7F) | 0x80 );
SSP_ReadWrite(0,((addr << 5) & 0xE0));
res = SSP_ReadWrite(0,0);
PinSet(PIN_CS);
return res;
}
```

Time charts for long registries are provided in Figs. 2 and 3. The time charts for short registries are analogically similar. Firstly, with the help of the microcontroller the reading function sets low level on PI0.2 outlet and the communication is commenced. The reading values are formed according to the time chart and the obtained result is displayed via 16 bit variable. In the end, the high level is formed on SPI data bus CS outlet again and the operation is considered finished. The same is with the recording function, only the address is provided instead. SSP_ReadWrite method is used in the functions, it is described in steps:

```
SSP0_DR = val & 0xf$\kern0pt$fU;
        while(SSP0_SR & (1U << 4));
        if   (SSP0_SR & (1U << 2)) return SSP0_DR;


void spi_write_long_addr(unsigned int addr, unsigned int val)
{
PinClear(PIN_CS);
SSP_ReadWrite(0,((addr >> 3) \& 0x7F) | 0x80 );
SSP_ReadWrite(0,((addr << 5) \& 0xE0) | 0x10);
SSP_ReadWrite(0,val);
PinSet(PIN_CS);
}
```

2. Energy minimizing circuit

Minimization of energy is one of the most important factors of wireless sensor networks. In order to ensure the functioning personal local network, sustainable energy supply must be available, i.e. a network access or a battery. However, as technologies are improving, the new options and new opportunities emerge. One of such solutions can be solar cells that provide the power to the electronic device and in simultaneously charge the battery.

The proper architecture of the device energy supply allows not only to achieve incredible results minimizing energy costs, but also using the semiconductor components allows to design autonomous energy distribution network. The solutions that are based on the solar energy development allow not only to reduce the dimensions of the network devices but also to give up the specific mounting or usage instructions. It is necessary to mention that the device which has the status of the coordinator is not fully capable of getting the solar energy on its own as the efficiency of the solar cells is rather small and favourable conditions are not created on the premises as well.

The designed architecture of electronic power supply circuit is focussed on the energy accumulation in the Li-ion battery. It is important that the level of the battery would not fall lower than 3.3 V since the lower voltage level is disrupting proper functioning of the stabilizer LM3670; the stabilized voltage can not be lower at the inlet than at the outlet. LM3670 stabilizer is not only very compact but also uses micron current for its operation. In order to understand the on-going processes more easily, we will explain the circuit operation according to the nodes marked in Fig. 4, and we will also discuss how energy costs are minimized designing the supply circuit.

The node marked as number one is the battery connection place. The battery is charged from the nearby LTC1734 chip. It is a special semi-conductive battery charger which, depending on the amount of the voltage at the battery outlets, either performs the charging process or not. The battery level is automatically checked by the microcontroller when the solar elements are inactive, using the outlet of the PIO1.3 microcontroller with the ADC converter.

The measuring circuit is comprised of 1 kΩ resistor divider, so that the voltage at certain times is not too high. Battery is charged only if the solar energy is being absorbed or the micro USB cable is connected to the power source, e. g. computer - node 2. Field transistor BSS884 performs the opening and closing functions in the circuit. The outlet marked as node 3 is needed for the charging the battery only from the external source of power supply when USB power supply is connected. The outlets marked as number 4 and 5 are connected to the resistor dividers, so that it would be possible

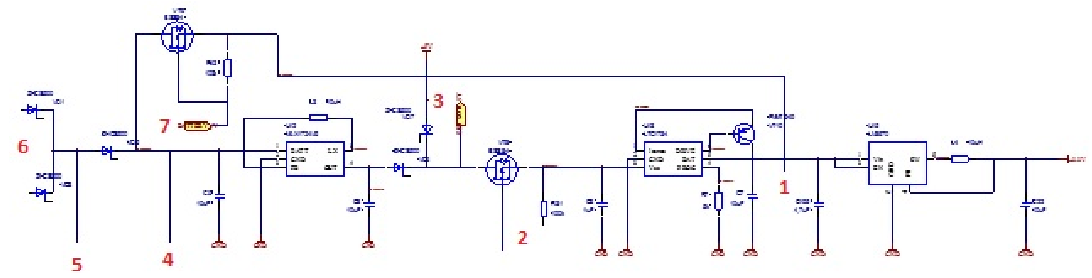

Fig. 4. Basic energy supply electronic circuit.

to measure the voltage of solar cells or of the system before the voltage regulator using the microcontroller outlets PIO1.3 and PIO1.11.

Resistor controllers are needed since the voltage which falls on the microcontroller is considered safe when the value does not exceed 3.3 V. At the outlets of the point 6 two solar cells are connected, as it was mentioned above, their task is to charge the battery during favourable conditions.

It is not enough to technically minimize the energy costs; therefore, the programmatically created algorithm will put in sleep mode, switch or stop all devices according to certain conditions or requirements. The objective is to completely minimize energy costs so that the battery without charging or charging it very rarely would last for a long time. For that particular objective, the electronic components, sensors and circuits that only consume the least energy and do not require many additional components were found and selected. The steps such as microcontroller speed reduction (internal tactic impulse generator 12 MHz) and gap vector system creation (CMSIS-RTOS RTX operating system) were used.

```
void os_idle_demon(void)
{
    for(;;)
    { __WFE(); }
}
```

The Zigbee chip coordination and the fulfillment of the programmatically used tasks are the steps that have more possibilities in the energy minimizing.

3. Formation of IEEE package

The following four different data package structure models are specified in IEEE 802.15.4 standard specification [4]:

i) command package;
ii) confirmation package;
iii) standard package;
iv) super-package;

Each model is used by applying different processes in the network. One of the most important models is the command model, since the network organization is performed using the commands of this model. Command package can transmit the network commands [3]:

a) access request;
b) access confirmation;
c) log-out message;
d) data request;
e) network ID mismatch;
f) "Foster" message;
g) super-package request;
f) reorganization of the Coordinator;
i) GTS request.

Each command has the specific data parameters that are formed according to the electronic device parameters, working condition, etc. During the formation of the network the so called "fosters" appear, they are not included into the network. The common case is that during the formation of the cluster topology network, the network overloads and the coordinator can not control the electronic device in the cluster branches. Due to that there is no possibility to integrate the device into the network. The other problem is the interference and repetitions from parallel channels which could mislead the coordinator or affect it in another way and the network will not be supplemented by one more piece.

The confirmation package is required in order to be able to easier process the data structure since the only function of this package is of the informational nature. The technical part of the MRF24J40 chip is fulfilled so that such packages are relayed and processed automatically - the programmer has to observe only one bit in the TXNCON registry. The standard package is the simplest and the most easily implemented element in Zigbee network. There is no need to incorporate the especially specific parameters. Most often the structure of this package is used in Zigbee networks. There is no need for any synchronization or other specific conditions.

The model of super-package is the most complex. It ensures the biggest advantage, i.e. energy minimization. This package is special in the way that it can be sent as a collective message or personal data warehouse. The main accent is the execution of super-package structure. The data is transferred via this model for a certain time and later the module is turned off although, the communication does not cease. According to the parameters of the super-package, if the confirmation is not received, the identical data will be sent again after some time. The specific parameters, certain synchronization elements are needed. All model package formation structures in MRF24J40MB module are shown in Fig. 5.

The confirmation package is not displayed since it is technically executed by the semiconductor device itself. As it may be seen from Fig. 5, using the semiconductor chip MRF24J40 which complies with the Zigbee specification,

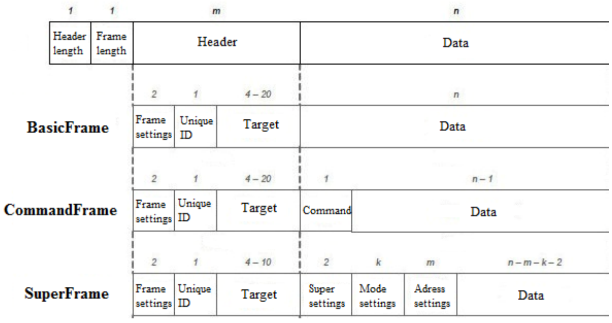

Fig. 5. Packages structure in MRF24J40 module.

regarding technical solutions, the models are simplified, since it is enough only to form the header and data array. All other additional symbols that are needed to fulfill the standard IEEE 802.15.4 are initiated or generated automatically. In this case, the length of the header and of the package which was to be transferred had to be calculated and the values had to be identically recorded into the transfer buffer.

The most important step is to properly initiate the header with all parameters and addresses. Depending on the model of the package not only the header structure but also the data changes as well. While forming the programme algorithm in the higher levels of Zigbee specification the additional data separation requirements arise.

One of the most important steps is to properly design and insert into the construction of the program the transfer and reception package formation algorithms. Before the algorithms are executed, the dynamic structure of variables needs to be formed. Each parameter is substituted by the external functions according to the introduced parameter. Essentially, this is the bit moving operations.

```
typedef struct
{
unsigned char *ADDRESS;
unsigned int   ADDR_TYPE[3];
unsigned char *DATA;
unsigned char  SEQUENCE;
unsigned int   FRAME_CONTROL;
unsigned char *GTS;
unsigned char *PENDING_ADDR;
unsigned int   PAN_ID;
unsigned int   SUPERFRAME;
}                       TRANSMIT_STRUCTURE;
```

The variables specified in the structure are needed for package formation. The main function is performed by ADDR_TYPE array. The first element of the array describes the type of the package, the second, address type and the third, the priority level of the data that are wished to be transferred. All parameters are updated before the algorithm of transfer. By using the SET_PACKAGE_MRF24J40(TRANSMIT_STRUCTURE* CONSTRUCTER) algorithm, the package is formed in the transfer buffer and the transfer sub-bit is enabled.

4. Design of wireless sensor network

The design of wireless sensor network is a complex process that begins with a design, construction and programming of proper electronic devices and going all the way to the network formation, synchronization, consistency assurance, security services and method execution and electronic device compatibility.

The first step is to select the technology of the radio communication, which would be a rational solution for the implementation of personal local network. The work result must comply with extremely flexible and easily configurable personal local network of smart houses which would connect the operation of security system, management of the electronic devices, electricity and climate control and other processes inherent to smart house systems. Firstly, for that purpose the chip MRF24J40 is selected and discussed in the third section, it corresponds with the network receiver.

Step two is management and control. It is not enough to choose the proper microcontroller. The main task occurs at the higher levels of Zigbee standard where the programme structure is needed.

Step three is energy minimization during design and programming stages.

The fourth step is the most essential one, i.e. the organization of network architecture; the network self-organizing abilities and adaptation of the autonomous innovative algorithm in the personal local Zigbee network. The purpose of this step is automatic formation of network topology without the use of command packages.

First three steps were reviewed and discussed in the previous sections. This section will focus on how the network will be formed, what will be its operating principle, network topology and why it is innovative and smart.

4.1. Network topology

The topology of Zigbee network may be a star or a node type. However, the discussed disadvantages are not acceptable, neither to the network specificity nor to the idea. Therefore, the selected network cluster topology is the mixture of a star and a node. The topology of the cluster is presented more graphically in Fig. 6.

The topology of this type is characterized by low energy costs and hopping communication is also possible. However, the delay time and big routing costs occur and it does not make the network very attractive. Moreover, it is necessary to identify the network parameters that are static and require static topology of the cluster. The solution of these problems is to modify the network organization and to apply innovative solutions in the management and data transfer algorithms.

As it may be seen in Fig. 6, one coordinator is used in the cluster topology network and the required number of the routers and elementary devices is also displayed.

The formation of Zigbee network starts with the initiation of the coordinator. If all technical capacities are satisfied by the device, it scans all 16 channels 100 times and finds an energetically suitable for itself. While forming the allocation

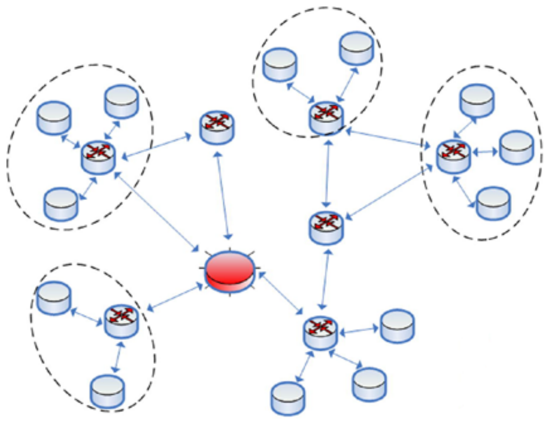

Fig. 6. Topology of cluster.

inquiries, the coordinator creates the local network by connecting the devices into one of three topologies which can be executed in Zigbee network, in other words first, the process of ring topology scanning is performed, and in case of the higher requirements the node topology is employed. Having completed necessary operations, the network is simulated according to the trend characteristic to the cluster topology. Each device receives 64 bit address which is used in the network as the identifier. Each assigned address in the network is allocated according to so-called allocation schemes.

While forming Zigbee network in normal conditions, the coordinator sets the maximum number of the devices (C_m) that belong to the Zigbee network level, maximum number of the devices allocated to the router (R_m), and the size of the network (L_m, number of cluster branches). The condition $C_m \geq R_m$ is always valid, and the Zigbee can connect to as many ordinary Zigbee devices, as belong to him (C_m-R_m). The implementation of such algorithm allows reaching every device through Zigbee router.

The coordinator address locations are proportionally divided into the (R_m+1) block. The first R_m blocks are dedicated to the coordinator's router devices, and the last ones are dedicated to the lowest hierarchy devices of the coordinator. Using several parameters of the device [4] such as C_m, R_m and L_m, the resulting parameter C_{skip} is being calculated. Such parameter is used to calculate the origin addresses for the coordinator devices.

After the network depth d is selected, the C_{skip} can be calculated [4]:

```
if (Rm == 1) Cskip =  1+Cm              * (Lm-d-1);
if (Rm <> 1) Cskip = (1+Cm -Rm-Cm * Rm ^ (Lm-d-1))/(1-Rm);
```

It is necessary to mention that the coordinator always serves as the initiation point in the network and the depth of the network in case of the coordinator is 0. That means that the parameter d is equal to zero.

Further developing the network with the Zigbee routers the size of the network expands linearly - (d+1). Therefore, each node x in the network can have node y. According to the parameter C_{skip} in the network we can connect as many nodes y to the node x as is the value of this node (the analyzed node is included into the maximum number of the nodes). Therefore, the trend of the C_{skip} parameter increase can be set out in the law:

$$C_{skip} = 1 + C_m + C_m * R_m + C_m * R_m^2 + A \quad (1)$$

$$A = C_m * R_m^{(L_m - d - 2)} \quad (2)$$

Using the C_{skip} value and other network parameters, we can calculate the address of the Zigbee router, and the addresses of the devices that belong to their star sub-network [4], where H represents the level of the Zigbee network hierarchy, n - the number of the device located in the sub-network. Fig. 7 shows that many reflections whether it is effective arise from the cluster topology and address formation logic.

$$Addr_r = H + (n-1) * C_{skip}(d) + 1 \quad (3)$$

$$Addr_s = H + R_m * C_{skip}(d) + n \quad (4)$$

Due to mentioned technique, the problems occur during the formation of the network infrastructure. The first step that should be taken is to keep all devices that are not a part of the network, in the neutral condition without the reduction of the network functionality, so that they were equivalent in respect of each other. Such method is achieved by linking the level of hierarchy with the constant dev_type, the value of which shows the level of the Zigbee network element hierarchy. The 4th degree is compared with the coordinator, and 0 with the neutral condition - the devices do not belong to the network. It is the neutral condition that is executing periodically generated allocation algorithm. Therefore, the program of the designed sensor is launched and the status is promptly checked.

Fig. 8 represents the whole process which repeats until the constant dev_type does not change and the next level of the network hierarchy is initialized.

According to the level of the hierarchy the algorithm is assigned, it ensures the functionality needed for that level.

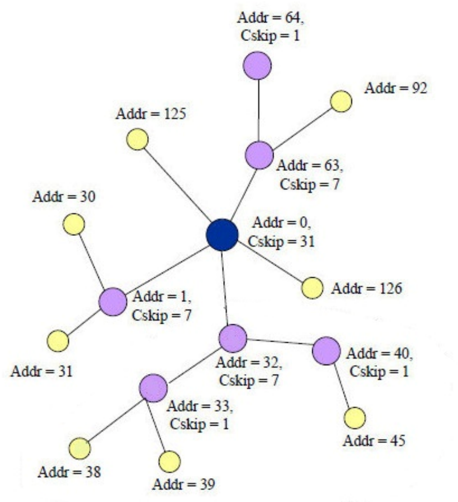

Fig. 7. The structure of Zigbee network device addresses, where the parameters of the network are: C_m =6, R_m = 4, L_m = 3.

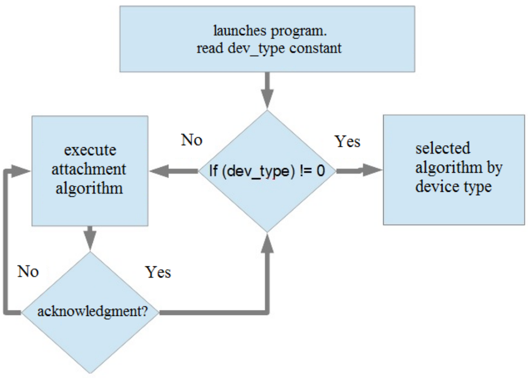

Fig. 8. Hierarchy checking and allocation algorithm.

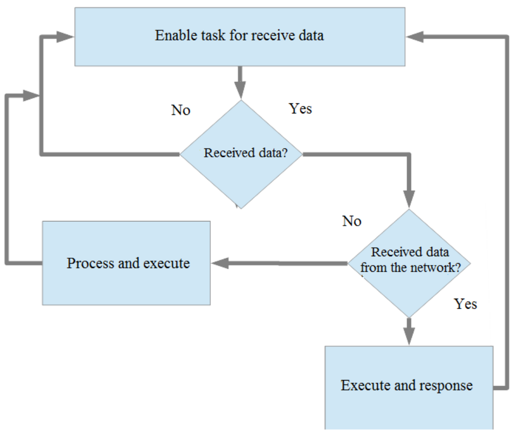

Fig. 9. The minimized structure of coordinator algorithm.

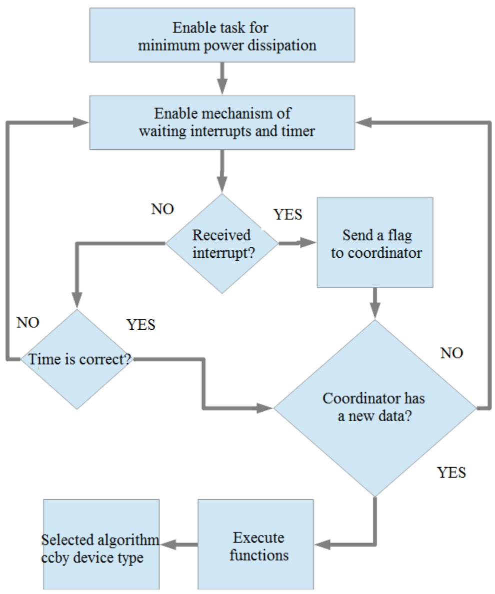

Fig. 10. The minimized structure of the lowest hierarchy device algorithm.

The simplified hierarchy operation algorithms can be seen in the structural charts. The electronic devices based exactly on such operation principle fully match the Zigbee network specifications.

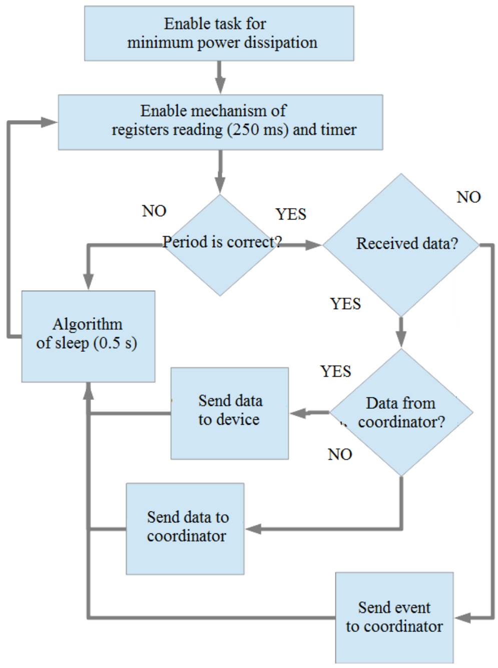

Fig. 11. The minimized structure of the router algorithm.

Essentially the task of the coordinator is to wait for the data from the external system (CMSIS-RTOS RTX operating system property - event detection, described by the condition

```
signals = osSignalSet (thread_network, 0xf$\kern0pt$f)
```

which initiates the data processing mechanisms, is used) via the UART interface or to check the INTSTAT registry first bit, the result of which contains the network data processing. The role of the router is similar, although it "follows" not only the INSTANT registry, but the sensor network physical properties as well. Figs. 9,10,11 show the operation principle of the router algorithm. The role of the ordinary device is to follow the changes of the sensor network parameters and check if the coordinator has any data.

4.2. Network automatization

The network self-organization process is a very complex task, since there is a need for a flexible, fast system algorithm which theoretically can model a network from 65536 elements. The algorithm is getting more complex since the network of cluster topology is being built. Therefore, after the coordinator performs all the necessary operations it has to know the 64 bit address of the device, the insertion into the network which is wanted. According to the minimized structure of the coordinator algorithm, this data have to be received via the UART data bus. In the systems of the smart house such operation is performed using the smart phone. When the address is obtained, the usual data transfer package is being formed and transferred. If the response is not received this procedure is performed by the rest of the devices that are in the network and the obtained results are sent to the coordinator. The data are processed and the most expedient route is selected.

Due to unexpected network failures or unexpected device malfunctions the primary and secondary routes are created. If the received data are not acceptable to the coordinator, it gives the notice via the UART interface that the device is not accepted into the network. According to the received data, the device address is recoded in such manner: first two bytes are used for the fast network device filtering, i. e. the youngest bit of the first byte is 0, and the oldest one is 1. The 6 interim bits show the number of the network cluster topology depth device. The youngest bit of the second byte is 1 and the oldest one is 0.

The 6 interim bits identify the cluster topology router device number. For example, the function void code_-addr(unsigned int val), the variable of which is 16 bits. Two bytes are received by bit moving operations.

```
void code_addr(unsigned int val)
{
addr_key1 = val & 0x3F;   addr_key1 <<= 1;   addr_key1 |= 0x80;
addr_key2 = val >> 6;     addr_key2 <<= 1;   addr_key2 |= 0x01;
}
```

The rest 5 unique bytes of the device are just left and moved by 2 bits. With the two bytes principle, the address search algorithm makes the management of the network more than three times faster. The network allocation operation is performed by the sequential scanning, while employing all devices of the network. If the sufficiency condition is not met, the value of the RSSI is not less than 70 dBm, the alternatives are sought. When the electronic device is being ejected from the network, its condition and routing route is being considered. Again, the analogue RSSI value scanning is performed in such way reconfiguring the network where necessary. The architecture of the coordinator routing database is displayed in Fig. 12.

Such data base architecture unit describes one address. The network filtering identifier is marked by numbers 1 and 2, further the numbers mark the modified address. The byte marked with the letter "A" shows the spare route address number. The remaining letters are identified as device address. When a cluster topology network grows the number of such data units increases linearly depending on the hierarchy of the device. The standard unit of the union database architecture is programmatically described as:

```
typedef union  {
                struct  {
                        unsigned int indentificator;
                        unsigned char addr[7];
                        struct  {
                                unsigned char count;
                                unsigned char *block;
                                }     CLONE_ADDR;
                        }             DIRECT_ADDR;
                }                     MEMORY_ADDR;
```

5. Realization

Principle scheme of the sensor was designed by using P-CAD software package. The designing of the device printed circuit board was performed. The device architecture which technically allows reducing energy needs was formed, the sensor network was integrated.

Fig. 12. Coordinator database architecture unit.

Fig. 13 represents the implemented super-package structure of Zigbee protocol. It can be divided into two blocks, into active and inactive duration. The part of each active duration is marked with i, where i = 1, 2, ..., 16. Therefore, such package in the network can transfer data when the active duration is being transmitted and go into the conservation mode, while the period of the inactive duration is being calculated.

Signal bits are formed in order to initiate the structure of the super-package, synchronize with other network devices, inform about the existing personal network, and inform the devices about waiting data. The CSMA-CA algorithm was used. To ensure the security the algorithm AES-128 was implemented.

The duration of the super-package in IEEE 802.15.4 standard is described by two parameters: active duration (AD) and super-package duration (SD), where the condition:

$$0 \leq AD \leq SD \leq 14, \tag{5}$$

must be satisfied. The number of the symbols transferred by the super-package was calculated according to derived formulas:

$$AT_{sym} = 960 * 2^{AT} \tag{6}$$

$$ST_{sym} = 960 * 2^{ST} \tag{7}$$

Therefore, knowing the number of the symbols which is being transferred, we can evaluate the durations of the super-package. Speed 250 kbps used modulation O-QPSK, IEEE 802.15.4 standard, requirements - it is not difficult to calculate that the speed of the symbol is 62500 symbols per second [5]. Using the algorithm of the super-package formation logic, the data transfer interval can be from 15 ms to 215 s. According to the features of the network AD and SD values are selected. The values are evaluated according to the construction of the super-package, which is defined as:

$$ST = [(MainCnt * SleepClk) + B]ms \tag{8}$$

$$B = [RemCnt * 50ns], \tag{9}$$

SleepClk is the value obtained calibrating MRF24J40 internal clock while using the function void SLEEP_CLK_CALIBRATION. RemCnt as freely selectable constant is equal to 1 ms.

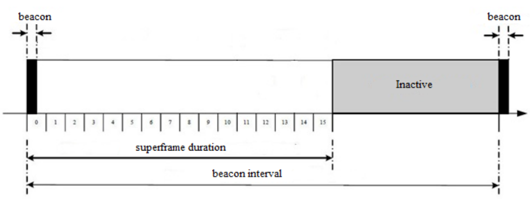

Fig. 13. Super-package structure of Zigbee protocol.

Table 1. The comparison of AD and SD values.

AT/ST value	Quantity of symbols	Duration, s
0	960	0,0154
1	1920	0,0307
2	3840	0,0614
3	7680	0,1229
4	15360	0,2458
5	30720	0,4915
6	61440	0,9830
7	122880	1,9661
8	245760	3,9322
9	491520	7,8643
10	983040	15,7286
11	1966080	31,4573
12	3932160	62,9146
13	7864320	125,8291
14	15728640	251,6582

MainCnt is calculated knowing the SD value from the compiled Table 1. Following the expression 12, the conservation mode can be configured and identified. The 7th bit in the INTSTAT registry indicates the end of the AT duration. Analogically, the registries SLPACK (the 7th bit) and INSTAT (the 6th bit) notifies when the MRF24J40MB chip goes to sleep and wakes up.

The active part of each device could be defined by time interval value m_1, inactive - by m_2:

$$m_1 = 2^{-(SD-AD)} \tag{10}$$

$$m_2 = 1 - 2^{-(SD-AD)} \tag{11}$$

Changing the (SD-AD) value we can adjust the stand-by mode of the devices and calculate the network longevity at the same time. Table 2 displays the calculated relationtion between the (SD-AD) values and the network device stand-by cycle. It may be seen that when the (SD-AD) value becomes significantly high the network device stand-by cycle rapidly declines.

If we are using the super-package without the signal symbols, (SD-AD) value is equal to 15, and it means that the structure of the signal is not formed and the active and inactive parts do not exist anymore. Then, technically formed algorithm is inserted - the elimination of multiple reception collisions is not in intervals, and, therefore, the network devices are not put to sleep and the energy is not being conserved. The stand-by cycle stays stable and the data are transferred at the moment when the package is formed.

However, such model is used in the allocation algorithm, where the configuration time and precision are more important parameters. Comparing the device allocation operations, the following changes are observed.

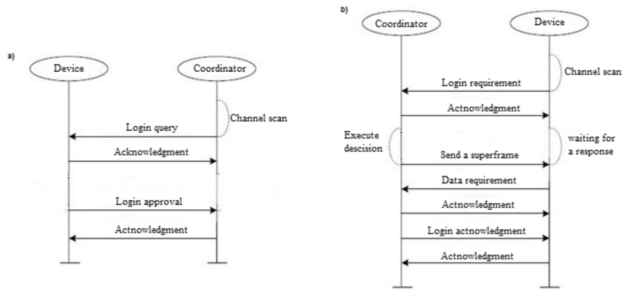

Fig. 14. Device connection procedure scheme of principle to network: a) ADD_NETWORK_TOPOLOGY(unsigned char *address) algorithm; b) IEEE 802.15.4 standard.

1. The number of allocation to network procedures was reduced by two times.
2. The star type topology allocation operation is performed two times faster.
3. 99.9% of the times positive answer from the coordinator, that the device was successfully accepted into the network.
4. The informational allocation message is formed for the external system.

In order to ascertain the benefits of the designing and the algorithm for the energy needs, two day experiment was carried out. During 48 hours, energy consumption data were collected (the average value of the hour) and the current value was calculated. For comparison with the sensors of such type, WC588P carbon monoxide, DG85 motion, PT1000 temperature and HR250 humidity sensors were selected, since the identical product to the one that had been created was not be found. The results of the test are presented in Fig. 16.

In order to ensure safe connection in the algorithms the recommendations of Ken Masica's [6] were implemented.

1. The monitoring of the network is performed externally using the functions of the higher level, the network reports are sent via the UART interface.
2. The network code is used to identify the network device, the devices have the unique 16 bit number.
3. Technically implemented and programmatically executed scanning of the address at the MAC level and the certain registers of that level are turned on in the MRF24J40 chip.
4. Data decoding service is turned on - the decoding key is specified in the MRF24J40 security buffer.
5. The address coding algorithm was inserted - the device address is recoded by 2 bytes.
6. The coordinator is initialized safely - the network devices cannot acquire the status of the coordinator and the coordinator cannot be removed without the special

Table 2. Relation between (SD-AD) values and network stand-by cycles.

ST-AT	0	1	2	3	4	5	6	7	8	9	≥10
Standby cycle (%)	100	50	25	12	6,25	3,125	1,56	0,78	0,39	0,195	<0,1

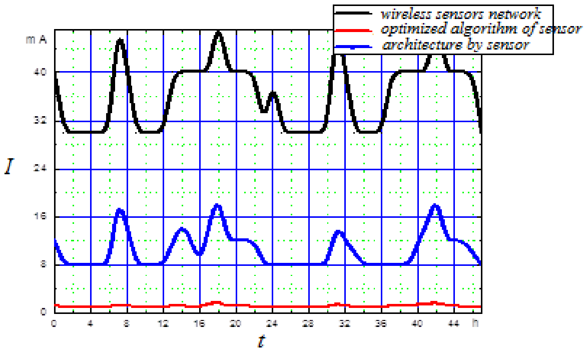

Fig. 15. The current consumption dependence on the time.

4 byte code - 0x55, 0xAA, 0xXX, 0xXX (X - unknown symbol, since it is generated automatically by the system).

7. The coordinator stores the network data in the non-volatile memory.
8. The devices can become the part of the network only if the coordinator receives via the UART interface the address of the device that is in the neutral state.

In order to ascertain the capabilities of the network the sensor radius evaluation test was performed. Conditions - the coordinator sends the data package, the other element of the network should receive the identical data. Maximum distance (700 m in the open area) was established, beyond it the data could be received despite the RSSI value. As it was expected, the nearby devices that are operating in the 2.4 Ghz range significantly influence the quality of the transferred signal (more than 50 m).

The signal was especially dampened in the office and the university, since there are many operating devices of the 802.11x standard. In household conditions the signal is affected not only by routers, but also by the position and intensity of the microwave. After the application of the network formation algorithm, where the RSSI value is important, the network radius could shrink up to 50%.

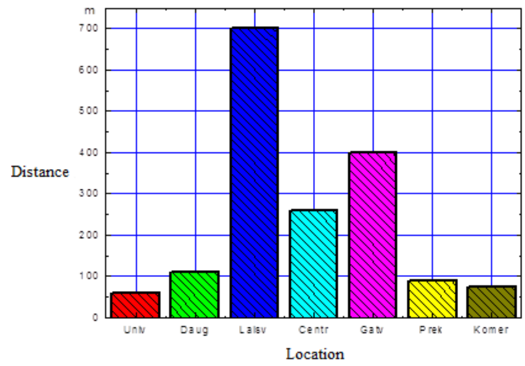

Fig. 16. The maximum data transfer distance of Zigbee sensor (electronic device):
Univ (Vilnius university, faculty of physics),
Daug (Antakalnis apartment building),
Laisv (field outside the city limits),
Cent (Rotušė Square),
Gatv (Zolynas street),
Prek (shopping and entertainment mall "PANORAMA"),
Komer (commercial premises).

Conclusions

1. Network configuration algorithm, which is more than two times faster, was created. The standard MAC command procedure was refused.
2. The devices in Zigbee network can transfer data over the distance of 700 m in the open area. The shortest distance of data transfer that was measured in the university premises was 60 meters since many radio communication stations of 802.11x standard operate on the same frequency.
3. Zigbee technology is a great alternative for the sensor cable network in smart house systems. Safe communication and low infrastructural costs are suitable not only for sensor network data collection, but for wireless security and energy management systems as well.

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