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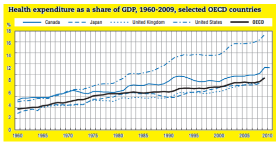

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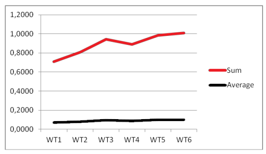

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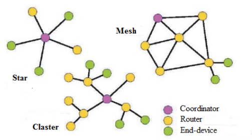

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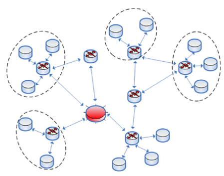

Remuneration System for Professionals with Requirements for Efficiency and Sustainable Quality. 1. Performance Indicators and Priority Distribution Method

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Abstract. In the age of raising healthcare expenditure, the efficiency of healthcare services has evidently become a top issue. This paper deals with the creation of a performance related remuneration system for medical professionals which would meet requirements for the efficiency and sustainable quality. In real world scenarios it is difficult to create an objective and transparent employee performance evaluation model having dealt with both qualitative and quantitative criteria. To achieve these goals, the usage of decision support methods is suggested and analyzed.

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Introduction

In this article we will address the question how a financial employee motivation model based on measured performance and individual added value can be applied in the healthcare sector.

In the scope of this article we cover planning, execution and monitoring steps, excluding the HR related activities associated with communication, legislation and financing. In the second section we analyze the current situation in the healthcare sector and the latest trends in remuneration models used. Having analyzed that, a multi-criteria decision support method is proposed for HPOs performance related remuneration model creation.

1. Formulation of general task

An overview of early and contemporary theories of motivation factors show that motivation, taking into account the way in which it is applied, is a force that influences employees' internal features and external behaviors, and affects their performance [1, 2]. It should be noted that many forms of motivation exist and do not in all cases lead to the same results. The choice of motivation instruments depends on industry, company policies, an employee's job profile characteristics, as well as other factors. The payment system in each organization forms a foundation for a multi-layer motivational system and must be fair, equitable, consistent and transparent. In addition, personnel performance related pay must be based on an individual's activities and, when that is not measurable, on the overall team's work results.

Performance or work output based employee motivation systems are used in many domains. The prerequisite for performance related remuneration is the ability to define regularly measurable work results and their qualitative parameters. By linking employee pay to individual and team work results, managers can use the remuneration system to promote high performance culture, teamwork and foster other organizational objectives.

The creation of a financial employee motivation model is a complex multi-level endeavor, which may influence an organization's business results. By implementing a financial motivation system, organizations harness two competing interests face twofold interest. On one hand, the employee is concerned to maximize his/her pay and shall be interested to improve his/her work results and, on the other, the employer is interested in cost savings. Since ancient times various payment systems have been created to ensure cost-effectiveness, employee motivation and social balance.

The main remuneration system types are time-based (basic pay for standard hours) and unit-based, also called piece rate reward systems. Additionally, bonus systems such as additional hours' reward, sales commission, and profit related pay may be applied. There are many variations and combina-

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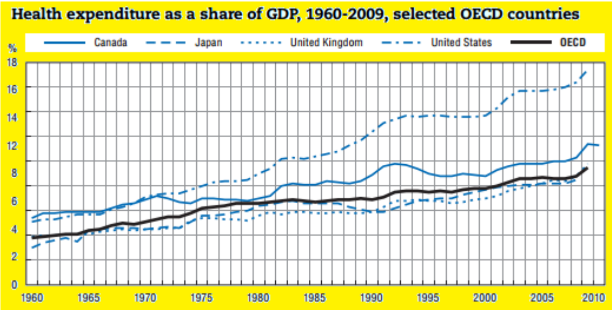

Fig. 1. Healthcare expenditure growth. Adapted according to Ref. [3].

tions of these forms, which are used in different industries for various job profiles.

Within these unit-based forms of remuneration schemes employees have an incentive to increase labor productivity which, in turn, leads to a higher pay. In the healthcare domain this type of payment is directly linked to the most popular reimbursement model, Pay-for-Service. It is heavily used by healthcare provider organizations (HPO) worldwide in private medicine, particularly in the USA.

Indirect unit-based remuneration is characterized by indirect employees' work results. For example, in order to support personnel, the performance related pay is linked to overall team achievements. E.g., the variable salary portion of an operational theatre nurse may depend on overall team performance.

However, in most public, as well as in some private HPOs, the financial organization's operation model is usually not transferred to the remuneration scheme where time-based remuneration is typically used. In Europe there is a higher public share of HPOs, therefore, the most common payment form in the European healthcare sector is a time-based salary system, where the amount paid is based on working hours and employee qualifications. The simplest time-based form of payment is called unified payment for work time system, which is a fixed basic pay for standard hours.

Employee qualification requirements and job profile complexity is understood differently in different countries, industries and even competing companies. A set of defining criteria should include all the factors affecting job characteristics and conditions. The criteria set may include the required level of education, cooperation, concentration, universality and working conditions.

This paper provides an overview of labor relations regulation through performance related payment schemes, which aims to ensure cost-effectiveness, employee motivation and social balance. This significantly increases the importance of human factor, with focused attention on personal responsibility, operational efficiency and continuous improvement processes.

The practical implementation of performance related payment models in an organization has three steps: planning, implementation and monitoring of the new remuneration model. A planning step consists of three parts.

1. Determination of performance indicators to be used in the model.
2. Creation of a calculation model for performance related pay.
3. Discussion and communication with personnel.

The implementation step consists of the actual implementation of new accountancy policies, performance measurements and changes to Human Resources (HR) policies.

The monitoring step is a routine activity aiming to monitor and analyze the changes in an organization caused by an implemented personnel remuneration model.

2. Remuneration scheme for medical professionals

There are substantially different financial healthcare models coexisting worldwide. Each proposes a different business model for healthcare providers. The following major healthcare services reimbursement methods and their combinations are prevalent:

i) Payment-per-Service;
ii) Patient Subscription;
iii) Performance-related Payment.

Regardless of the financial model, a public or private insurance entity reimburses all legally approved medical services provided for a patient covered by the insurance. In some cases, healthcare organizations will get fixed payments for each subscribed patient. This model is typically used for primary care and is used in the UK, USA, post-Soviet Union countries and others. Performance related payment is usually paid by insurance agencies as a bonus, i.e. if healthcare facility meets the quality and performance requirements set.

In the era of steady healthcare expenditure growth [3], which is illustrated in Fig. 1, society demands better efficiency from healthcare providers. Thus, healthcare policy makers are asking themselves what systematic changes would result in better quality of service, more efficient health provider work and less money spent for a healthier population. There are a few answers to address this issue, however, some recent examples of different initiatives for tackling the chronic problems of healthcare systems do exist. The USA recently introduced a new financial model for healthcare providers called ACO, or Accountable Care Organizations, which aims to financially motivate providers by setting metrics for qualitative factors and overall performance. This model complements the fee-for-service model with a performance bonus based on quality and cost savings. Some European countries have introduced special programmes in order to encourage early diagnoses and prevention of diseases like diabetes, tuberculosis, HIS and breast, prostate and lung cancers. Different financial incentive systems have been applied to encourage healthcare providers to participate in these programs.

Getting better results from doctors and nurses requires active performance monitoring and management. Different contract types and bonus packages have been used to improve the quality of the services provided by medical professionals. Paying clinicians based on a "Fee-for-Service" method has caused justified concerns that the balance of medically necessary services being delivered is distorted and has also led to unjustified admissions and other activities [4]. In contrast, time-based salary does not lead to efficient work and encourages lower output. The most innovative healthcare providers have introduced payment mechanisms that combine incentivized output and quality outcomes [5]. There are known examples where up to 20 per cent of doctors' salaries are performance related with nearly half being linked to team performance and quality improvement measurable values[6]. At top class HPO Kaiser Permanente doctors are monitored and ranked in real time on a wide variety of clinical outcomes [6]. The monitoring data is immediately available for the doctors to compare their personal results with peers in their group or even across the region.

Not only are the doctors subject to the anticipated financial incentives change. Nursing personnel are typically the most populous group of professionals in healthcare and their contribution is an essential component in achieving the improved productivity, better quality of care and higher effectiveness in the health sector [7].

In terms of medical personnel payment, the reimbursement methods, used by HPOs influence remuneration schemes, are different. Firstly, there are different financial motivators driven by these methods. Payment-per-Service financially encourages high output of the services provided to the patient, patient subscription financially rewards minimization of services provided while only performance related payment results in long - term patient health quality. Due to the complexity of coexisting financial models there are different medical personnel remuneration models. However, in practice the two most popular payment forms are: time based fixed salary in public HPOs and performance related salaries in private healthcare facilities. The performance related salary scheme is typically calculated considering quantitative results, e.g. number of patient visits, examinations, surgeries, etc.

In private HPOs, employee salaries are determined by these main factors:

i) amount of services provided;
ii) price level in the market;
iii) employee's personal contribution.

Different countries undergo continuous reform of their healthcare systems and the determination of medical personnel remuneration scheme in public HPOs has become one of the central issues. In public HPOs, salaries of medical professionals are usually time-based and formally defined by the governing body. Obviously, this payment method alone does not provide adequate motivation for higher quality or performance. However, usually there are some possibilities to introduce bonuses or performance related payment based on individual or team work results, which can be used as financial motivation instruments.

When an employee's contribution cannot be expressed by its monetary equivalent or percentage of revenue, it is considered to be a subjective decision of the employer. In the public sector, the remuneration scheme is determined by a job evaluation system. The International Labor Organization has suggested a job evaluation system based on the evaluation within four general factors. Each factor has a certain maximum number of points with a total amount of four factors equal to 1000 points. The maximum value of 450 points is assigned to the work complexity factor. Work complexity is seen as an aggregative factor of required professional education and experience, decision magnitude and managerial level.

A social value of work is evaluated with a maximum of 220 points, and is determined by these two criteria: appointment procedures and social significance of the work. A professional responsibility is evaluated by a maximum of 180 points and described by three criteria: impact on the safety of other people, material and moral responsibility and cooperation with external organizations. The last factor is work complexity and work environment which is evaluated by maximum of 150 points. It is characterized by two criteria: mental and physical stress, caused by the level of nervous strain at work and working conditions. According to this system each job profile is rated within the listed four factors by assigning points accordingly. Finally, total sums are calculated and normalized and the resulting coefficient is applied to the official minimum of monthly salary.

Regardless of the ownership form of HPO and the reimbursement model of the healthcare institution, the introduction of a balanced medical personnel performance related payment scheme, which considers both qualitative and quantitative factors may provide the answer to the current efficiency problems faced by the healthcare sector. Implementation of such a balanced performance related remuneration scheme requires determination of measurable indicators. There are a number of healthcare quality and performance indicators which are part of the best practice of business metrics or governmental programs and legislation. However, there is a lack of methods to select, rank and weigh these indicators, gathering them in one system suitable for financial employee performance evaluation. For this purpose, we propose to use the Priority Distribution Method, described by Žaptorius in earlier publication [8].

3. Selecting performance indicators

The first step of an organization's personnel remuneration system change is determination of performance indicators to be used in a new model. Typically, the initial area to look at is a list of key performance indicators defined by the organization itself. However, in healthcare there are external sources, such as governmental bodies or insurance companies, which set financial incentives for meeting certain criteria. Therefore, depending on the healthcare facility profile and region, one can select from different sources. To name a few, the "Meaningful Use" program [9] established by the U.S. Department of Health and Human Services has a set of criteria for organizations meaningfully using electronic health record systems. Another initiative from the U.S. is called Accountable Care Organizations (ACOs), which proposes that participating healthcare facilities receive additional payments based upon specified quality and savings criteria. Another example is the law setting healthcare providers performance indicators, approved by the Ministry of Health of the Republic of Lithuania.

One can conclude that there is no lack of performance indicators for the healthcare industry, however there is a lack of methodologies for the selection of optimal sets of indicators for a specific healthcare provider. There are a high magnitude of HPOs, with different clinical domains and different financial schemes. Below, we propose a generic method which allows an organization to analyze and choose performance evaluation indicators for a performance related remuneration model.

Step 1. Generate a comprehensive list of clinical, financial and management indicators, derived from the following sources: a) KPIs used internally; b) HPO performance related indicators applied by insurance agents; c) HPO performance related indicators applied by government authorities.

Step 2. Filter indicators which are practically measurable and applicable for financial incentives calculation and assign them to job profiles. It will be useful afterwards to define the indicators' value scale, evaluation period and method.

Step 3. Transform interrelated indicators by combining them. For example, indicators such as overtime hours per month and number of night shifts per month can be combined to the composite indicator - *higher compensated work hours per month*.

Step 4. Preliminarily prioritize the indicators (final ranking of indicators will be done using PDM method). The rule of thumb is to give higher priority to indicators linked to the organization's strategy and to raise priority of indicators which have low performance values.

Step 5. Identify potentially dependable indicators, i.e. indicators which are definitely dependable from other measurable indicators, which were not selected for the financial incentives model. This can be achieved manually or by applying statistical regression analyses tools. A wide range of clinical, statistical and financial data available in organization's IT systems should be used. The data collected in hospital information systems (HIS) has significant potential for these types of analyses.

Step 6. Identify any specific factors leading to unsatisfactory values of selected indicators. We propose to perform this kind of analysis applying data mining methods, such as association rules analysis upon the data prepared in step 5.

Let us consider the following example; an association rules discovery algorithm was used on data collected from a provider's HIS. One of the rules showed with high confidence a longer average length of stay for patients diagnosed with hospital acquired pneumonia, which was developed after using extra corporeal lung support systems.

Out of this rule the management decided to introduce a specific performance indicator related to a careful following of the defined algorithm and used it for the responsible medical personnel in appropriate wards.

Step 7. Update each job profiles performance criteria list per organizational unit based on the results of step 6.

Step 8. Use the PDM method to rank quantitative and qualitative criteria and calculate performance related pay. Data mining methods can be helpful to determine other important indicators which influence initially defined (primary) indicators.

The benefit of this type of analysis is automated intelligent analysis of the aggregated data from different domains:

i) patient demographics, clinical patient data;
ii) illness scripts, including epidemiology and average prognosis;
iii) computerized physician order entry systems (CPOE) data;
iv) data collected from nursing charts;
v) surgery and minor interventions protocols;
vi) medical personnel HR data.

For example, using classification trees [10,11] we can determine what factors influence longer LOS, higher mortality rate for specific nosology, or readmission rate. This approach is suitable for HPOs that have already implemented HIS and or EMR. This approach is considered to be not lower than STAGE 4 according to HIMMS electronic medical record adoption model [12]. Modern HIS, EMR and medical decision support systems are able to provide vast amounts of data and allow us to apply data mining techniques to discover hidden patterns and dependencies, and to facilitate route-cause analysis.

4. Priority distribution method

The *Priority Distribution Method* (PDM) belongs to the family of multi criteria decision support methods, based on expert pair wise comparison of criteria.

In 1977 T. L. Saaty proposed a multi-criteria decision support methodology Analytic Hierarchy Process (AHP) to rank alternatives by pair wise comparison [13]. This method, called the analytic hierarchy process, requires evaluation by how many times one alternative (criterion) is better than the other.

There are other applicable methods for this task as well: Simple Additive Weighting, TOPSIS (Technique for Order

Preference by Similarity to an Ideal Solution), to name but a few. Each has its pros and cons, however, the strongest feature of the proposed PDM, and the reason it was selected, is its high practical applicability.

The weakest part of most pair wise comparison methods is the difficulty of normalizing the experts' opinions. For instance, defining how many times mortality rate in a ward is more important than patient acquired post-surgery complication is very doubtful even for a domain expert. Therefore, the following reduction of a comparison result range just to three categorical values, as proposed in PDM, is very helpful: <less important>, <equal> or <more important>.

The downside of PDM is that the method is not mathematically precise. For a mathematically proven method we recommend a modified AHP version, which addresses the rank reversal problem.

According to J. Žaptorius [8], the application of the *Priority Distribution Method* (PDM) to the financial portion of an employee remuneration package is possible under the following conditions:

a) the employees are working in teams or shifts and have similar job profiles;
b) a variable salary part or performance bonus is applicable;
c) it is impossible to directly and precisely evaluate the productivity of the employees.

PDM is based on the expert evaluation of qualitative and quantitative features of the object, i.e. job profile, in comparison with each other. The method allows to evaluate objects which have incomplete or only qualitative differentiation parameters. In practical settings, a panel of experts shall be formed, who will analyze initial data and define comparison criterion for the investigated objects.

The method prioritizes a group of objects in ascending or descending order, depending on the magnitude of their characteristics manifestation, thus, calculating their ranks. Using pair wise comparisons, the relative importance of one criterion over another can be calculated.

Accordingly, for each object PDM defines relative weighting, which expresses the rank of each object's characteristics and helps to select and prioritize the criteria.

PDM is flexible in adjustment of precision and degree of justification required for management tasks and optimal decision support.

Typically, when indicators with different origin and measurement units exist, we face the problem of normalization and conversion to a unified measurement unit or non-dimensional unit. To tackle this problem, the method proposes the conversion of indicators' values to their relational values (ratios), which will be expressed in uniform, quantitative and therefore arithmetically comparable units. The initial step is to define the most important differentiating criteria, which will be used to calculate performance related payments. There are a number of possibilities for the selection of criteria, e.g.

Table 1. Comparison of all possible criterion pairs

Criteria pair	Experts					Average priority value P*
	1	2	3	4	5	
w_1 & w_2	>	>	>	>	>	>
w_1 & w_3	>	>	=	>	>	>
w_1 & w_4	>	=	>	<	>	>
w_1 & w_5	>	>	>	>	>	>
w_2 & w_3	<	<	>	=	<	<
w_2 & w_4	=	=	=	>	<	=
w_2 & w_5	<	>	<	<	<	<
w_3 & w_4	>	>	>	>	=	>
w_3 & w_5	>	=	=	=	=	=
w_4 & w_5	>	=	>	>	=	>

contracting external HR consultants, surveying employees and defining by number of votes, or basing definition on an individually generated added value aligned with the company's business goals and key performance indicators.

As indicated in section "Selecting performance indicators", there is a set of typical indicators used in healthcare; some of which can be successfully projected to personal employee job evaluation indicators.

There are two potential classes of employee productive input evaluation criteria: quantitative and qualitative. We will assume criteria as quantitative if they are measurable, numerical and their measurement or evaluation is not dependent on subject matter expert opinion, e.g. number of patient visits, hospitalization length of stay, percentage of postoperative complications and percentage of patient readmissions. In contrast, a qualitative criterion usually has categorical values which are indirectly evaluated by subject matter experts, e.g. teamwork, discipline, loyalty, creativity, or proactivity. Such a qualitative criterion can be valued, compared to the etalon value if it exists, or compared to the respective criterion of other employees in the group or region.

According to the pair wise decision rule formulated by Terstown [14], if a pair wise comparison is performed by a group more or equal to 25 independent experts then their evaluation values have a normal distribution with variance equal to 1. In a practical setting the typical number of experts is less than 25 and so distribution is close to normal.

Let us define the most important criteria set as

$$K\{k_1, k_2, k_3, k_4, k_5\}. \quad (1)$$

Each criterion k_n shall have a defined value range, source, and calculation method.

To rank the criteria we need to define each criterion's weight w_n. In the frame of PDM it is achieved by comparing criteria in pairs. In order to mutually compare k_n we will use the Table 1 of all possible pair wise comparisons.

All possible criteria pairs' comparison ratios are defined by the experts. In this example, we analyze simplified and more practical comparisons, where the only ratio values the experts can assign are: greater than ">", equal to "=", or less than "<", assuming that the same degree of criteria pairs' relative difference applies. Then, the comparison matrix

$$A = \| a_{i,j} \| \quad (2)$$

is derived by using average priority values $P*$, criteria conditional priorities P_{ij}^{s} are incrementally calculated. ||A|| is a square matrix with size equal to the number of criteria l. As in many multi-criteria decision making methods using pair wise comparison [13,15,16], the matrix $\| A \|$ is naturally reciprocal, where

$$a_{i,j} = a_{j,i}^{-1}. \quad (3)$$

Therefore only the upper or lower part of it shall be calculated and another is easily derived. PDM uses formula for data when $a_{i,j} \in [0;2]$:

$$a_{i,j} + a_{j,i} = 2 \quad (4)$$

According to PDM, the following heuristic is used to derive the comparison matrix.

$$\text{a(x)} = \begin{cases} 1+z, & \text{when } x_i > x_j \\ 1, & \text{when } x_i = x_j \\ 1-z, & \text{when } x_i < x_j \end{cases}$$

where z is defined as:

$$z = \frac{K_r - 1}{K_r + 1} + \sqrt[2]{\frac{0.05}{l}} \quad (5)$$

and l represents the number of criteria.

K_r represents the preliminary estimated maximum and minimum criterion weight ratio:

$$K_r = \frac{X_i^{max}}{X_j^{min}} \quad (6)$$

where X_i^{max} and X_j^{min} - compared i and j indicators with a maximum and minimum value.

By ranking expert ratios values (see Table 1), let us estimate K_r=4. Given the above estimated K_r:

$$z = \frac{4-1}{4+1} + \sqrt[2]{\frac{0.05}{5}} = 0.7 \quad (7)$$

and

$$\text{a(x)} = \begin{cases} 1.7, & \text{when } x_i > x_j \\ 1, & \text{when } x_i = x_j \\ 0.3, & \text{when } x_i < x_j \end{cases}$$

This derives a comparison priority matrix ||A|| as presented in Table 2.

Considering the matrix above, the criteria priorities P_i and then subsequently normalizing P_i , $P_i^{'}$ has been derived.

5. Calculation routine

The calculation is provided using following routine.

1. Calculate priority sums for each row:

$$\sum_{j=1}^{i} a_{i,j} = b_i \quad (8)$$

Table 2. Criteria weight comparison matrix.
Indexes: i (vertical), j (horizontal)

i j	w_1	w_2	w_3	w_4	w_5	$\Sigma a_{i,j}$=b_i	P_i	$P_i^{'}$
w_1	1	1.7	1.7	1.7	1.7	7.8	37.04	0.348
w_2	0.3	1	1.7	1	1.7	5.7	23.60	0.222
w_3	0.3	0.3	1	0.3	1.7	3.6	13.10	0.123
w_4	0.3	1	1.7	1	1.7	5.7	23.60	0.222
w_5	0.3	0.3	0.3	0.3	1	2.2	9.04	0.085
Sum							106.38	1.000

Table 3.Recalculated criteria weight comparison matrix.
Indexes: i (vertical), j (horizontal)

i j	w_1	w_2	w_3	w_4	w_5	$\Sigma a_{i,j}$=b_i	P_i	$P_i^{'}$
w_1	1	1.69	1.69	1.69	1.69	7.8	36.90	0.345
w_2	0.31	1	1.69	1	1.69	5.7	23.69	0.222
w_3	0.31	0.31	1	0.31	1.69	3.6	13.34	0.125
w_4	0.31	1	1.69	1	1.69	5.7	23.69	0.222
w_5	0.31	0.31	0.31	0.31	1	2.2	9.30	0.087
Sum							106.91	1.000

2. Calculate P_i by summing the product of row priority $a_{i,k}$ and b_k:

$$P_i = \sum_{k=1}^{i} a_{i,k} \times b_k \quad (9)$$

3. Normalize conditional priorities $P_i^{'}$ values:

$$P_i^{'} = \frac{P_i}{\sum_{k=1}^{i} P_i} \quad (10)$$

With calculated $P_i^{'}$ values, actual K_r^f ratio is being calculated and compared to preliminary estimated ratio K_r:

$$K_r^f = \frac{P_i^{'max}}{P_i^{'min}} = \frac{0.348}{0.085} = 4.094 \quad (11)$$

Thus, $K_r^f \neq K_r$, and we have to align the initially calculated z value. The calculation of correction coefficient α will be provided.

$$\alpha = \frac{K_r}{K_r^f} = \frac{4.000}{4.094} = 0.98 \quad (12)$$

The aligned z value will be calculated using initial $z_p$value:

$$z = z_p \times \alpha \quad (13)$$

Thus result:

$$z = 0.7 \times 0.98 = 0.69 \quad (14)$$

Considering the new z value, a new a_{ij} value has been derived:

$$\text{a(x)} = \begin{cases} 1.69, & \text{when } x_i > x_j \\ 1, & \text{when } x_i = x_j \\ 0.31, & \text{when } x_i < x_j \end{cases}$$

A recalculated comparison priority matrix ||A|| is presented in Table 3. Weighted criteria ranks are expressed as normalized numeric weights $P_i^{'}$.

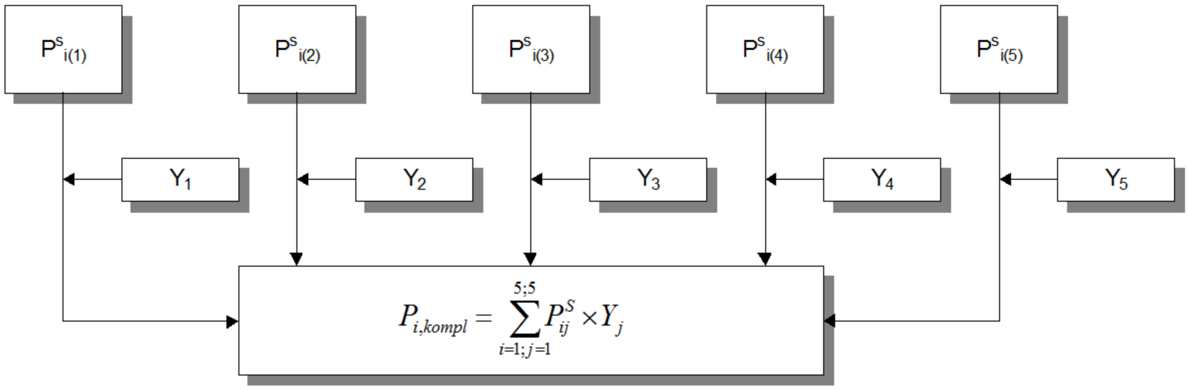

Fig. 2. Complex employee performance value indicator.

The next step is to evaluate employees individually. Quantitative criteria evaluation can be directly performed, applying normalized measurement ranges. Individual employee criteria ranking shall have the biggest weight value for the best performance value, accordingly, as the biggest weight value for the most important criterion was calculated in $\|A\|$. Therefore, if a minimizing criterion exists, its value shall be converted as follows using $\min c$ as the smallest value of an object's criterion:

$$\bar{c} = \frac{\min c}{c_i} \tag{15}$$

This transformation of minimizing criteria values will convert the smallest value to the largest equal to 1.

For evaluation of individual employee's qualitative criteria we apply PDM. The external experts or the team of employees themselves evaluate each employee pair wise, according to the steps described above. The results of the evaluation are combined with the PDM results of criteria ranking. The complex employee performance value indicator $P_{i,compl.}$ is calculated using routine as presented in Fig. 2.

$P_{i,compl.}$ represents the i-th employee performance value indicator; $P^{S}_{i(j)}$ - i-th employee evaluation weight for j-th criterion; y_j - j-th criterion weight.

The employee performance related payment is calculated using a fixed salary part, called the Base. Typically, the variable salary part is formed as a specific percentage K% of the Base, as defined by company policies. Applying the calculated complex employee performance value indicator (see Fig. 2), the variable salary part equals to:

$$Salary_{var,i} = Salary_{fix,i} \times K \times PVI \tag{16}$$

where $Salary_{var,i}$ - i-th employee variable salary part (performance related pay); $Salary_{fix,i}$ - i-th employee fixed salary part.

According to [8], this method can also be used as a method for employee job profile evaluation. From a HR management point of view, this heuristic method expresses a comparative view of the market value of the job performed by certain employees.

The most practical outcome of the PDM is the definition of employee evaluation criteria weights, which can be universally used in the frame of the analyzed company/department/team.

Conclusions

Healthcare policy makers and Healthcare Provider Organizations are in a constant battle with rising healthcare expenditure; there is a high need for innovative financial schemes, promoting greater effectiveness of services provided. A method utilizing multi-criteria decision support for the creation of a performance related remuneration model in inpatient healthcare facilities was created.

The implementation of a well-balanced performance related remuneration model needs a systematic approach. Having analyzed the issues of practical implementation of performance related pay schemes in the healthcare domain, a methodology consisting of performance indicators selection, usage of the Priority Distribution Method and a method for monitoring its efficiency is proposed.

A pair wise criteria comparison method called *Priority Distribution Method* (PDM) was used for weighed personnel performance criteria ranking. The defining of an HPO's personnel remuneration model is a complex and manifold task, which highly influences overall enterprise results. In order to determine individual work outputs healthcare providers have to use personnel work performance evaluation models. Recent global changes in the healthcare domain have resulted in a new understanding that a complex set of quantitative and qualitative criteria should be applied for the overall provider's activity evaluation. When projecting this perspective to the evaluation of individual performance, we face the issue of the qualitative criteria relative weight determination and its influence to overall employee performance, expressed in weighed criterion rank. PDM was specifically created to address these issues and provide a practically usable method, in which not directly measurable qualitative criteria shall be subjectively evaluated by experts [8].

Additionally, the issues of performance criteria selection for PDM and evaluation of PDM application results were discussed.

A method for healthcare specific criteria selection consisting of 6 steps was provided. The method emphases the usage of well-defined criteria in healthcare legislation and healthcare sector best practices for setting the initial indicators. Enterprise specific indicators shall be derived from initial by applying intelligent data analysis techniques to the available provider's statistical, clinical and HR data. Usage of association rules learning and other data mining methods can reveal additional non-obvious indicators, which will/should be included in PDM calculations.

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Remuneration System for Professionals with Requirements for Efficiency and Sustainable Quality. 2. Application of Priority Distribution Method

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Abstract. Usage of decision support methods allows to solve practical tasks of big importance. The systematic approach of Priority Distribution Method's practical application for healthcare provider organizations is created and described.

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Short title: Remuneration System. 2. Application.

Introduction

Previous publication [1] was devoted for analysis of the *Priority Distribution Method* (PDM). This work is aimed to the usage of PDM for inpatient healthcare providers by means of following methods: decision support, data mining for the determination of performance indicators and subsequent monitoring of the achieved results.

The article illustrates the practical solution how to use the mentioned methods for healthcare provider organizations; how to evaluate the value of each job profile, considering subjective and objective social factors which might affect the salary amount.

1. PDM application in healthcare in-patient facilities

In this section we will create a performance related remuneration model for a hypothetical inpatient healthcare facility. We will use PDM to create a performance related payment model for a hospital's ward physicians and nurses.

Table 1. Qualitative and quantitative indicators for performance evaluation.

Indicators	Quantitative criteria	Qualitative criteria
inpatient facilities	average length of stay; ratio of inpatient day surgery visits to overall inpatient visits (including surgery); mortality rate; frequency of pressure sores in bedridden patients; usage of disinfectant liquids.	patient satisfaction level; participation in internal training programs; practiced hygiene level.
healthcare quality and key performance	postoperative complications rate; rehospitalization rate; medical errors / claims.	
non - domain specific criteria	work hours; shift coefficient; medical qualification coefficient; experience coefficient; number of non-compliance / audit issues; number of claims.	team work orientation; help to colleagues; discipline.

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Table 2. Nurse performance evaluation indicators.

Code	Criteria	Description
k_1	Work hours × shift coefficient × medical qualification coefficient	Composite evaluation of workload, assuming different ratios for weekday and night shifts and formally acquired medical qualifications
k_2	Accumulative number of registered issues and claims per quarter	Number of internal issues or external claims during ongoing quarter
k_3	Teamwork ability (half year/yearly)	Shares information with colleagues. Ready to help colleagues. Demonstrates positive attitude. Problem solving orientation
k_4	Personal discipline (half year/yearly)	Physician or head nurse orders performed in time and in quality. Documentation activities performed according to hospital rules
k_5	Average quarter length of stay to average LOS ratio	Quarterly average patients' LOS compared to the country or region's normative average LOS for the ward's specialty
k_6	Mortality rate to average mortality rate ratio	Half yearly or annual average patients' mortality rate compared with the country or region's normative average mortality rate for the ward's specialty
k_7	Frequency of pressure sore in bedridden patients to average frequency ratio	Half yearly or annual amount of pressure sore patient incidents
k_8	Practiced hygiene level	Quarterly quality metric, according to hospital standard (e.g. usage of disinfectant liquids, hygiene quality checks)
k_9	Patient satisfaction level	Half yearly or annual quality metric defined and digitized thorough patient surveys
k_{10}	Participation in internal training programs	Annual quality metric, defined as a percentage of participation in internal training programmes or individual yearly goals

Table 3. Ward physician performance evaluation indicators.

Code	Criteria	Description
k_1	Work hours' × shift coefficient × medical qualification coefficient	Composite evaluation of workload, assuming different ratios for weekday and night shifts and formally acquired medical qualifications
k_2	Accumulative number of registered issues and claims per quarter	Number of internal issues or external claims during ongoing quarter
k_3	Teamwork ability (half year/yearly)	Shares information with colleagues. Ready to help colleagues. Demonstrates positive attitude. Problem solving orientation
k_4	Personal discipline (half year/yearly)	Orders of superior performance in time and in quality. Documentation of activities performed according to the hospital rules
k_5	Average quarter length of stay to average LOS ratio	Quarterly average patients LOS compared to the country or region's normative average LOS for the ward's specialty
k_6	Mortality rate to average mortality rate ratio	Half yearly or annual average patient's mortality rate compared to the country or region's normative average mortality rate for the ward's specialty
k_7	Postoperative complications rate	Half yearly or annual average patients' postoperative complications rate compared to the country or region's normative average rate for the ward's specialty
k_8	Rehospitalization rate	Half yearly or annual average patients rehospitalization rate compared to the country or region's normative average rate for the ward's specialty
k_9	Patient satisfaction level	Half yearly or annual quality metric defined and digitalized thorough patient surveys
k_{10}	Participation in internal training programmes	Annual quality metric, defined as percentage of participation in internal training programmes or individual year goals

As was stated previously, the initial step of PDM is to define indicators which will be used to evaluate the overall outcome of the job. For our use case example, we will use HPOs' performance indicators as approved by the MOH of the Republic of Lithuania in 2012 [2], which aim to raise overall treatment quality and become a strong complementary evaluation to the quantitative metrics of provided medical services. Some of them can be aggregated and successfully projected to the personal employee job evaluation indicators. To restrict different types of healthcare providers and their operation modes, we will use indicators applicable to the general profile hospitals.

The following quantitative and qualitative indicators from the inpatient facilities indicators list [2] were selected as presented in Table 1. Additionally the following healthcare quality and key performance indicators and non-domain specific criteria will be added.

Let us define the criteria sets for ward physicians and ward nurses combining both criteria lists. The ward nurse job profile criteria can be defined as presented in Table 2. The ward physician job profile criteria can be defined as presented in Table 3.

To rank and weigh the identified criteria, we use pair wise comparison as defined in PDM. Below, we provide exemplary calculations, which should be recalculated for each healthcare institution, aiming to apply this method. As explained before, the nature of financing model used in each particular facility will strongly affect individual personnel motivation. Therefore, the ranking and weight of the criteria defined will differ from one healthcare organization to the other.

As a second PDM step, all defined criteria are compared in pairs by the expert panel. The resulting tables for physicians and nurses criteria are provided - Table 4 and Table 5, respectivelly. Using the results of pair wise comparison, the priority matrixes with justifiable a_{ij} are derived - see Table 6 and Table 7.

After the series of priority matrix perturbations described in PDM, K_r estimation error is minimized. Thus when $K_r^f \neq K_r$, z value is adjusted by multiplying it by correction coefficient α iteratively. After the series of initial matrix transformations, the priority matrixes are calculated, see Table 8 and Table 9.

The normalized weight $P_i^{'}$ of each criterion is derived in the resulting matrixes. When the criteria weights are defined, the next step is to evaluate each employee of the same position, i.e. nurse or physician, by assigning measured values for each criterion. This can be done in a number of ways. For quantitative indicators it is a mathematically trivial operation. However, for the qualitative criteria different approaches exist. The formal evaluation is typically easier for hospitals where routine HR processes are established and all employees undergo regularly scheduled performance appraisal meetings. In other cases, we suggest to use PDM to derive possibly more neutrally scored values of employees' qualitative features.

The overall employee performance related value (PRV) calculation is based on derived criteria weights (see Table 10) and measured or evaluated by individual employee's indicator values. Mentioned table was used for ward nurses and physicians PRV calculation.

The overall i-th employee value for j-th criterion equals to product G:

$$G_{i,j} = P_j^{'} \times p_i^{'} \tag{1}$$

The employee's performance related value equals the sum of overall employee's criterion values:

$$PRV_i = \sum_{k=1}^{j} p_{ik}^{'} \times P_k^{'} \tag{2}$$

where i-th - employee and j - number of criteria.

Applying the calculated employee performance related value, the variable salary part is calculated as follows:

$$Salary_{var,i} = Salary_{fix,i} \times K \times PVR \tag{3}$$

where $Salary_{var,i}$ represents the i-th employee variable salary part (performance related pay); $Salary_{fix,i}$ represents the i-th employee fixed salary part.

Table 4. Ward nurses pairwise criteria comparison.
C - Criteria, AV - Average value

C	AV	C	AV	C	AV
w_1 vs w_2	$>$	w_2 vs w_9	$<$	w_5 vs w_6	$<$
w_1 vs w_3	$>$	w_2 vs w_{10}	$>$	w_5 vs w_7	$<$
w_1 vs w_4	$>$	w_3 vs w_4	$<$	w_5 vs w_8	$<$
w_1 vs w_5	$>$	w_3 vs w_5	$<$	w_5 vs w_9	$<$
w_1 vs w_6	$>$	w_3 vs w_6	$<$	w_5 vs w_{10}	$<$
w_1 vs w_7	$>$	w_3 vs w_7	$>$	w_6 vs w_7	$<$
w_1 vs w_8	$>$	w_3 vs w_8	$<$	w_6 vs w_8	$>$
w_1 vs w_9	$>$	w_3 vs w_9	$<$	w_6 vs w_9	$>$
w_1 vs w_{10}	$>$	w_3 vs w_{10}	$>$	w_6 vs w_{10}	$<$
w_2 vs w_3	$>$	w_4 vs w_5	$>$	w_7 vs w_8	$>$
w_2 vs w_4	$<$	w_4 vs w_6	$>$	w_7 vs w_9	$<$
w_2 vs w_5	$>$	w_4 vs w_7	$>$	w_7 vs w_{10}	$<$
w_2 vs w_6	$<$	w_4 vs w_8	$>$	w_8 vs w_9	$>$
w_2 vs w_7	$<$	w_4 vs w_9	$<$	w_8 vs w_{10}	$>$
w_2 vs w_8	$<$	w_4 vs w_{10}	$>$	w_9 vs w_{10}	$>$

Table 5. Ward physician performance evaluation indicators.
C - Criteria, AV - Average value.

C	AV	C	AV	C	AV
w_1 vs w_2	$>$	w_2 vs w_9	$<$	w_5 vs w_6	$<$
w_1 vs w_3	$>$	w_2 vs w_{10}	$>$	w_5 vs w_7	$<$
w_1 vs w_4	$>$	w_3 vs w_4	$<$	w_5 vs w_8	$<$
w_1 vs w_5	$>$	w_3 vs w_5	$<$	w_5 vs w_9	$<$
w_1 vs w_6	$>$	w_3 vs w_6	$<$	w_5 vs w_{10}	$<$
w_1 vs w_7	$>$	w_3 vs w_7	$<$	w_6 vs w_7	$>$
w_1 vs w_8	$>$	w_3 vs w_8	$<$	w_6 vs w_8	$>$
w_1 vs w_9	$>$	w_3 vs w_9	$<$	w_6 vs w_9	$>$
w_1 vs w_{10}	$>$	w_3 vs w_{10}	$>$	w_6 vs w_{10}	$<$
w_2 vs w_3	$>$	w_4 vs w_5	$>$	w_7 vs w_8	$<$
w_2 vs w_4	$<$	w_4 vs w_6	$>$	w_7 vs w_9	$<$
w_2 vs w_5	$>$	w_4 vs w_7	$<$	w_7 vs w_{10}	$>$
w_2 vs w_6	$<$	w_4 vs w_8	$<$	w_8 vs w_9	$<$
w_2 vs w_7	$<$	w_4 vs w_9	$<$	w_8 vs w_{10}	$>$
w_2 vs w_8	$<$	w_4 vs w_{10}	$>$	w_9 vs w_{10}	$>$

Table 6. Initial priority matrix for a ward nurses criteria weight evaluation

i j	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9	w_{10}	$\Sigma a_{i,j}=b_i$	P_i	P_i'
w_1	1	1,404	1,404	1,404	1,404	1,404	1,404	1,404	1,404	1,404	13,6	135,59	0,1401
w_2	0,596	1	1,404	0,596	1,404	0,596	0,596	0,596	0,596	1,404	8,8	82,25	0,0850
w_3	0,596	0,429	1	0,596	0,596	0,596	1,404	0,596	0,596	1,404	7,8	76,31	0,0788
w_4	0,596	1,571	1,404	1	1,404	1,404	1,404	1,404	0,596	1,404	12,2	117,16	0,1210
w_5	0,596	0,429	1,571	0,429	1	0,596	0,596	0,596	0,596	0,596	7,0	66,85	0,0691
w_6	0,596	1,571	1,571	0,429	1,571	1	0,596	1,404	1,404	0,596	10,7	103,08	0,1065
w_7	0,596	1,571	0,429	0,429	1,571	1,571	1	1,404	0,596	0,596	9,8	94,77	0,0979
w_8	0,596	1,571	1,571	0,429	1,571	0,429	0,429	1	1,404	1,404	10,4	97,96	0,1012
w_9	0,596	1,571	1,571	1,571	1,571	0,429	1,571	0,429	1	1,404	11,7	112,34	0,1161
w_{10}	0,596	0,429	0,429	0,429	1,571	1,571	1,571	0,429	0,429	1	8,5	81,64	0,0843
Sum												967,96	1,0000

Table 7. Initial priority matrix for a ward physician physician's criteria weight evaluation

i j	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9	w_{10}	$\Sigma a_{i,j}=b_i$	P_i	P_i'
w_1	1	1,571	1,571	1,571	1,571	1,571	1,571	1,571	1,571	1,571	15,1	147,74	0,1643
w_2	0,429	1	1,571	0,429	1,571	0,429	0,429	0,429	0,429	1,571	8,3	68,65	0,0764
w_3	0,429	0,329	1	0,429	0,429	0,429	0,429	0,429	0,429	1,571	5,9	52,98	0,0589
w_4	0,429	1,671	1,571	1	1,571	1,571	0,429	0,429	0,429	1,571	10,7	93,90	0,1044
w_5	0,429	0,329	1,671	0,329	1	0,429	0,429	0,429	0,429	0,429	5,9	51,55	0,0573
w_6	0,429	1,671	1,671	0,329	1,671	1	1,571	1,571	1,571	0,429	11,9	113,36	0,1261
w_7	0,429	1,671	1,671	1,671	1,671	0,329	1	0,429	0,429	1,571	10,9	93,65	0,1042
w_8	0,429	1,671	1,671	1,671	1,671	0,329	1,671	1	0,429	1,571	12,1	107,85	0,1200
w_9	0,429	1,671	1,671	1,671	1,671	0,329	1,671	0,329	1	1,571	12,0	106,59	0,1186
w_{10}	0,429	0,329	0,329	0,329	1,671	1,671	0,329	0,329	0,329	1	6,7	62,72	0,0698
Sum												898,99	1,0000

Table 8. Resulting priority matrix for a ward nurses nurse's criteria weight evaluation

i j	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9	w_{10}	$\Sigma a_{i,j}=b_i$	P_i	P_i'
w_1	1	0,682	0,682	0,682	0,682	0,682	0,682	0,682	0,682	0,682	7,1	39,1	0,1389
w_2	0,289	1	0,682	0,289	0,682	0,289	0,289	0,289	0,289	0,682	4,8	24,1	0,0856
w_3	0,289	0,209	1	0,289	0,289	0,289	0,682	0,289	0,289	0,682	4,3	22,2	0,0788
w_4	0,289	0,763	0,682	1	0,682	0,682	0,682	0,682	0,289	0,682	6,4	34,0	0,1209
w_5	0,289	0,209	0,763	0,209	1	0,289	0,289	0,289	0,289	0,289	3,9	19,5	0,0695
w_6	0,289	0,763	0,763	0,209	0,763	1	0,289	0,682	0,682	0,289	5,7	29,9	0,1065
w_7	0,289	0,763	0,209	0,209	0,763	0,763	1	0,682	0,289	0,289	5,3	27,5	0,0978
w_8	0,289	0,763	0,763	0,209	0,763	0,209	0,209	1	0,682	0,682	5,6	28,6	0,1016
w_9	0,289	0,763	0,763	0,763	0,763	0,209	0,763	0,209	1	0,682	6,2	32,6	0,1160
w_{10}	0,289	0,209	0,209	0,209	0,763	0,763	0,763	0,209	0,209	1	4,6	23,7	0,0844
Sum												281,21	1,0000

Table 9. Resulting priority matrix for a ward nurses nurse's criteria weight evaluation

i j	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9	w_{10}	$\Sigma a_{i,j}=b_i$	P_i	P_i'
w_1	1	5,590	5,590	5,590	5,590	5,590	5,590	5,590	5,590	5,590	51,3	1601,9	0,1662
w_2	1,528	1	5,590	1,528	5,590	1,528	1,528	1,528	1,528	5,590	26,9	725,0	0,0752
w_3	1,528	1,172	1	1,528	1,528	1,528	1,528	1,528	1,528	5,590	18,5	570,0	0,0591
w_4	1,528	5,946	5,590	1	5,590	5,590	1,528	1,528	1,528	5,590	35,4	1001,4	0,1039
w_5	1,528	1,172	5,946	1,172	1	1,528	1,528	1,528	1,528	1,528	18,5	551,8	0,0573
w_6	1,528	5,946	5,946	1,172	5,946	1	5,590	5,590	5,590	1,528	39,8	1225,3	0,1271
w_7	1,528	5,946	5,946	5,946	5,946	1,172	1	1,528	1,528	5,590	36,1	994,6	0,1032
w_8	1,528	5,946	5,946	5,946	5,946	1,172	5,946	1	1,528	5,590	40,5	1151,9	0,1195
w_9	1,528	5,946	5,946	5,946	5,946	1,172	5,946	1,172	1	5,590	40,2	1137,6	0,1180
w_{10}	1,528	1,172	1,172	1,172	5,946	5,946	1,172	1,172	1,172	1	21,5	678,0	0,0704
Sum												9637,67	1,0000

Table 10. Performance related value matrix for ward nurses and physicians

Criterion weight value	Criteria rank weights and employee performance values									
Employee's personal label	P_1'	P_2'	P_3'	P_4'	P_5'	P_6'	P_7'	P_8'	P_9'	P_{10}'
P_j' for nurses	0,14	0,09	0,08	0,12	0,07	0,11	0,10	0,10	0,12	0,08
P_j' for physicians	0,17	0,08	0,06	0,10	0,06	0,13	0,10	0,12	0,12	0,07

2. Methods and toolsets for monitoring PDM efficiency

The described method for calculating performance related payment of medical personnel is theoretical and needs practical approbation. Therefore, it is essential to provide method and tools for evaluation of the PDM implementation's outcomes. The change of financial personnel incentives may lead to a wide spectrum of implications which, in turn, may influence organization activities not covered by the metrics of the selected PDM indicators. Hence, we propose methodology for monitoring and timely identification of PDM usage effects on HPO's operation. The application of statistical analysis, pattern recognition, dimension reduction and other data mining methods allows us to acquire more detailed information at early stages. Data mining can help determine if new patterns or associations come into force and the way they evolve after the introduction of the new employee remuneration scheme.

We propose the following systematic organization performance monitoring and evaluation approach:
Activity 1: Collect and analyze the change of each criterion K over time (time series analyses)
Activity 2: Calculate correlation coefficient to determine the influence of criterion weight to the measured values of PDM indicators.
Activity 3: Perform direct association rules analyses, i.e. generate rules on acquired PDM indicator values and analyze the interdependent rules.

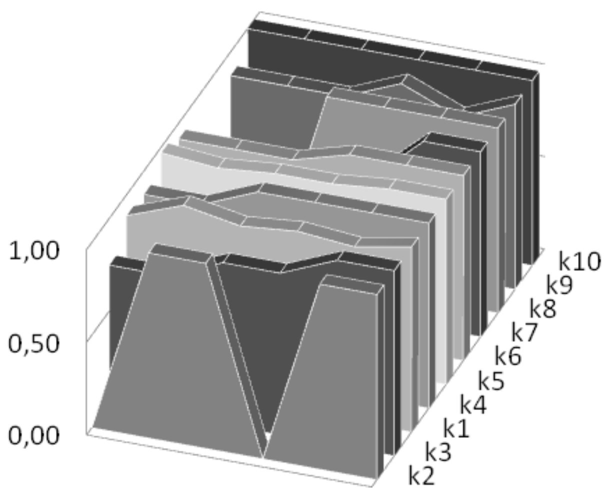

Fig. 1. The trend of measured PDM criteria values over 6 months.

Activity 4: Perform comprehensive association rules analyses, i.e. generate rules on all available indicators collected from an HPO's medical information systems, e.g. HIS, EMR.

The 1st activity is a basic one and shows direct results of PDM application. Different visualization methods shall be applied for periodic analyses of change in indicators. Following our case example, two visualizations of the values of criteria set's $w_n[w_1; w_{10}]$ changes over a period of 6 months, are provided below. Fig. 1 illustrates normalized measured criteria values. The normalization was performed by rescaling values to [0;1] scale and applying weight calculated by PDM. The minimized values were adjusted to its maximizing values.

Fig. 2 represents the same trend applying dimension reduction. In this example elementary reductions to criteria value sum and mean values were performed.

The next recommended step is to formally calculate correlation R_n (2nd activity) of criterion K_n weight and averaged measured indicator value. Linear regression calculation may be used, which provides statistically well-defined evaluation criteria. Higher correlations coupled with higher variance of measured indicator values will show higher effect of the indicator weight in the applied PDM model.

Finally, deeper analyses for hidden effects may be applied by using association rules learning or inductive logic programming methods. Identified rules with higher confidence and smaller support values will identify non-obvious rules with higher correctness of the rule. Different existing algorithms can be applied for association rules discovery. Depending on the quality of the existing data (missing data and noisy data), appropriate algorithms shall be applied.

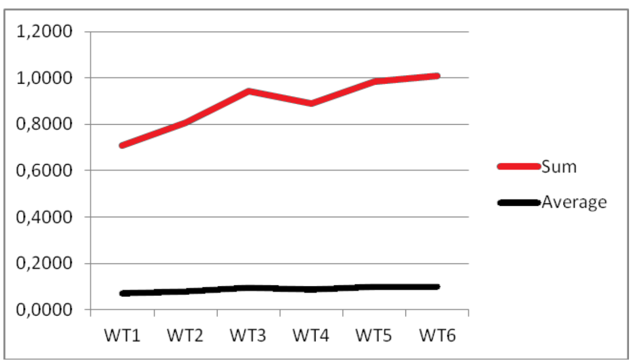

Fig. 2. The trend of descaled PDM criteria values over 6 months.

According to multiple researches the best results are achieved by performing data preprocessing, proper parametrization and applying a set of different DM algorithms [3,4].

From a system engineering perspective, each organization is a complex system interfacing with other external systems. Therefore, the information gained in activities 2-4 should be considered with care, by involving domain experts and analyzing critically the causes of each change.

Conclusions

For the understanding of the applied PDM outcomes the routine monitoring and recurring evaluation of individual and overall HPO performance will be performed. The change of financial personnel incentives may also lead to unpredictable implications, which could influence the provider's activities not covered by the indicators selected for PDM. Therefore, four activities allowing direct and indirect evaluation of enterprise operation were proposed. Data visualization and dimension reduction techniques are useful for regular monitoring of criteria used in PDM. Criteria weight and measured criteria values change correlation analyses may be used for more formal evaluation of the resulting criterion weighed rank performance. Finally, data mining methods, i.e. association rules mining, and inductive logic programming may be used for the discovery of hidden patterns.

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Network Supplemented by Wireless Sensors. 1. Overview.

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Abstract. As new wireless technologies become more and more advance so does their expanse of applications. Among other new and innovative wireless network, 802.15.4 standard has emerged as highly flexible and dynamics facets that are being deployed in almost wireless sensors networks. The Zigbee technology has the powerful integration degree of society habits. We must be clear when talk about "smart" definition otherwise we can't understand what is "smart" sensor or network. Review represents smart things which describe wireless sensors network.

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Keywords: wireless sensors; Zigbee.
Short title: Wireless Sensors. 1. Overview.

Introduction

Rapid improvement of silicon technology in the nineties led to the development of especially favourable conditions for the installation of a greater variety of digital solutions in mobile communication systems. These solutions include the creation of low noise transistors which are able to receive very weak signals, as well as creation and development of new fully digitized, low power standards for mobile communication systems. The usage of digital signals in the radio channel allows to efficiently use time-division and code multiplexing. Such technological step provides the conditions for the development of M2M technological progress, which in these days is very significant and has exciting prospects. M2M includes technologies, which are linked with electronic devices by wireless and cable communication.

The analysis of wireless networks of sensors reveals that the technological process is not advanced. It is distinguished for high energy consumption, capability limitations, short operational range, control reachability and versatility, and the price which is especially relevant in the Lithuanian market. Many producers rely on their own patented technology or franchise; therefore, artificial barriers for electronic device flexibility are created and the competition is distorted.

IEEE 802.11x radio communication family of exceptional success provides new possibilities not only for the fulfilment of individual needs, but also creates the grounds for the appearance of radio communication systems that work on the same high frequency and are oriented towards energy minimisation and simple design of wireless networks. This technology, which is defined by IEEE 802.15.4 standard, is known as *Zigbee*.

Review represents smart things which describe wireless sensors network.

1. Overview of IEEE 802.15.4 standard

Zigbee technological concept defines the lowest levels that are defined by IEEE 802.15.4 standard, which was approved in 2003 [1]. During the decade, it was adjusted and supplemented. However, the specifics of physical and MAC level formation technique did not change. Twenty-five international companies initiated the creation and development of IEEE 802.15.4 standard [2]. Looking at the prospects of 2015, the electronic devices of IEEE 802.15.4 standard will be accessible to 50Low price and especially low energy consumption are the main drivers of developing infrastructure. Highly specialized *Zigbee* standards are already being distinguished and perform certain functions [2]: "ZigBee Building Automation", "ZigBee Remote Control", "ZigBee Smart Energy", "Smart Energy Profile 2", "ZigBee Health Care", "ZigBee Home Automation", "ZigBee Input Device", "ZigBee Light Link", "ZigBee Retail Services", "ZigBee Telecom Services", "ZigBee Network Devices".

When detailing *Zigbee* technology, the following specifications can be distinguished [1]:

i) depending on frequency used, the speed can be 20 kbit/s, 40 kbit/s, 250 kbit/s, with a possibility to increase it up to 625 kbit/s;
ii) the devices communicate with each other directly or by using the principle of ring topology;
iii) 16 bit or 64 bit addresses are formed;

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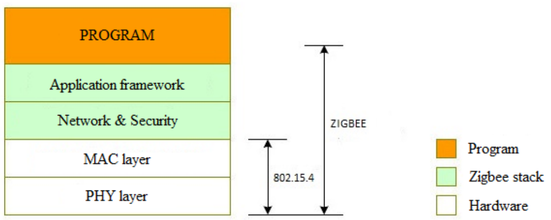

Fig. 1. "Zigbee" protocol.

iv) CSMA-CS algorithm is executed;
v) standardized response protocol;
vi) battery longevity function;
vii) channel quality identification;
viii) energy authorization;
ix) 27 channels are utilized to operate in three frequencies;
x) the devices could be described as fully or partially standardized;
xi) network hierarchy levels are formed accordingly.

IEEE 802.15.4 standard is defined by physical and MAC levels that define technical architecture of the device. The remaining three levels digitally complement "Zigbee" protocol, see Fig. 1. The network and safety and the program construction levels are oriented towards digitization processes that supplement the part of the protocol with specific *Zigbee* parameters. The other part is freely improvised in the creation process, i.e. the mechanics of the program. Namely, the mechanics of the program, i.e. the program of the higher level, provides *Zigbee* technology with flexibility and innovative inclusive solutions. It also should be mentioned that such standard is developed only in low rate wireless personal networks, where the need for minimal energy and low price are emphasized. Mostly the devices operating in such network are less capable of specific transfer and have limited power. Yet they are perfectly suitable to be used for longer intervals of time.

1.1. Physical Level

The physical level of IEEE 802.15.4 standard is responsible for the performance of certain tasks, which are as follows [1]:
i) coordination of transmitter's status;
ii) energy detection;
iii) evaluation of the accepted package channel quality;
iv) application of CSMA - CA algorithm;
v) selection of channel frequency;
vi) data transfer and reception.

Physical channel can operate in the following three frequencies [3]: 868 MHz, 915 MHz and 2.4 GHz. The whole physical level is divided into 27 channels that are sequentially allocated according to the operational frequency - see Fig. 2.

The so-called *Binary Phase Shift Keying* (BPSK) is used for channels [0÷10] [3]. The *offset Quadrature Phase Shift Keying* (O-QFSK) is used for the remaining channels working on 2.4 GHz operational frequency [3]. According to Ref.

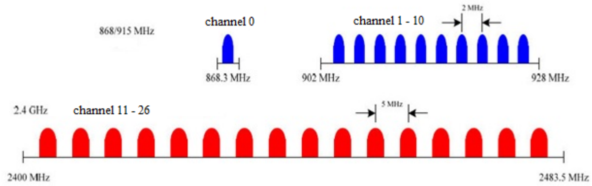

Fig. 2. Layout of radio channels in IEEE 802.15.4 standard.

[1], if you need to calculate the central frequency of operational channel (so called F_c value) you need to use simple equation.

868 MHz: only the channel zero is used,

$$F_c = 868,3 \quad [MHz]. \tag{1}$$

915 MHz: one of ten channels [1 ÷ 10] needs to be selected for the k value:

$$F_c = 906 + 2(k-1) \quad [MHz]. \tag{2}$$

2400 MHz: one of sixteen channels [10 ÷ 26] needs to be selected for the k value:

$$F_c = 2405 + 5(k-11) \quad [MHz]. \tag{3}$$

In order to detect the receivers, 0÷10 signal channels of IEEE 802.15.4 standard have to be provided with sensitivity, which is no less than 92 dBm [4], and for the [11÷26] channels, the sensitivity has to be no less than 85 dBm. The weakest signal transfer strength could be 3 dBm, and that is actually 0.5 mW [4].

$$dBm = 10 * \log_{10}\frac{P}{1mW} \tag{4}$$

The largest signal transmission radius is up to 75 meters. However, there are negative aspects as well, since the maximum length of physical level useful package is restricted to 127 bits. Moreover, specific parameters are set for each region, and they are defined by standards described in Ref. [1] - see Table 1.

1.2. MAC Level

The MAC level of IEEE 802.15.4 standard is defined as logical interfaces and acceptance controls [1]. When analysing IEEE 802.15.4 standard, data reception control shall be equal to data interface level, since the logic control of the interface is defined by IEEE 802.15.4 standard [4]. The level of access control is responsible for the structure of the signal. It controls access signal, transmission of confirmations, etc. The reception level of IEEE 802.15.4 standard is suitable to implement the low power operations and safety mechanisms.

The main tasks of MAC level could be formulated as presented below.

Table 1. Basic physicals parameters of IEEE 802.15.4 standard for several regions. Adapted according to Ref. [6].

Region	Organization	Specification
Europe	European Telecommunications Standards Institute (ETSI)	ETSI EN 300 328-1 [B11] ETSI EN 300 328-2 [B12] ETSI EN 300 220-1 [B10] ERC 70-03 [B13]
Japan	Association of Radio Industries and Businesses (ARIB)	ARIB STD-T66 [B14]
USA	Federal Communications Commission (FCC)	FCC CFR47, Section 15.247 [B14]
Canada	Industry Canada (IC)	GL36 [B15]

Frequency, MHz	Spectrum width, MHz	Quantity of channels	Maximum speed, Kbps	Modulation type	Region
868	868 ÷ 686,6	1	20	BPSK	Europe
915	902 ÷ 923	10	40	BPSK	America, Australia
2400	2400 ÷ 2483,5	16	250	O - QPSK	Cover all regions

i) to ensure network functionality when the device acts as a coordinator;
ii) to synchronize communication between devices;
iii) to maintain the functions of network allocation and disconnection;
iv) too ensure security of transferred packages;
v) to implement unique functions and algorithms (such as CSMA-CA, GTS...) of 802.15.4 standard;
vi) to ensure uninterruptible connection between other levels, services.

Most of the processes that take place at the MAC level will be discussed in the later sections that deal directly with the higher levels, since the service which is running at this level has to link the transitional processes that take place at the levels. We are not only talking about the checking of the package, but about formation, security and other important parameters and processes as well.

2. Zigbee network

Fig. 3 represents topology diversity of *Zigbee* network. By analysing the electronic devices that comply with *Zigbee* protocol, the following two types that are suitable for the implementation in the networks of such type can be distinguished:

1. Reduced functionality devices (RFD). Such devices have limited memory, low energy capabilities and perform elementary processes. The main condition for the devices of such level is as follows: they cannot perform the functions of the coordinator or router.
2. Full functionality devices (FFD). In the *Zigbee* network the devices of such type have the resources that can perform complex tasks; therefore, they usually have coordinator's or router's role. They are fully capable of performing all procedures of IEEE 802.15.4 standard.

During design of *Zigbee* network, i.e. when implementing "Zigbee" protocol, it is possible to insert the definitions of different hierarchy devices that perform a certain role in the network.

1. *Zigbee* coordinator. This device is responsible for the performance of the main functions, such as network creation, address allocation to the devices that exist in the "Zigbee" network, control during the network formation and while performing the operations. Only one device of such hierarchy can be in the network.
2. *Zigbee* router. The device of this type is equipped with resources with which it performs the route algorithms and advance messages to and from network devices.
3. *Zigbee* reliance centre. This is the core component in *Zigbee* security architecture. It is entrusted to the other devices that exist in the network. The main task of this centre is to provide reliability, device and network control with proper services. Such device is not used in local personal network, since all the needed infrastructure is implemented in higher levels of "Zigbee" devices.

Zigbee device. The simplest unit of *Zigbee* network hierarchy structure. Such electronic device barely meets *Zigbee* standard and is able only to accept and receive necessary data and information;

Zigbee bridge. The device of this type does not participate in the network processes and is only an interface for *Zigbee* network to transit to a network of another type. It often performs the protocol transformation for necessary network.

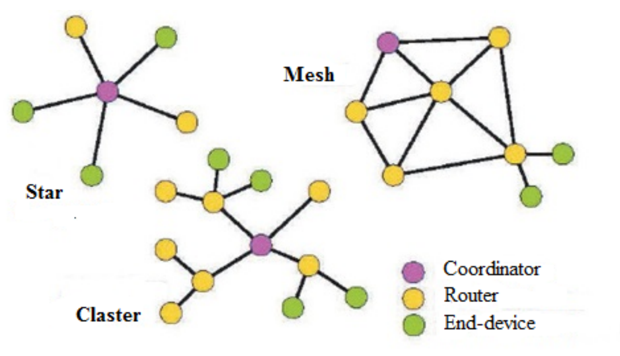

Fig. 3. Topology diversity of *Zigbee* network.

Table 2. Star, cluster, node topology according to Ref. [4].

Properties		Topology	
	Star	Cluster	Node
Advantages	Easy synchronization	Low routing costs	"Energetic", multi-hopping communication
	Low energy operations	Super-package formation	Flexible network structure
	Short time of delay	Multi-hopping communication	Short time of delay
Disadvantages	Small scale network	High costs of alternating routing	Inability to form super-packages
		Long delay time could occur	High costs of route finding
			Storage vault is required to store routing addresses

It should be noted that "Zigbee" network could have the star topology or be linear (the so- called node topology). Combining both topologies together, we could create structurally more complex network which usually is deemed as having a cluster topology. Every topology of "Zigbee" network has its specific advantages and disadvantages. Usually the network topology features different parameters and unique network formation algorithms.

Advantages and disadvantages of star, cluster and node topology [4] are presented in Table 2.

3. MRF24j40 chip. Overview of properties

MRF24J40 chip is a receiver of 2.4 GHz frequency that complies with the technical requirements of IEEE 802.15.4 standard. The lowest "Zigbee" levels, physical and MAC, are integrated in this receiver [6], see Fig. 4.

Such semi-conductor chip is described in the market as cheap wireless local personal network device which consumes little energy and transfers and receives data at low speed [250÷625] Kbit/s. This device is the product of "MICROCHIP" corporation, designed for the series of PIC microcontrollers. MRF24J40 is controlled with four SPI and three additional outlets: "RESET" (the outlet of chip's initial parameters), "INT" (chip events outlet) and "WAKE" (chip's awakening outlet) [6]. Not only all lowest levels of IEEE 802.15.4 standard are included in the solution of one chip, but also are technologically implemented solutions that describe "Zigbee" technical protocol [6]:

- i) energy detection;
- ii) function of channel sensitivity setting;
- iii) three CCA models;
- iv) implementation of CSMA-CA algorithm;
- v) automatic organization and transmission of confirmations;
- vi) automatic forwarding of sent package;
- vii) technological solutions that enable the super-package mode were created;
- viii) security engines that provide the possibilities of coding and decoding not only at the level of data transferring but at the higher ones, too.

Such multi-functionality of the chip reduces the load on the microcontrollers, due to which the energy costs diminish in the controlling semiconductor devices as well. MRF24J40 chip is ideally suitable to be used not only while creating *Zigbee* network, but also implementing the technological solutions of "MIWI" (the strain of *Zigbee* standard) or "MIWI P2P".

Fig. 5 represents the topology of MRF24J40 chip [6]. The external 20 MHz oscillator is the synthesizer of the required frequency. It ensures 2.4 GHz operational frequency. The signal reception circuit is created by using conditional architecture which is comprised of a low noise amplifier, recalculation mixer, multiphase channel filter and the basic stripe restriction amplifier with the received signal strength indicator (RSSI). The signal transmission circuit architecture is based on the 0 dBm maximum output and 36 dB range power controller [6]. Both transmission and reception circuits are combined by switching method and controlled by two chip outlets: RFN and RFP. The outlets of shared usage are used smartly: the access and transfer logics are being controlled (switched) through PA/LNA circuits.

The voltage regulator (LDO) is integrated into the whole energy management architecture to ensure the suitable conditions for the purposeful operation of the chip while receiving and transmitting the signals. Due to the internal 100 kHz or external 32 kHz tactical frequency generators, the MRF24J40 chip can switch into sleep mode, where the current needs are only 2μA. It should be noted that the structure of this chip's memory is comprised of short 8 bit and long 16 bit registries. Short registries are used for the parameters of MRF24J40 chip. Long registries are used not only to control the parameters, but also to upload security keys, store received and transferred information. This semiconductor device has 4 different 128 byte transfer buffers, depending on the selection of IEEE 802.15.4 standard type, and one 144 byte

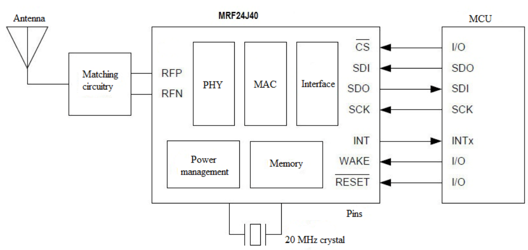

Fig. 4. MRF24J40 chip block diagram. Adapted according to Ref. [6].

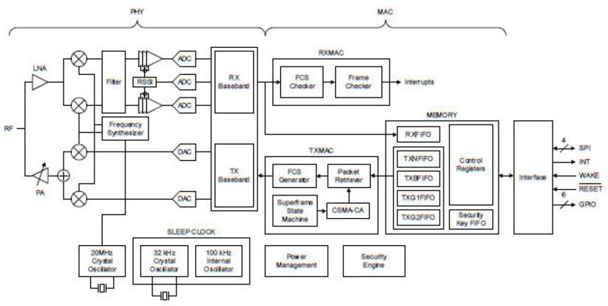

Fig. 5. Topology of MRF24J40 chip. Adapted according to Ref. [6].

reception buffer [6]. As it was mentioned before the registries are accessed via SPI bus.

4. What is a sensor?

Usually the sensors are the part of electronic equipment which converts certain changes into the signal known to the receiver. The function of the sensor is informational, since the main process is to identify the changes of temperature, motion, pressure, humidity and other parameters. Many electronic devices are full of various sensors that ensure proper functionality of the device. Nowadays smart phones, security systems and other processes that surround us simply will not be technologically implemented without sensors.

The main sensor need is of the thermal nature, when the thermal energy is converted into electric, or when due to the thermal change the signal or current or voltage values change. It should be noted that the whole electronic circuit which generates the scope of influence is being considered as a sensor - see Fig. 6. Fig. 7 represents the principal design of sensor in the network chain.

However, nothing is ideal in nature; therefore, the holes and electrons in the electronics act differently, as such creating sensor deviations [5]:

a) theoretical sensitivity differs from the real one - linear deviation is called the error of sensitivity;
b) stability of measurement result interval;
c) zero value of input sensor;
d) instability of sensitivity throughout the range - nonlinear deviation;
e) dynamic tolerance;
f) output signal slowly changes despite the outside influence;
g) long term drift;
h) noise influence;
i) occurrence of hysteresis;
j) digital tolerance;
k) dynamic errors due to repeatable frequencies;

All these deviations are divided into systemic and random errors [5]. Systemic errors can be corrected with calibration methods, while the random errors can be corrected by using various filters or other components that reduce noise.

All sensors are divided into two groups: natural and biological [5]. The following items can be considered as natural sensors:

i) sensors of external setting effects: temperature, motion, humidity;
ii) sensors of internal setting effects: tension, movement of organism;
iii) environmental molecules: toxins;
iv) interaction of biomolecules and kinetic parameters;
v) internal setting of metabolism;
vi) internal signalling molecules: hormones...;
vii) differences between proteins in the organisms and the formation of protein structure groups.

5. Sensors network

Networks of wireless sensors are the systems of new type. The interest in such networks rapidly increases due to the independence and smartness of the network. It has great potential for the processes, like smart electricity networks, energy conserving buildings, smart house concepts that require large programs. Despite big demand for smart services, there still is a lack of suitable analysis and calculations - practical knowledge, energy conserving schemes and autonomous algorithms in the networks of wireless sensors. Recently the progress of dynamic spectral access was achieved. Cognitive radio, wide and cooperative communications will perform an important role in the structure of advanced wireless networks. The following requirements that properly describe the networks of wireless sensors are distinguished [7]:

i) smart protocols of design and organization;
ii) energy consumption issue;
iii) smart zone of implementation/visibility;
iv) security and privacy issue;
v) smart applications that include appropriate network functionality logic;

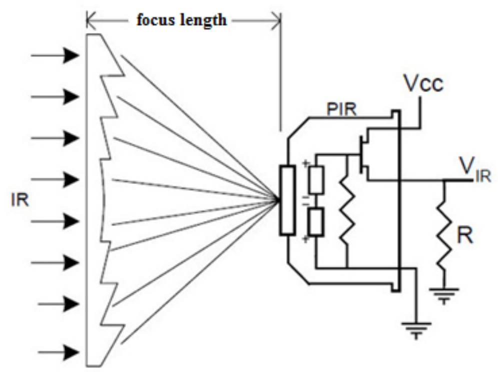

Fig. 6. IR sensor.

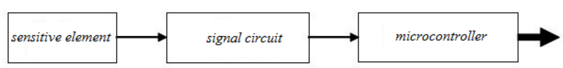

Fig. 7. Principal design.

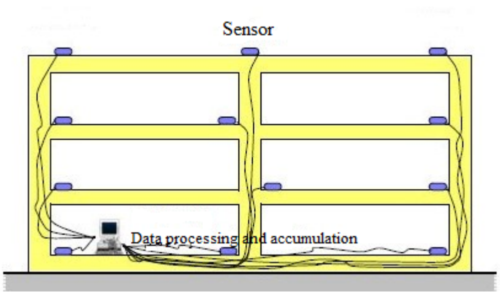

Fig. 8. Basic sensors network.

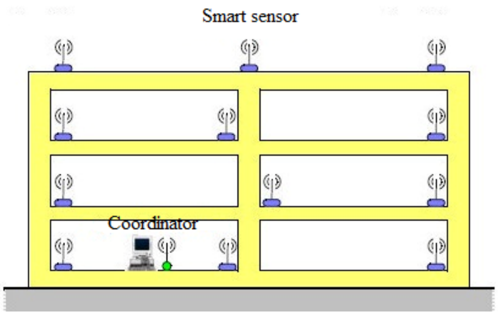

Fig. 9. Wireless sensors network.

Talking about the networks of wireless sensors, firstly we should ascertain the integral part of the network, i.e. the sensor. Sensors in wireless network systems can be only smart since such sensor has the microcontroller which can perform many digital, data transfer and other functions [7]. Basically, the appearance of microcontroller gave the start to the development of smart sensors.

In 2001, Kiremidjian presented wireless sensor network which works in real conditions. This network was one of the first systems that complied with all requirements. In addition, smart sensor self-diagnostics and self-calibration became its main innovation which allows the user to completely distance himself from the implementation of sensor functionality - the data are no longer stored on the computer, the signals are no longer processed by specific developed computer applications [8], see Fig. 8.

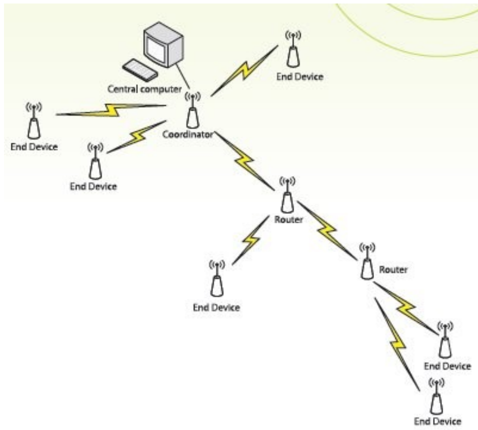

Fig. 10. Basic topology of wireless sensors network.

Usually the structure of the sensor wireless network is comprised of three types of nodes and the access to the internet or data vault [7]. The simplest network node is a smart sensor, which transfers information to the other point, until the intermediary (local data) vault is reached. From the local data vault the contact can be made with another type sensors or wireless networks. In 2001, Evans presented a set of alternatives how wireless network systems could be implemented - see Fig. 9.

The main reasons were to use free frequencies of 2.4 GHz and 915 MHz. Such reflections have determined the appearance of energy conserving wireless networks that comply with "Zigbee" technology - see Fig. 10.

Conclusions

1. The designed electronic device uses approximately 4 mW of energy.
2. The electronic device can play the role of the coordinator, router and common device without the alteration of electronic circuit board and software.
3. The energy needs of electronic device (sensor) are three times lower than those of commercial sensors.
4. After the use of energy conservation activities, it was possible to reduce energy consumption costs by six times.

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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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Keywords: wireless sensors; Zigbee.
Short title: Wireless Sensors. 2. Realisation

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-

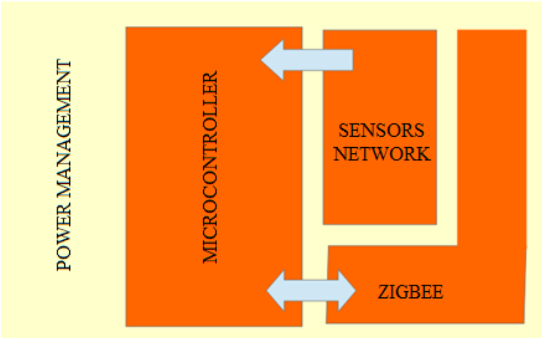

Fig. 1. Simplified topology of smart sensor.

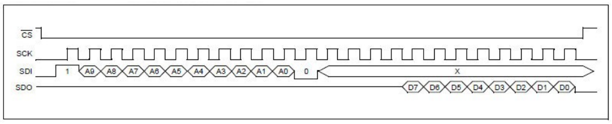

Fig. 2. Time diagram of long reading register

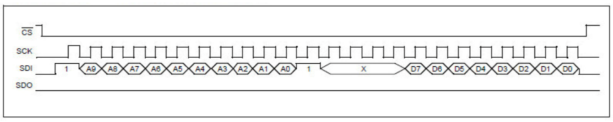

Fig. 3. Time diagram of long writing register.

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

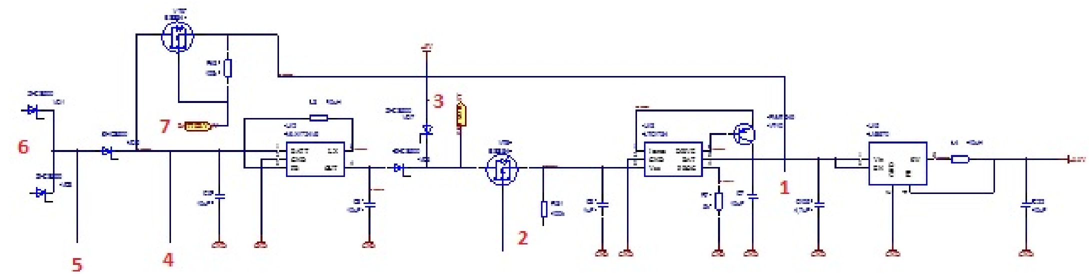

Fig. 4. Basic energy supply electronic circuit.

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,

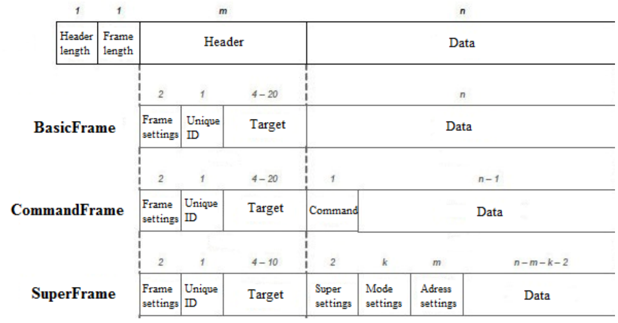

Fig. 5. Packages structure in MRF24J40 module.

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

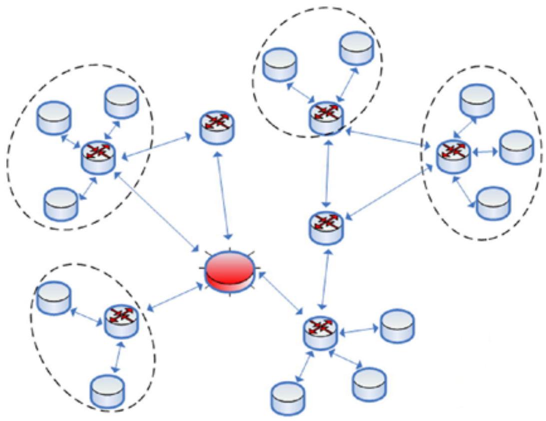

Fig. 6. Topology of cluster.

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.

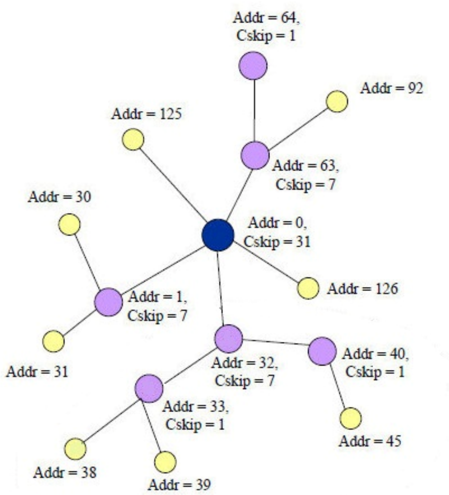

Fig. 7. The structure of Zigbee network device addresses, where the parameters of the network are: C_m =6, R_m = 4, L_m = 3.

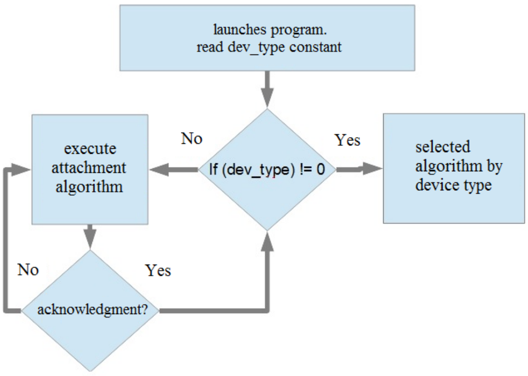

Fig. 8. Hierarchy checking and allocation algorithm.

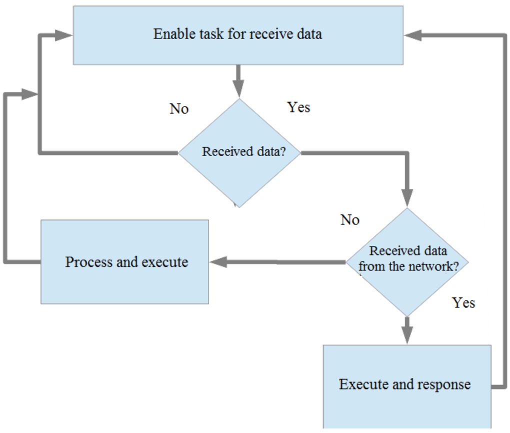

Fig. 9. The minimized structure of coordinator algorithm.

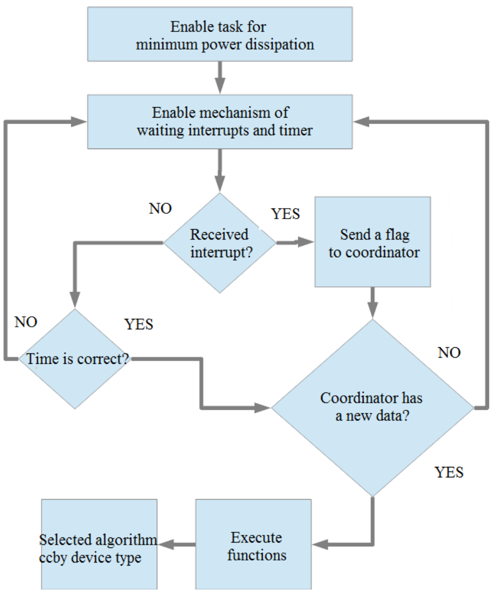

Fig. 10. The minimized structure of the lowest hierarchy device algorithm.

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.

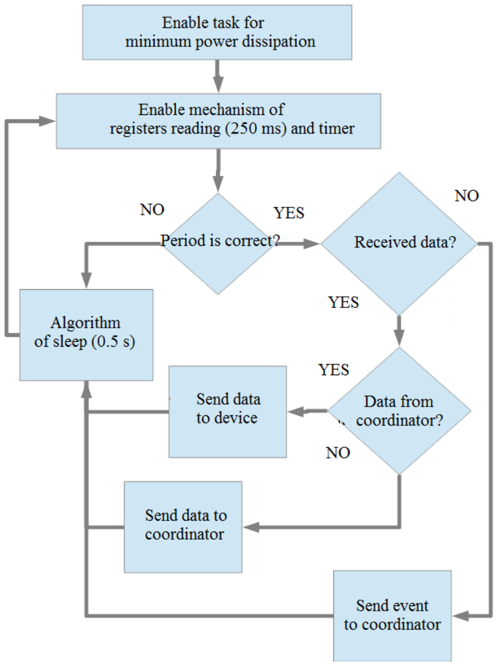

Fig. 11. The minimized structure of the router algorithm.

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:

$$0 \leq AD \leq SD \leq 14, \quad (5)$$

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

$$AT_{sym} = 960 * 2^{AT} \quad (6)$$

$$ST_{sym} = 960 * 2^{ST} \quad (7)$$

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:

$$ST = [(MainCnt * SleepClk) + B]ms \quad (8)$$

$$B = [RemCnt * 50ns], \quad (9)$$

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.

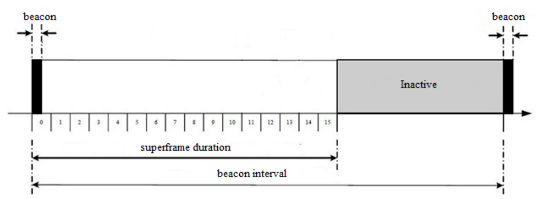

Fig. 13. Super-package structure of Zigbee protocol.

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:

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

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

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.

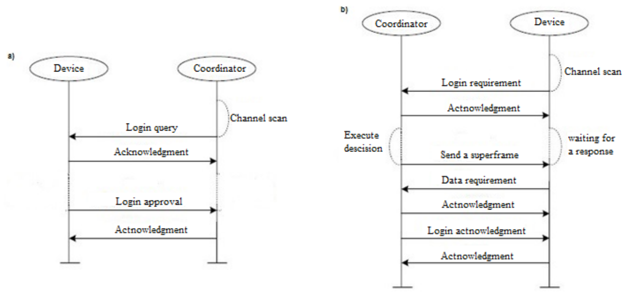

Fig. 14. Device connection procedure scheme of principle to network: a) ADD_NETWORK_TOPOLOGY(unsigned char *address) algorithm; b) IEEE 802.15.4 standard.

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

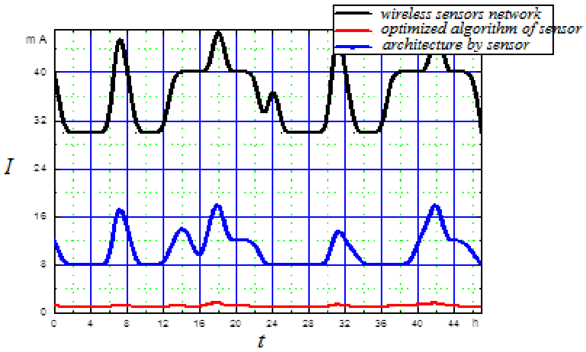

Fig. 15. The current consumption dependence on the time.

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%.

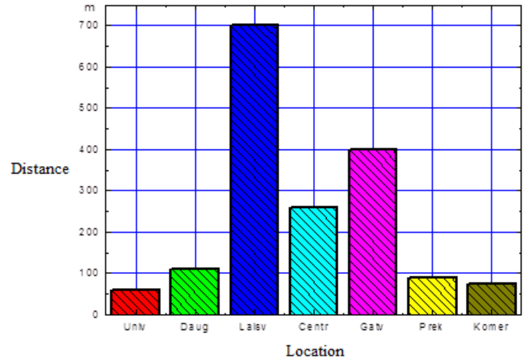

Fig. 16. The maximum data transfer distance of Zigbee sensor (electronic device):
Univ (Vilnius university, faculty of physics),
Daug (Antakalnis apartment building),
Laisv (field outside the city limits),
Cent (Rotušė Square),
Gatv (Zolynas street),
Prek (shopping and entertainment mall "PANORAMA"),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