Transfer and Validation of Adaptive Method for Assessing the Life Expectancy of a Wireless Sensor Network in Smart Environments Applications

Aleksejs Jurenoks, Viktorija Ponomarenko, Leonids Novickis

Abstract— Technology transfer is a bridge between research organizations and industry. It is an important task to find right way how to present a new technology for the audience. This paper describes the conditions of the distribution of network nodes and determines the basic coefficients that affect the overall life expectancy of a wireless sensor network. The goal of this research is to validate the provided methods for calculating the lifecycle of the main nodes in a wireless sensor network to be transferred to the market. To achieve this goal was applied technology transfer model developed during the Baltic Sea Region INTERREG Program project. First results of validation are presented in this paper.

Keywords— Technology transfer; Sensor networks; Validation.

I. Introduction

The process of Technology Transfer is a normal practice nowadays. There are various ways and best practices how to organize this process.

The term of Technology Transfer can be understood as information flow from the sender to receiver with two main processes: transmission and absorption [13, 14, 19]. Scientific centers and Industry have bipolar relationships. An economy can lose its competitiveness without innovation, but scientific findings must find their end-users. An interaction between them help to understand needs of market, areas for research and thus get new solutions for problem field.

More institutions are concerned with the problems of processing real time data every day. The bigger the data flow, the longer the processing time is necessary. According to IDC data in year 2008 information data size of "digital universe" was 1,6 ZB and it will be increased at least twice to year 2019 [18].

In order to assess the life expectancy of a wireless sensor network, a method has been developed, which allows determining the maximum amount of iterations in the network using individual assessment of life expectancy of the nodes during the time of structure function as well as using the factors affecting the quality of the transmitted information.

Therefore, this article discusses the developed method of sensor network, which allows to assess the life expectancy of network by using the way of working of each network element and it's validation in context of technology transfer to business environment.

II. Related Works

The number of studies relating to problems on expanding the life expectancy of a wireless sensor network has recently increased. The modern research can be divided into two categories:

1) Research related to the modeling and optimization of data flow [2, 9].
2) Research related to the improvement of the technical characteristics of a wireless sensor network for increasing the life expectancy of a network. The main drawback of a wireless sensor network is the low power battery, which significantly limits the life expectancy of a network. At present, there are a number of methods that allow solving this problem [2, 6, 17].

Relatively recently, a new method for balancing energy through the mobility of the network coordinator node has been offered [22], which provides the opportunity of dynamic network reconfiguration or, in other words, the change of network topology.

However, the main drawback of this method of study is absence of mathematical model of the dynamic network.

III. The Concept of Wireless Sensor Network

A sensor network is a well-known wireless network with the possibility of reconfiguring the network nodes, which consist of small dimension intellectual sensor devices [11]. Each device is equipped with a central low-power computing processor, radio transponder, power supply and with the necessary sensors in order to make any external environment measurements (e.g. temperature, brightness of light, vibration, pressure, sound level, etc.).

The sensor networks are part of the "situation based" network category (ad hoc) [23] consisting of equally distributed nodes where each node can exchange data (converse) with other adjacent nodes. The largest technical feature of the sensor network is the ability to accurately divide the network elements according to the operational tasks through the criteria assigned to a node.

Any sensor network has three types of nodes - terminals, routers, and data collectors. Let us assume that the data collectors do not affect the lifecycle of the overall system because they are provided with independent power supply or are equipped with a much more powerful autonomous power supply. Currently, there is a variety of creators/indicators of network lifecycle.

The concept of a sensor network provides that any network node uses an independent power supply. Any network element performs certain tasks in the common network, which according to the network scenario, are pre-programmed (Fig.1).

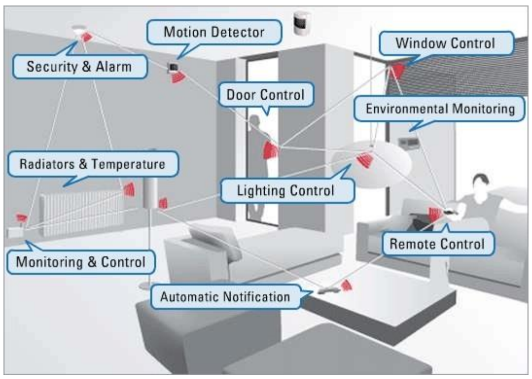

Fig. 1. The concept of smart environments wireless sensor network in smart house.

According to wireless sensor network technical information [1] the power consumption of individual elements depends on several factors to consider when designing networks:

- The technical parameters of node;
- Frequency of data collection;
- Physical and channel level protocols;
- Network topology;
- Use of routing protocol.

Nowadays, a wireless sensor network is one of the most promising directions of development of communication networks in smart environments applications.

IV. CALCULATION OF CONSUMED ENERGY PERTAINING TO THE NODES OF SENSOR NETWORK

As it was proved in other paper [10] wireless sensor network nodes can be seen as active for as long as they are capable of reading the information from the sensors correctly as well as transferring it to the coordinator node within a network. Whilst developing the network it is necessary to timely assess the approximate duration of each network element until the element requires battery replacement.

Let us consider the terminal and the router life expectancy assessment method. It is based on some assumptions:

- The operating algorithm of the network nodes is strictly determined. In case the system is affected by external factors, there is a clear mathematical reasoning for any changes in the methods.
- There are no battery renewal options. If there is such a possibility, it can be used by increasing the size of the initial amount of energy. As a result, knowing the initial amount E_0 of battery energy as well as the total power ΔP used by the node, the life expectancy of the system is defined as $t = \frac{E_0}{\Delta P}$.

A. *The Terminal Life Expectancy Assessment Method*

The terminal node of the sensor network is intended to reading information from the sensors for the further transmission of data in the network.

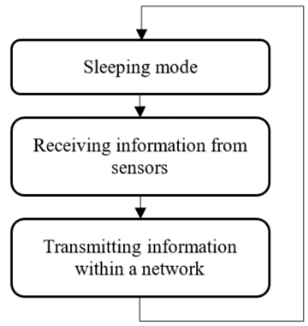

Fig. 2. The operating algorithm of the terminal node.

The main difference in the node from the router is the impossibility of information transmission. This means that the terminal node does not use power and time for reception of information.

Using an event-based or list-based model, node uses a cyclical activities scheme (Fig. 2).

The consumed terminal energy in one operating cycle of the system can be defined by the following formula:

$$P_{\text{term}} = P_{\text{tx}} t_{\text{tx}} + P_s t_s + P_a t_a, \quad (1)$$

where P_{tx}– the average conumed energy in the transmission mode; t_{tx} – time required for the information transmission in the network; P_s – average power consumed in a sleeping mode; t_s – time in which the system is in the sleeping mode; P_a– consumed power on processing of data (reading the information from sensors); t_a – time intended for processing the information.

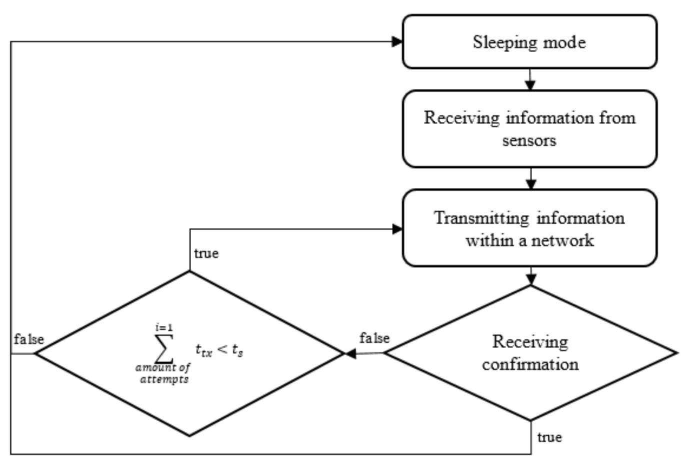

Fig. 3. The terminal operating algorithm with error validation.

It is assumed that $t_{tx} + t_a > t_s$, which means that the system has sufficient time to be in the sleeping mode. The value of parameters is determined by the technical data of processor and properties of software algorithm (Fig. 3.)

B. The Router Life Expectancy Assessment Method

It is known that in sensor networks oriented on events, which use asynchronous data access environment, a router is the weakest point regarding the duration of lifecycle of the system [12].

It is based on the fact that a node spends very little time or at all does not spend time in the sleeping mode, but consumes power to receive information from the network and transmits information to a network.

The total power consumption of the router depends largely on the selected routing protocol that in the end determines the table of service data flow for safety.

A router has four operating conditions: t_s – sleeping mode of the system, t_s – information reception from a network, t_{tx} – information sharing in a network, t_a – reading the information from the sensors.

Since the performance of the network is highly determined, it can be considered that the router $\Delta t_{rx} + \Delta t_{tx} \leq t_s$. While transmitting the information, an error may appear in the network; consequently, it will take more time to send and receive data. As a result, it is necessary to introduce an additional parameter p_e – percentage denoting error probability.

The amount of time the system spends to receive all the information is equal to:

$$r_{\mathrm{rx}}(T) = \sum_{i=1}^{n} t_i{}^T I_i, \tag{2}$$

where $t_i{}^T$ – the time necessary for the reception of information from one terminal; I_i – the intensity of data flow, n – number of iterations.

The amount of time that the system will spend to send the information in the network is equal to:

$$r_{\mathrm{tx}}(T) = \sum_{i=1}^{n+1} t_i{}^T I_i, \tag{3}$$

There is a situation when the system is not able to transfer all the necessary information that has been received by the node $r_{rx} > r_{tx}$. Before the information is received the system checks whether there will be sufficient time for transferring the information.

When planning the router load, the total lifecycle of the router Δr must be taken into account.

$$\Delta r < p_{\mathrm{e}}(r_{\mathrm{rx}} + r_{\mathrm{tx})} + r_{\mathrm{a}}, \tag{4}$$

where r_a –the time consumed by the system to receive information from the sensors.

Let us consider the situation $r_{rx} + r_{tx} + r_a \leq r_s$, when the router is able to fulfill its task and transfer the information to the network. In this case, the router's power consumption will be equal to:

$$P_{\mathrm{m}} = P_{\mathrm{a}} r_{\mathrm{a}} + P_{\mathrm{tx}} r_{\mathrm{tx}} + P_{\mathrm{rx}} r_{\mathrm{rx}} + (r_{\mathrm{s}} - r_{\mathrm{tx}} - r_{\mathrm{rs}}) P_{\mathrm{s}}, \tag{5}$$

where P_{tx} – the average power of router in the transmission mode, P_{rx} – the average power of router in the receiving mode, P_a – the average power of router receiving information from sensors, P_s – the power of router in the sleeping mode.

C. The Impact of Operating Range on the Work of the Terminal

It is known that the system consumes certain power for the transmission of data to the maximum distance [10]. Using the formula for determination of radio signal amplitude provided by Boris Vvedensky, it is possible to determine the admissible maximum distance to which the information can be transmitted.

$$E_{\mathrm{np}} = \frac{4\pi\sqrt{PG}}{\lambda r^2} h_1 h_2, \tag{6}$$

where: E_{np} – wave amplitude in the receiving point; P – power coefficient of router; G – coefficient of wave amplifier; λ – wavelength; r – distance of radio communications; h_1, h_2 – height to which radio antenna was lifted.

It is assumed that all network nodes in our system use antennas of the same type and do not use additional intensifiers; thus, the simplified formula can be used:

$$E_{np} = \frac{4\pi\sqrt{P}}{\lambda r^2}. \tag{7}$$

Changing the distances of network node, it is important not to lose the quality of signal. It is assumed that in case of increasing the distance the E_{np} value will remain unchanged. As a result, the P_k coefficient of consumed power pertaining to router is equal to:

$$P_k = \frac{E_{np}{}^2 \lambda^2 r^4}{(4\pi)^2}. \tag{8}$$

When planning the operation scheme of sensor network there is a possibility to equalize the consumed power of network element by adapting the power of transmitter and operating range to a certain network segment. This approach will allow equalizing the total duration of lifecycle pertaining to nodes by decreasing the amount of energy left out in the nodes.

As a result, the consumed power of router while transmitting the information in the network is equal to:

$$P_{tx} = \begin{cases} P_{tx}, & K_r <= 1 \\ P_{tx} \frac{E_{np}{}^2 \lambda^2 K_r{}^4}{(4\pi)^2}, & K_r > 1 \end{cases} \tag{9}$$

where K_r – the coefficient of working range against the standard working range.

V. THE ALGORITHM OF THE MODEL FOR ASSESSING THE LIFE EXPECTANCY OF A WIRELESS SENSOR

Let us consider the assessment task of the life expectancy of a wireless sensor network. The task at hand is to assess the life expectancy of the network N, considering the starting amount of energy in all nodes P.

The life expectancy of a network depends on the selected network topology determined by the location of the network coordinator. Let us suppose that the coordinator in the given network is static and network uses the same amount of energy in each node.

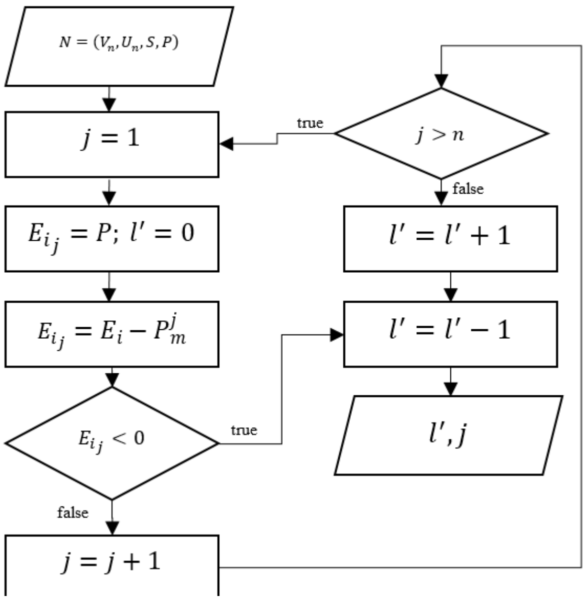

Fig. 4. The algorithm for defining the maximum number of iteration in the network.

The first step is to calculate the remaining amount of energy in the network nodes when the coordinator gathers information from the network l nodes:

$$E_{r_i}(l) = E_i - (\sum_{j=1}^{l} P_m), \tag{10}$$

where $E_{r_i}(l)$ is the remaining amount of energy considering the number of node i.

The assessment of the WSN life expectancy depends on the performance scheme of a network and coordinator position in it. The network will cease to function when at least in one of the nodes the remaining amount of energy is $E_r \leq 0$.

Let us consider the algorithm (Fig. 4) that allows setting the maximum number of iterations in the network until at least one of the nodes stops functioning.

As a result, the algorithm refers to the maximum number of iterations that a network can execute provided that the data is collected every time when the coordinator node activates in the network or if it changes the position in the network.

Let us consider the case when it is impossible to predict the possibility and time of the coordinator movement and how long the coordinator will be in each position. If there is a possibility to change the time in which the coordinator stays in any position, it is necessary to choose any position k which will allow the network to operate effectively without changing the network topology as long as possible within time Δt:

$$\exists k \in \max_{j\in[1..m]}(\min_{i\in[1..n]} \frac{E_{r_i}}{p_j^i}) \tag{11}$$

As a result, the life expectancy of the network will be determined on the condition that the coordinator is in position k and the network is able to function as long as all the elements are active $T_n^n = min_{i\in V_n} T_i$, using the algorithm shown in Fig. 5.

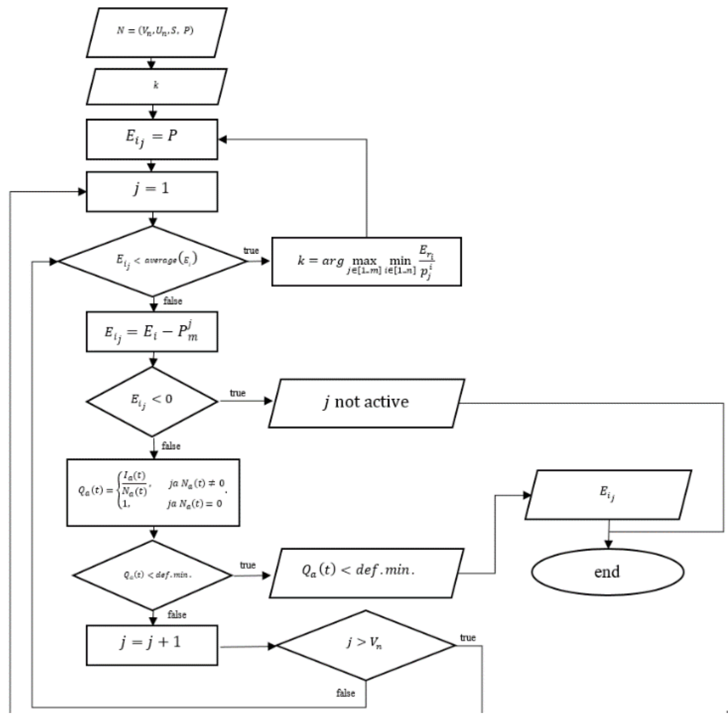

Fig. 5. The algorithm for evaluating the network life expectancy through the network topology change.

While the network is functioning there is time when it is necessary to perform the change in the network topology. The topology change can be promoted by the change of the coordinator location within the network as well as by the network node management module.

When the algorithm for assessing the life expectancy is executed, in the beginning the coordinator is located in position k. The amount of initial energy in all the nodes is defined in the WSN model $E_{i_j} = P$. The network operates using the generated topology as long as the remaining amount of energy in each node is not less than the average amount $E_{i_j} < average(E_i)$ of energy in the network. If necessary, the network performs the topology change locating the coordinator in a position at which the network is able to function as long as possible without changing the topology.

VI. TECHNOLOGY TRANSFER MODEL

Technology Transfer Model applied the results of developed models and standards in the domain of software engineering.

The research was based on concepts which developed from capability maturity models [3, 4, 15] Carnegie Melon University Software Engineering Institute was elaborated it since 1987. These concepts have expanded into CMMI 1.3 version known as CMMI for Services, CMMI for Development, CMMI for Acquisition and International Standard for process assessment ISO/IEC 15504 [8, 16] initiated by Ministry of Defense of United Kingdom in 1991 and become known as project "Software Process Improvement and Capability determination" (SPICE). And the last key source in the capability maturity process is integrated Capability Maturity Model (iCMM v2.0) [5, 7] developed by United States Federal Aviation Administration and guiding to the model integration issues and representation of architecture. It had an essential influence on the current framework of CMMs and is along the same lines as SPICE and CMMI models. The convergence of ISO/IEC 15504 and iCMM models is finished by the Enterprise SPICE and the first results of the standard are public available.

The method used here is the "white box" approach, i.e. the technology, innovation, and knowledge transfer activities are decomposed into process set and their descriptions of performance.

A capability maturity model can be interpreted as knowledge oriented codified process. The process of capability maturity modelling can be treated as a system of notions, method, best practice, tool etc. It allows the equally the knowledge systematization of process-oriented activities and the real performed activities description by an institution [20, 21]. The core processes of the ICT transfer capability maturity model cover following processes:

1. Method for Assessing the Life Expectancy of WSN generic transfer concept.
2. Initial market assessment of target group
3. Evaluation for transfer suitability to target group
4. Analysis of components to be transferred to target group
5. Determination of intellectual property protection of Method for Assessing the Life Expectancy of WSN
6. Market and competitive analysis
7. Value evaluation of methods components
8. "Go To" market estimation
9. Confirmation of transfer interest of Method for Assessing the Life Expectancy of WSN to be transferred to target group
10. Business case establishment
11. "Go To" market strategy establishment
12. Business plan establishment
13. Financing sources raising for Method for Assessing the Life Expectancy of WSN to be transferred.

The set of questionnaires for validation of findings of Adaptive Method for Assessing the Life Expectancy of a Wireless Sensor Network have been created.

VII. THE VALIDATION OF LIFE EXPECTANCY ASSESSMENT METHODS USING TECHNOLOGY TRANSFER MODEL

A. The Aim of the Validation

- To check the wireless sensor network life expectancy assessment method proposed in this paper using the created sensor network of water / air temperature, water flow and water pressure control.
- To validate developed method transfer from research to business environment.
- Identify method transfer readiness to be implemented in business environment.

B. The Object of the Validation

The object – a wireless sensor network provided by the company Syxthsense consisting of 54 terminal nodes Syxthsense TX-VTRX TX, 17 routers Syxthsense as well as 1 coordinator node ModBusMaster RX JaCe. Each node operates using 2x1.5V (AA) type batteries. The network topology is defined manually and is constant for the entire duration of the network.

C. Validation process

The validation process was based on communication with potential end-users and method developer with the help of questionnaires.

Two levels of questionnaires for validation are applied. First is model level questionnaires or list of questions for complete technology transfer process model. Second level is process level or simplified list of questions oriented on potential end-user based on one generic process of technology transfer

There were elaborated technology aspects important from the user point of view. More important aspects to user needs are:

- Method description
- Important method features
- Technologies characteristics
- Benefit for technology users.

D. The Summary of validation Results

The method developer answers on the questions from the questionnaire about performance of corresponding base practice were rated in four grade: fully performed (100%), largely performed (75%), partly performed (50%) or not performed at all (0%).

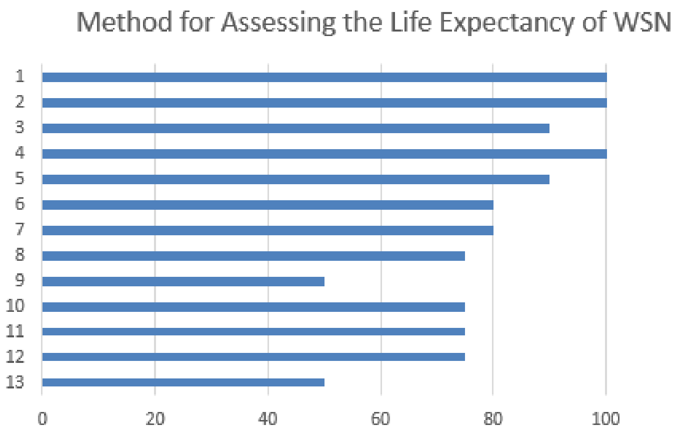

Fig.6 Method for Assessing the Life Expectancy of WSN transfer process capability profile

Evaluation of method for assessing the Life Expectancy of WSN provided in Figure 6 demonstrates that most defined processes are largely performed and method is ready to be transferred to the business needs.

8. CONCLUSION

The article describes the developed wireless sensor network life expectancy assessment method, which allows to evaluate the lifecycle of each network element and to determine the overall lifecycle of the network using the developed structure of network. Described method is design to fit any Wireless sensor network devices that are using IEEE 802.15.4 transmission protocols. Additional protocol changes structure need to be taken to use it with any 802.x technology. This approach differs from the others with as follows:

- description of each element of network by using the quantity coefficient of the consumed power;
- using the coefficient of object-range transmission for calculation of power;
- uses the coefficient of changes of network configuration and determines the denial of time pertaining to the system.

The Terminal Life Expectancy Assessment Method method was validated by technology developer and potential end-users. The proposed model of transfer from scientific world to the business sector was successful applied for this purpose.

The validation of Assessment Method transfer was based on the set of corresponding questionnaires:

- Developer assessment of technology transfer process capability
- Potential end-users estimation of functionality and user interface of wireless sensor network Life Expectancy Assessment Method transferred to target group.

The Technology Transfer model allowed to systematize process-oriented activities and to identify real performed activities description for Life Expectancy Assessment Method. The first results of assessments show that the Life Expectancy Assessment Method meets target end-users requirements and its main functions has been estimated positively.

Further research will be further development and improvement of Life Expectancy Assessment Method functionalities based on potential-end user's feedback. And from the technology developer point of view, one of the future tasks will be an improvement of "financial implementation" strategy for Life Expectancy Assessment Method systematic transfer.

In the article the developed methodology allows efficient planning of the structure pertaining to the network by dividing the tasks between the network nodes, thus increasing the overall lifecycle of network.

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