fetal monitoring, fetal heart rate,
wireless networks, routing protocol, simulation

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A ROUTING PROTOCOL FOR WIRELESS NETWORK OF BEDSIDE MONITORS IN FETAL SURVEILLANCE SYSTEM

The paper presents the methodology of wireless network design, developed according to the requirements originating from existing wired fetal surveillance systems. The proposed network structure is based on popular radio frequency modules, operating in 433/866MHz band. The described solution is a simple and cost effective alternative to the wired networks, and it will vastly increase the mobility of fetal monitors. The authors also describe software tools which were designed for this purpose and the results of simulations performed on their basis.

1. INTRODUCTION

The fetal monitoring, enabling evaluation of the fetal condition during pregnancy and in labour, is usually accomplished by means of cardiotocography (CTG). Cardiotocography relies on the analysis of characteristic fetal heart rate patterns in relation to the uterine contractile activity and fetal movements [9]. These signals are recorded by bedside fetal monitor and provided in a form of printed traces as a standard. However, in an attempt to improve the objectivity and reproducibility of visual evaluation of CTG traces [7], centralized fetal monitoring systems were developed and introduced into clinical practice [4]. In such system the data from fetal monitors are transmitted to the central computer (surveillance center), and provided to the clinicians together with the quantitative results of their analysis [6].

The structure of traditional wired network for fetal surveillance system is presented at Fig 1. Surveillance center collects the data from CTG monitors through RS485 interface [5]. Main disadvantage of this classical solution is the susceptibility to mechanical damage. Cable connections are the most often damaged elements of the system. This type of damage may not be detected as soon as it occurs, which may lead to incorrect analysis results and false interpretation done by medical staff. Our research will lead to the development of the routing protocol that ensures the proper functioning of the system. What is more, devices can be used only close to CTG network sockets, thus they are not fully mobile. The solution of this problem is possible with implementation of wireless network compliant with specific requirements [3]. An example location and range of wireless devices in fetal surveillance system is presented at Fig.1b. In such systems [9], where some wireless nodes are beyond the range of central unit, the devices might also act as intermediary stations, forwarding data toward the surveillance center. However, the solution in which network nodes transmit data frames to the destination node using intermediary nodes, requires development of a special routing protocol [2]. Designing the protocol for wireless sensor networks of fetal monitors is a special challenge, because of specific information flow.

Routing protocols for wireless sensor networks comprise some unique features that make them different from other wireless networks. Designer of WSN (Wireless Sensor Network) should follow the most important issues: minimizing the computational power and requirement for memory, assuring autonomy and self-organization of the network, easiness of implementation, mobility and scalable architecture [8]. Routing techniques commonly used in sensor networks for data collection can be classified as:

- time-based, where data transmission is periodic,
- event-based, where nodes immediately react to the specified event,
- query-based when nodes respond to the requests from the network.

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Nevertheless, solution of routing protocol can be based on more than one of these methods [1].

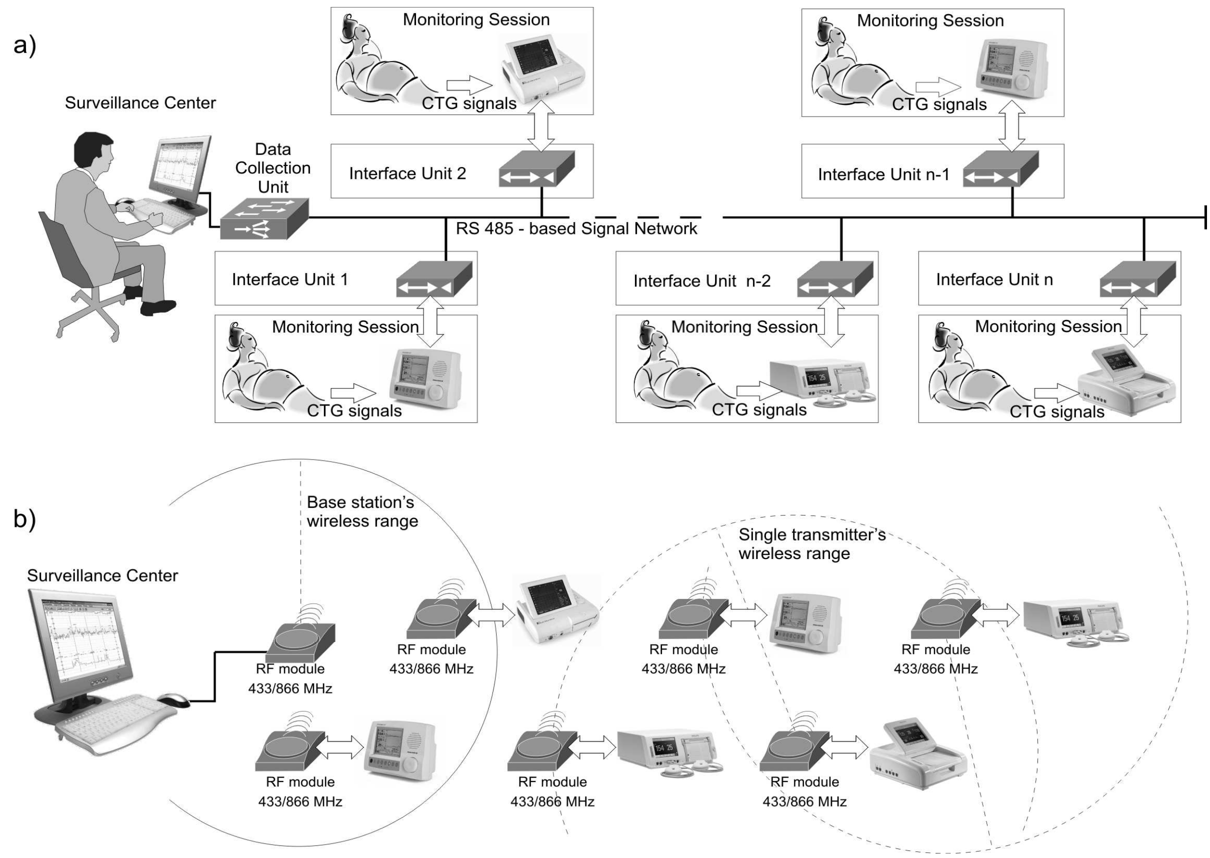

Fig. 1. Overall structure of fetal surveillance system: the existing solution based on RS485 network (a), a new wireless approach based on 433/866 MHz transceivers (b).

The authors make an attempt to develop and simulate special routing protocol dedicated for wireless network, based on simple radio frequency modules, operating in the unlicensed 433 or 866MHz band. Following the rules for design of wireless sensor network, some outlines for CTG network development were established. The project rules were specified for two elements: a single node and a routing protocol.

Each node consists of a classical fetal monitor and wireless transceiver. The fetal monitor provides fetal heart rate (up to two-channel) and uterine activity measurements every 250 ms. Thus, the total amount of data to be sent to the surveillance center from a single node is equal to five bytes transmitted four times per second. The data are buffered in the memory of radio modem and sent to the surveillance center every one second. Before a transmission the 20 bytes of CTG data are additionally extended by a unique monitor number (which is constant for the node and unique within the network) and a CRC information, forming a data frame of 22 bytes. As the node intermediates in data transmission toward the surveillance center, it has to work in continuous mode, even if there is no patient monitoring performed at the moment. Information is sent cyclically, so the distribution of activity periods in time is uniform for all nodes in the network. The communication is based on unique, dynamically assigned node addresses and flat routing protocol, which means that all nodes perform identical tasks.

2. SIMULATION ENVIRONMENT

The simulation environment was written in C# language. Due to ensure good representation of network node operation, a separate thread is started for each of them, executing a program written in simple pseudocode developed for this purpose. Additionally, the environment enables testing the performance of real sensors, connected using a RS232/USB port, co-operating with virtual network structure. Such sensor can be used in place of virtual node, significantly facilitating the process of embedded software development and evaluation. Due to such solution, the nodes are able to receive, process and send frames independently and in any time.

Table 1. The list of instructions implemented in pseudocode.

Name	Application
Frame	Wireless channel frame definition
Var	Variables list definition
Const	Constants list definition
Tab	Tables definitione
Send	Sending the frame to wireless channel
Serialport	Connection of wireless channel with RS232 port
Move	The station placement change
Range	The stadion range change
Power	Station on/off
Execute	Executing external program
If, Goto..	Program flow control

In the Sensor Network model employed in the simulation environment two elements can be distinguished: the wireless channel and sensor node. Each introduced sensor node is connected with the wireless channel, which consists of connection manager and data manager. During the introduction of a new sensor node in the environment, its range and location on the area are defined. Basing on these parameters, the connection manager determines which nodes are connected to each other. The connection graph is being prepared and updated each time the placement of a node is changing, when a new node appears in the connection range or disappears from it. When the node sends a frame, an event is submitted to the data manager, which creates sufficient frame copies and sends them to the appropriate nodes, relying on the knowledge of the connection manager. As it was mentioned above, there is a possibility to plug-in the external device through the serial port. In this case the system operation does not change. The data incoming from the serial port are divided into frames defined in the system and submitted as an event to the connection manager, which forwards them to objective stations. Similarly, the data directed toward the external node are being sent through the serial port, so that the device is fully integrated with the virtual environment.

The developed programming language is interpreted and executed by every virtual node in the network. Instructions implemented in the pseudocode are listed in Table 1. The pseudocode editor enables the development of an algorithm for operation of a single, all or selected nodes, what can be defined using selection fields next to the list of nodes. The following options are available during the simulation:

- view of variables values,
- view of transmitted frames,
- list of current connections,
- graph of station activity over the time,
- list of simulation program errors.

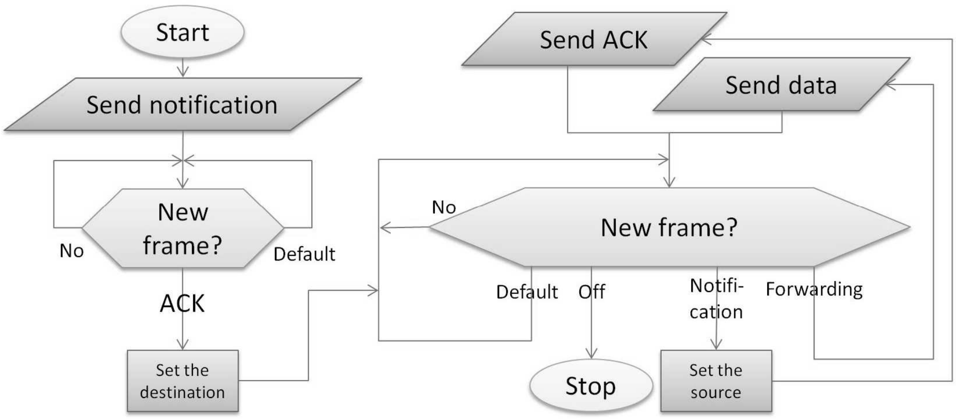

Fig. 2. Block diagram of the proposed routing algorithm.

The activity of the nodes can be observed on timeline graph. The environment also provides the possibility of viewing the content of transmitted frames. However, there is no possibility for a node to detect situation when transmitted data frame superimposes in time with frame sent by another node in its range. This conflict can be only detected by the third device, located within the range of two transmitting nodes. In the simulation environment each detected collision is submitted as a message on the list of sent frames. For development purpose a connection graph is provided, which allows to observe the data flow, namely which node has sent the frame and which nodes have received it. On the timeline graph there can be also observed which stations are in the range of transmitting node.

Table 2. Routing tables for nodes 0, k and n, where: $k \epsilon [1,n-1]$, $k \epsilon N+$.

Station (0)		Station (k)		Station (n)	
Destination	Source	Destination	Source	Destination	Source
-	1	k–1	k+1	n–1	-

3. ROUTING PROTOCOL

A set of protocol elements, enabling simulation of routing algorithm for wireless fetal surveillance network, was implemented and tested in the developed system. The following assumptions were made:

- there is a single station for data management,
- all data are forwarded to management station,
- new stations are placed in the range of previous ones,
- flat routing protocol,
- minimal requirements for memory and computational power in a single node,
- single, half-duplex logical channel,
- the total number of stations not exceeding 64.

First, the management station should be turned on (0). Each next station (n) sends submission frame when turned on. Being in the range of management station (0) or the last station turned on (n–1), it receives confirmation frame, containing number of that station. Station (n), saves the node number (n–1) as a destination station in routing table and waits for submission from the new station. Station (n–1) saves the station (n) as a source station in routing table, while the number of destination station (n–2) already exists. As a result of the above activities, station (n–1) has got numbers of destination and source stations and it is ready to forward the data toward the management station. Station (n) waits for new submission. Block diagram of the algorithm is presented at Fig. 2. The algorithm is the same for all stations and it was implemented in the environment described in section 2, using pseudocode. After network configuration, last station (n) starts to cyclically send data frame, which is passing through all the stations, and each station fills the frame up with its data. As a consequence, the length of a frame increases after each transmission. Finally, a frame containing all data collected in this chain reaches the management station. The routing table is presented in Table 2.

Table 3. The data frame structure with mandatory and optional fields indicated.

Number of broadcasting station	Confirmation request	Data	Control
0..n	0,1 or 2		
Mandatory fields		Optional fields	

The assumed frame structure contains two types of fields: mandatory and optional (see Table 3). The mandatory part consists of the number of transmitting station (n), which is necessary for the frame to reach the destination station (n–1), and the confirmation request. The latter carries an instruction for the receiver and it means:

- send the frame without confirmation (0),
- add and commit new station in the network (1),
- confirmation that the station was added successfully (2).

The number of the last station (n) is also the count of all stations in the network. The data gathering sequence is initialized by the last station.

4. RESULTS

The algorithm implemented in the system is presented as a block diagram in Fig.2, and the results and simulation windows for the algorithm are presented in Fig. 3 and Fig. 4. Using these figures, it is possible to analyze the performance of the protocol. New stations submit their existence in the network, receive confirmations and fill up the routing tables. The last station (with the highest number) sends frame with data, which is forwarded to management station.

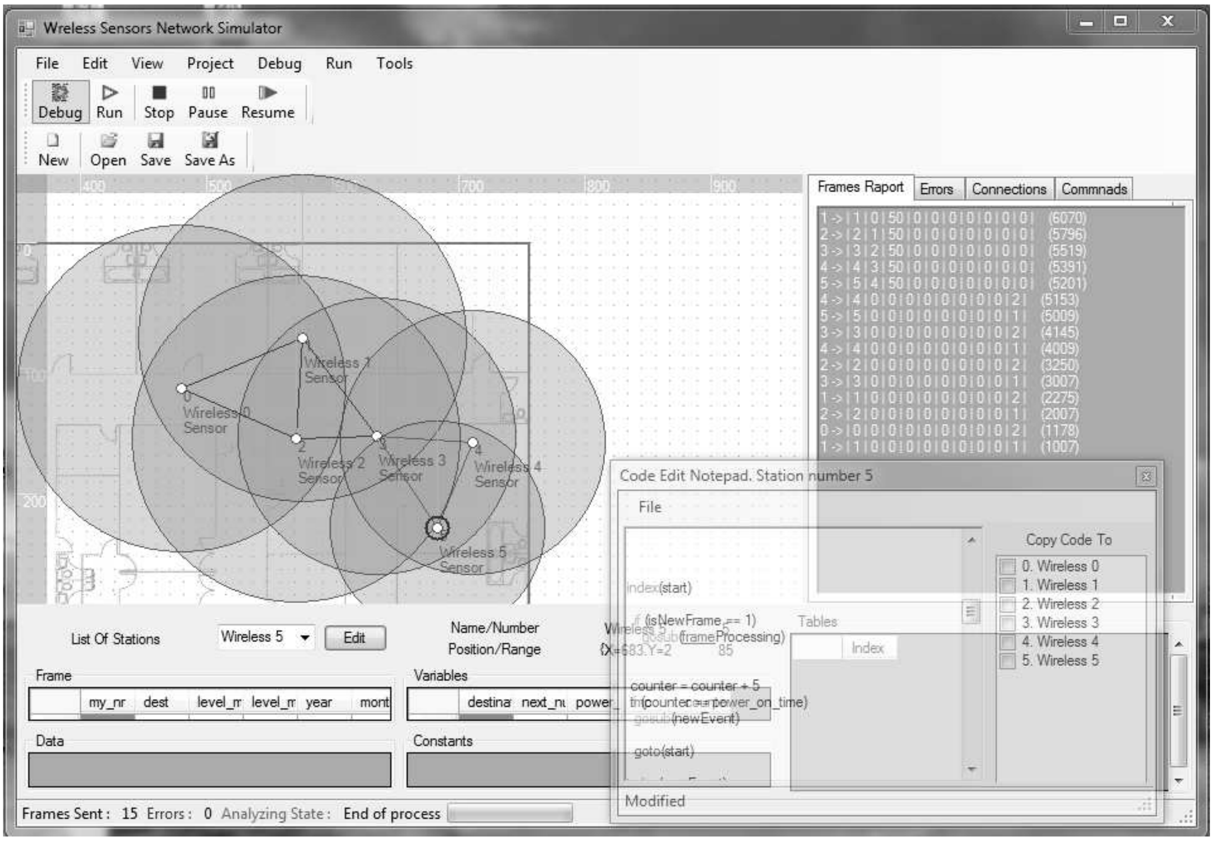

Fig. 3. Simulation of routing protocol performance. Locations of wireless nodes are marked with white dots, whereas grey circles are related to the range boundaries. Additionally, a list of frames containing data and network connections between the nodes are presented.

The operation of the protocol can be observed in Fig. 3. The stations are numbered from the top and correspond to the numbers of stations from Fig. 4. Time, in milliseconds, is marked on vertical axis. Station (1) sends submission frame and station (0) responds with confirmation frame. It means that from now on station (0) will ignore submission frames from other stations and will wait for data from station (1). Station (1) waits for new submission. This procedure repeats for following stations. During the execution of the algorithm, there can be observed values from transmitted frames and routing tables, what enables the verification of network performance. After network configuration, the last station (5) initializes transmission of a frame which is passing through all nodes, and whose task is to collect information about measurements and forward it to management station. Due to the real time simulation, the cooperation of system with physical devices is analyzed in the same way, but it was not performed in this test.

5. CONCLUSIONS

The studies show, that the development of routing protocol with minimal requirements for operation memory, program memory and computational power was successful. It works properly on wireless network simulator. This outcome was a simple subjective assessment. Its application to the fetal surveillance system is possible in a simple microprocessor system cooperating with a single-channel, half-duplex wireless module. The solution moves away the problem with accessing the physical link, because in such network only one station can begin the transmission, regardless of the number of stations. The fact, that large amount of various events does not cause increased network activity is an important advantage of the application.

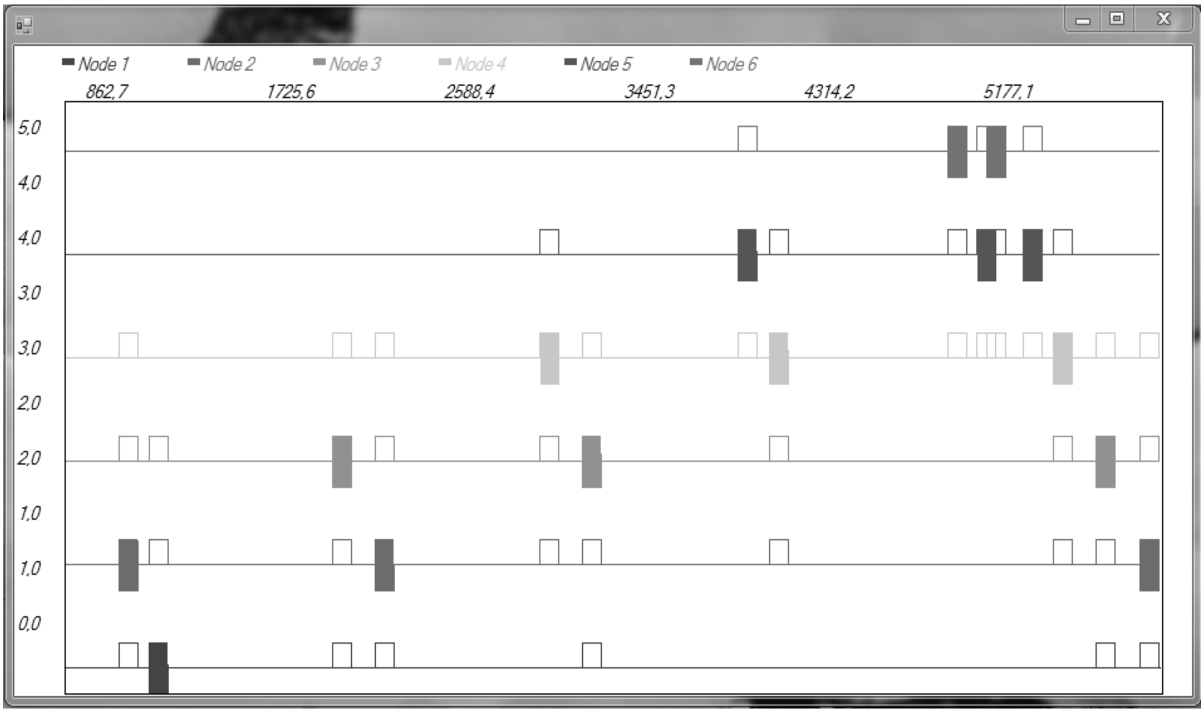

Fig. 4. Activity of wireless stations during the network configuration procedure, followed by normal operation when collected data is successively transmitted toward the central station.

The proposed routing algorithm will be a basis for further improvements. At a present stage of development it ensures the communication of management station with all other stations in the network, according to the presented requirements. However, its biggest disadvantage is the fact that disconnection (failure) of one node stops the activity of the whole network. Therefore, in the future the algorithm will be extended by mechanism of failure detection and network reconfiguration.

6. ACKNOWLEDGEMENT

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