# Methodology of the Tactical Wireless Sensor Networks Control


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***Abstract – the tactical wireless sensor networks control problem formalization was formulated, theoretical bases development directions of tactical WSN control (methods of sensor network control with variable topology for providing the given quality of monitoring and data transmission) are proposed.***



***Keywords: Wireless sensor networks, control system, objectives functions.***


## I. INTRODUCTION

Wireless sensor networks (WSN) are considered – distributed networks (ground, air, underground) consisting of sensor nodes (stationary small-sized sensors, mobile robots-sensors, sensor aerial platforms), with integrated functions of environmental monitoring, processing and data transmission [1].

WSN belong to the class of self-organized radio networks [2]. However, they have their own features: the limited resources of the network nodes (for memory, processor, transmit power), the small distance and bandwidth of the radio links between the nodes, the concentration of traffic around the gateway, etc. The type of nodes (stationary, mobile), the number of monitoring parameters, the dimension of the network, the type of traffic, management organization (centralized, decentralized or hybrid) depends on the purpose of the WSN and its functions.

An analysis of the control methods for tactical WSN suggests that today there is a contradiction between the possibilities of existing methods and models of sensor networks control (both wired and wireless) and the requirements for promising tactical sensor networks and them managing, therefore the actual problem is directed at the development a new wireless sensor networks tactical control level with variable topology to ensure the desired quality monitoring and data transmission.

## II. WSN MANAGEMENT

In accordance with the main operation stages of tactical sensor networks, the task for WSN managing is divided into: the task of planning, deployment and operational control (Figure 1). The planning stage includes: deployment area and time definition, type of sensor nodes, network operation total duration, type of monitoring information collection. The deployment phase includes: random placement of sensor (UAVs, special shells) or deterministic by robot or man. At the stage of the operational control, coverage, monitoring and communication are managed.

The subject of this report is the formalization of the tactical WSN control problem and its decomposition into subtasks by levels and control functions.

*A. Mathematical formulation of the WSN control problem*

Determine the following initial output data.

WSN is presented as a graph $G = (V, E)$ with set of vertices $V = \{i\}$, $i, = \overline{1, N}$ and plurality of edges $E = \{(i, u)\}$, $C_i$ − set of sensors, $d_{iu}$ – the distance between the sensor nodes $i$ and $u$, set of base stations $D \in V$.

Given:

*Sensor node parameters* $i$: placement coordinates $(x_i, y_i)$; transmission power $p_з = p_{\min} \ldots p_{\max}$; the intensity of the generation of monitoring information $Q_i^{\xi}$ $\xi$-th traffic type; battery power $e_i^{\mathrm{b}} \le e_{\max}$; energy is needed for sending, receiving information and monitoring in accordance $e^{\mathrm{Tr}}, e^{\mathrm{Rec}}$, $\mathring{a}^{\mathrm{Mon}}$.

*Information Exchange Options*: $Z_j$ − set of goals (observation zones) $j = \overline{1, J}$, which determine the intensity of the input streams $Q^{\xi}(t) = \left\| Q_{aD}^{\xi}(t) \right\|$, $\sum_{a=1}^{n} \sum_{d=1}^{D} q_{aD}^{\xi}(t) \le q_{\max}^{\xi}$, where $a$ − sender, $D$ – base station, $t_з^{\xi}(m_{aD})$ − transmission delay $\xi$- th type of traffic along the route $m_{aD}$, $l_{aD}^{\xi}(m_{aD})$ − number of retransmissions along the route $m_{aD}$; $\xi = \overline{1, 2}$ – traffic type (data, video); $q_{aD}^{\xi}$ the intensity of the packet flow in the direction $aD$, that coming on all routes *Network parameters*: $\omega(t) \le \omega_{\max}$ – the intensity of the change in the topology; $R(t) = \|r_i(t)\|$ – speed of data transmission in the radio channel; $E(t) = \| e_i (t)\|$ – battery power;

Taking into account the given output data, it is necessary to synthesize methods and models of WSN control, which, when used as part of the functional subsystems of nodes, should meet the following requirements $\{\mathrm{B}_q^l\}$, $l = \overline{0, 5}$, $q = 1 \ldots Q$:

- monitoring and transmission all types of information with the given quality of service;

- providing adaptive and distributed functioning of the WSN with the possibility of self-organization;
- optimization of node performance and WSN as a whole;
- decision making in real time;
- minimal battery consumption of sensor nodes.

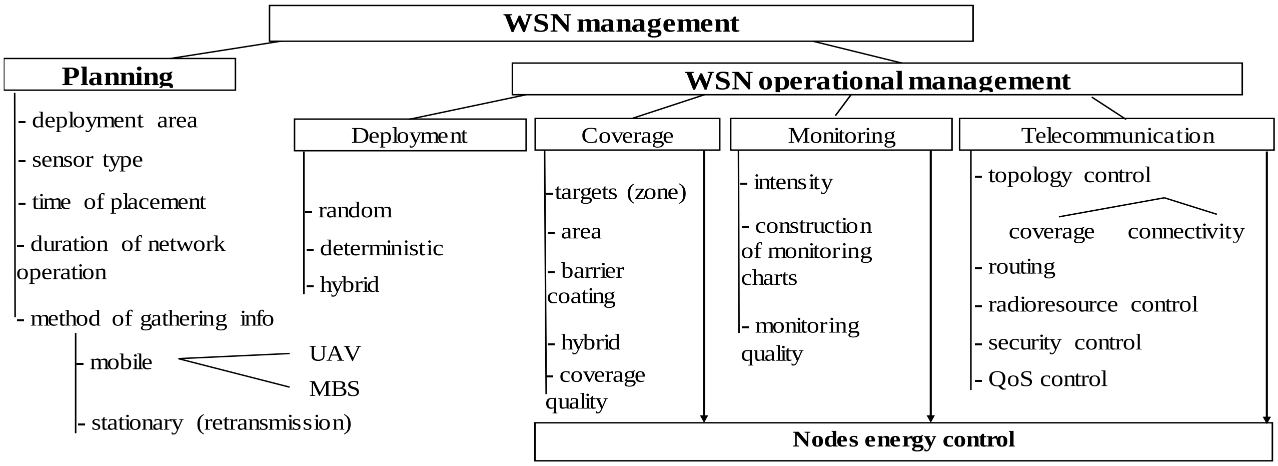


Fig. 1. Stages of WSN operation control.

The main purpose of the WSN control can be decomposed into a number of partial tasks (for example, the maximum coverage of the observation area, the minimum transmission power, the maximum duration of the network operation, etc.) for the entire WSN, or in the monitoring areas between the sender and the base station in this WSN, taking into account the existing nodes and network resources.

At the stage of operational control, WSN CS implements a plurality of control objectives $W=\left\{W^{COV}, W^{MON}, W^{TLC}\right\}$, depending on its function (coverage monitoring, telecommunications component) provided that restrictions on service quality in monitoring and transmitting information and available resources:

$$U^*(t)=\arg \underset{U \in \Omega}{opt}\, W(K(t),\, U(t)),$$

$$W=\left\{W^{COV}, W^{MON}, W^{TLC}\right\},$$

$$W^{COV}=\left\{\max \alpha O,\ \min n_{act}^{cov},\ \min O^{nococ},\ \max T_F^{n\,cov}\right\}$$

$$W^{MON}=\left\{\min n_{mon},\ \max p_{dee},\ \max T_F^{n\,mon}\right\},$$

$$W^{TLC}=\left\{\min P,\ \min l_{aD},\ \max S(m_{iD}), \max T_F^{n\,tlc}\right\}$$

$$K(t)=\left\{n(t),\ E(t),\ \left\|Q^{\xi}(t)\right\|, \omega(t), O(t), Cv(t)\right\}$$

with restrictions on a plurality of control influences and network resources $\Omega=\Omega_{\text{cov}}\times\Omega_{\text{mon}}\times\Omega_{\text{tlc}}\times\Omega_{\text{res}}$, $\Omega_{\text{cov}}$ – restrictions on coverage control, $\Omega_{\text{mon}}$ – limitation in monitoring control, $\Omega_{\text{tlc}}$ – limitation in the control of the telecommunication component, $\Omega_{\text{res}}$ – restrictions on network resources

$$\Omega_{cov}=\begin{Bmatrix} 0<e_i(t)\le e_{\max} & i=\overline{1,\ n_{O\,cov}} \\ p_i(t)\le p_{\max} & \\ Cv_{iD}=1 & \end{Bmatrix}$$

$$\Omega_{mon}=\begin{Bmatrix} r_{mon}^{\xi}\le r_{mon\max}^{\xi}, \quad \xi=1,2\,(\text{data, video}) \\ \alpha\{O\}\le\alpha\{O_{giv}\}, \\ \{n_{mon}\}\subset\{n_{O\,cov}\}, \\ \{C_{mon}\}\subset\{C\} \\ e_i\le e_{\max},\ \ i=\overline{1,\ n_{mon}} \\ Cv_{aD}=1 \end{Bmatrix},$$

,

$$\Omega_{tlc}=\begin{Bmatrix} t_d^{\xi}(m_{aD})\le t_{dper}^{\xi}\,(l_{iD}^{\xi}(m_{aD})\le l_{per}^{\xi}), \\ q_{iD}^{\xi}\le s_{per}(cv_{aD}), \\ S_{rout}^{\xi}\ge S_{thr}, \\ Q^{\xi}(t)=\left\|Q_{aD}^{\xi}(t)\right\| \\ Cv_{iD}=1 \end{Bmatrix},$$

$$\Omega_{res}=\begin{Bmatrix} p_i\le p_{\max}, \\ e_i\le e_{i\max}, \text{for } i\in C \end{Bmatrix}$$

where $W$ – WSN control target that defined by the parameters of the network and surveillance zones $K(t)$; $U^*$ – optimal control effect in WSN from a plurality $U(t)$; $T_F=\min\left\{T_F^{COV}, T_F^{MON}, T_F^{TLC}\right\}$ – duration of network operation; $O(t)=\left\{X(t)\ or\ Z(t)\ or\ B(t)\right\}$ – objects of coverage ( $X$ – observation targets, $Z$ – observation area, $B$ – construction of an observation barrier); $\alpha$ − grade of coverage ( $\alpha=\left]0...1\right]$); $\omega(t)$ − the intensity of the changes in the topology; $Q^{\xi}=\left\|q_{iD}\right\|$ − intensity and type of $\xi$ - th monitoring traffic; $S_{\text{rout}}^{\xi}$ − capacity of the route for $\xi$- th traffic type; $Cv(t)=\|Cv_{iD}(t)\|$ – availability of a route between $i$ and $D$; $t_{d}^{\xi}$ – traffic delay $\xi$- th type; $s(cv_{iD})$ – bandwidth of the radio channel; $l_{aD}^{\xi}$ – number of relays for a pair of nodes $(a,D)$ by route $m_{aD}$, a – sender, D – destination (base station); $p_i$ – the power of the i-th node transmission in accordance with the adopted route decisions; $C$ $(C_{mon})$ – set of sensor nodes; $Z$ – observation targets; $r_{mon}$ – monitoring radius, $e_i^{b}$ – energy of sensor cells; $t_{dper}^{\xi}$, $l_{per}^{\xi}$ – allowable parameters values.

*B. Functional model of WSN control system*

To solve the problem of WSN control, a new architecture of the CS (Fig. 2) is proposed, which involves the implementation of control stages (planning, deployment and operational control) [3].

Monitoring control includes the following steps $U_{mon}(t)=\{U^{P},\ U^{C},U^{O}\}$:

$U^{P}$ *–placement control* - collecting information about observation objects, determining the methods of node placement, selecting the type of sensor nodes (taking into account parameters and monitoring environment), the type of WSN organization, etc.;

$U^{C}$ *– coverage control* - definition the type of coverage (target coverage, the coverage of the area (zone, sector), the barrier coverage), choice the coverage model depending on the coverage ratio) [4];

$U^{O}$ *– observation control* – calculation of sensor observation sessions (observation and transfer method choice) and network connectivity.

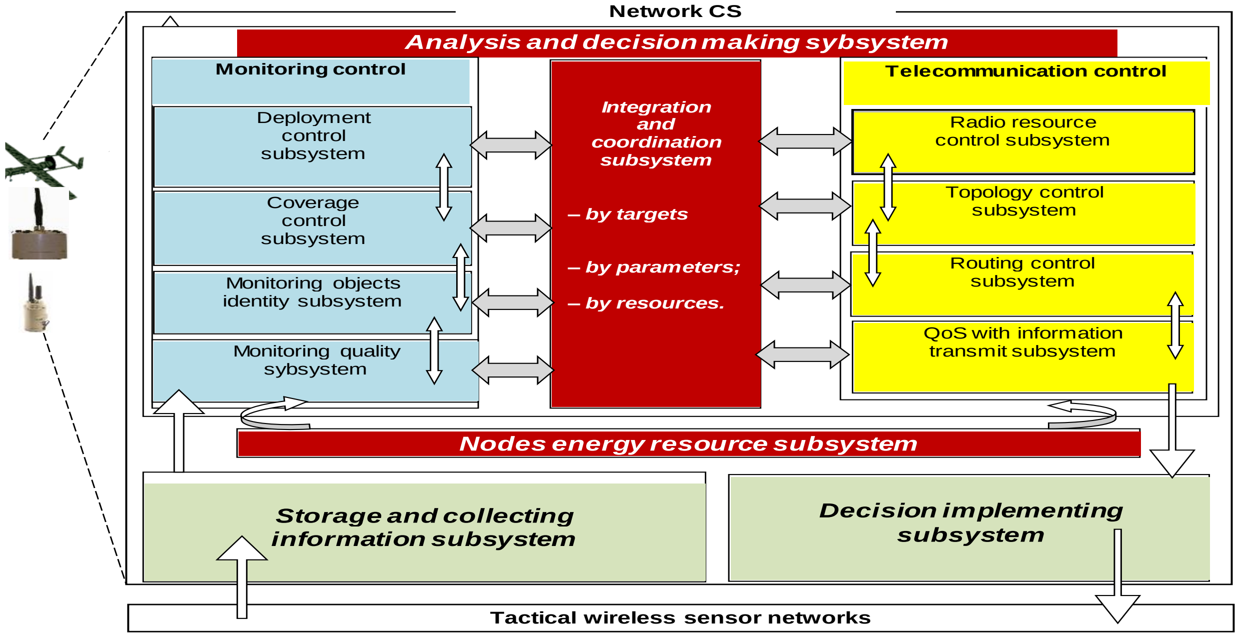


Fig. 2. Functional model of WSN control system

The control of the telecommunication component includes the following steps [5]:

$$U_{TLC}(t)=\{U^{T},\ U^{R},U^{E},U^{QoS},\text{etc}\},$$

– $U^{T}$ – *topology control* - depending on the control purpose, the construction of the network topology for obtaining the coverage or for obtaining connectivity is carried out [6].

– $U^{R}$ – *routing control* - construction and support of information transmission routes for the monitoring of the given quality is carried out while execution the requirements for their operation (minimizing service traffic, reducing energy consumption of batteries, using several routes of information transmission, etc.) [7].

– $U^{E}$ – *power control* - the purpose is to minimize the power consumption of the network nodes (maximizing the "duration of the network operation" - the network operating time until the failure of a given number of nodes through the zero capacity of their batteries) [8];

– $U^{QoS}$ *–the quality of service control in the transmission of information* - controlling the set of parameters (bandwidth, delay delivery of packages and its variation, etc.) for a certain stream of information (data, video).

The main task of the WSN is to identify the objects of observation and to transfer information to monitoring authorities. The WSN effectiveness and duration of the operation depends on the interaction of monitoring control methods with the telecommunication component control methods. In connection with this, there is the task of coordinating and integrating the subsystem of WSN monitoring (deployment, coverage, object identification, monitoring quality) with the telecommunication component subsystem control (topology control, route control, radio resource control, quality control of service during transmission ) A new paradigm is proposed for the control system construction –introduction of the integration and coordination subsystem functions in the monitoring and the telecommunication component subsystem that coordinates the operation of a plurality of OSI control methods (telecommunication component) with monitoring control methods in order to optimize the performance of the network.

The main difficulties of integration are the target functions and coordination parameters definition between the subsystems of the telecommunication component (according to the functions and levels in the OSI model) The main difficulties of integration are the definition of the target functions and parameters of coordination between subsystems of the telecommunication component (according to the functions and levels of the OSI model) and the subsystem of monitoring and decision methods determination that will allow network optimization.

The general idea is at the first stage the topology of WSN with the implementation of monitoring requirements is constructed (Fig. 3).

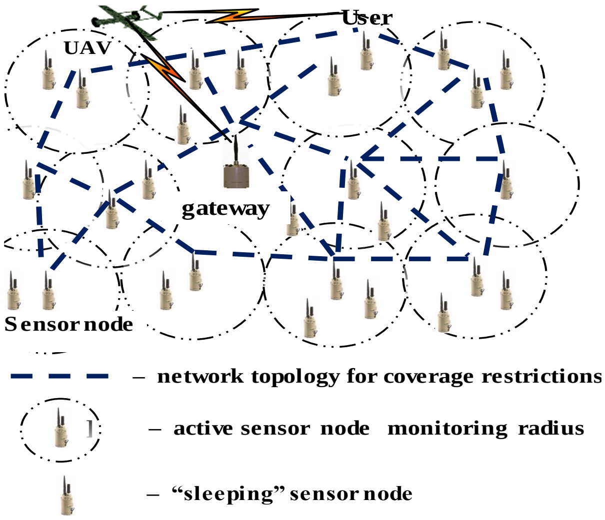


Fig. 3. Topology of the network, with the coverage requirements

At the second stage, the construction of the topology and transmission routes is carried out, which implements a coordinated target control function (Fig. 4).

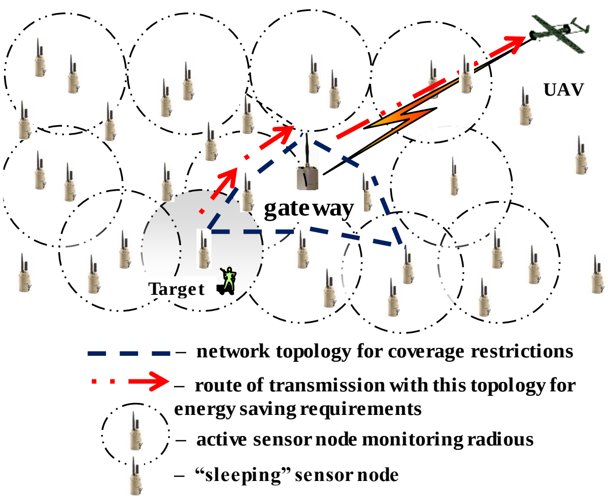


Fig. 4. Network topology with coverage requirements and information transfer routes

## III. CONCLUSION

The control problem of tactical wireless sensor networks has been defined. All stages of the tactical WSN functioning (planning, deployment, monitoring of coverage, data transmission) are taken into account.

The decomposition of the general statement of the control problem into separate control tasks by stages and functional subsystems is carried out.

To reconcile the functions of different subsystems, it is proposed to introduce a subsystem of integration and coordination of the monitoring subsystems functions and telecommunication component that coordinates the operation of a control methods plurality by the OSI levels (telecommunication component) with monitoring control methods

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