ALGORITHM OF SCHEDULE CALCULATION FOR CENTRALIZED SENSOR NETWORK

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Abstracts

Algorithm of transmissions schedule calculation for distributed control system is described in this article. The considered network is working in «many-to-one» mode. The calculated schedule guarantees absence of collisions. For networks with different topologies analysis of duration of duty cycle, calculated by this algorithm, is also included.

I. INTRODUCTION

This project is focused on wireless systems of monitoring and control. Such systems are more and more introduced in the plants, medical centers, security systems cause they have plenty of advantages over wired systems. Absence of necessity to conduct a wire to distantly situated objects and low energy consumption make wireless systems cheap and flexible and simplifies the process of expansion and upgrade of control system. So, wireless monitoring systems is a very perspective field of science

Obviously, that a number of closely situated sensors can cause interference for each other. Since the sensors' antennas are isotropic there is no opportunity of space channels division. Fig. 1 illustrates the situation when sensors 1 and 5, transmitting their messages to sensors 2 and 6, make interference for the transmission «sensor 3 – sensor 4». Such a situation is called "collision".

One of the ways of collision avoidance is working under the schedule. We suggest the algorithm of schedule calculation for distributed control system. The schedule, calculated by this algorithm guarantees absence of collisions.

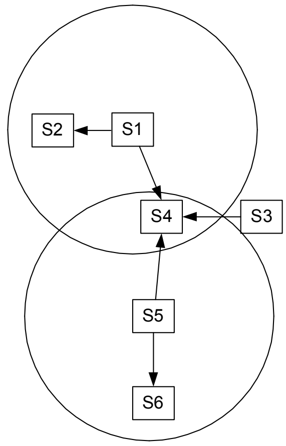

Fig. 1. Sample of collision

II. METHOD OF SCHEDULE DESCRIPTION

We consider sensor network consisting N sensors and the base station (BS). Time is split into a sequence of slots. Slot – is time interval, which duration is equal to sum of one message duration and guard interval: $\tau = \tau_{mes.} + \tau_{gi}$. We consider all messages to be of equal size. Such a consideration is right for the networks all sensors of which control similar environment parameters. [1]. Each transmission is strictly attached to one of the slots. *Duty cycle* is a sequence of slots during which BS gets all N messages (one message from one sensor) [2]. Power of set of transmission ***P***, fulfilled during duty cycle, is equal to $L = |P| = \sum_{i=1}^{N} l_i$,

where l_i – the number of retransmissions, that are to be done to deliver *i*-th sensor's message to BS. Differently l_i – length of the route, connecting *i*-th sensor and BS. Each of L transmission is to be attached to ones of the slots so that there were no collisions.

After finishing previous duty cycle next duty cycle begins. Thus if numbers of slots are equal mod T, where T – duty cycle duration, then sets of transmission in these slots are equal (look fig. 2). On fig. 1 P_j – is a set of transmissions, done in slot, which number is equal to $j \bmod T$. Obviously $\bigcup_{j=1}^{T} P_j = \boldsymbol{P}$.

Let's formulate conditions under which the transmission in slot is collision-free:

1. During the slot each sensor can be either source of message or receiver of message or be in sleep mode. This condition follows from technological features of components from which the sensor units are produced [3, 4].
2. Each of the receiving sensor is to be in work range of only one transmitting sensor. This condition is obvious, cause otherwise there will be a mixture of signals of a few sensors, that is collision.

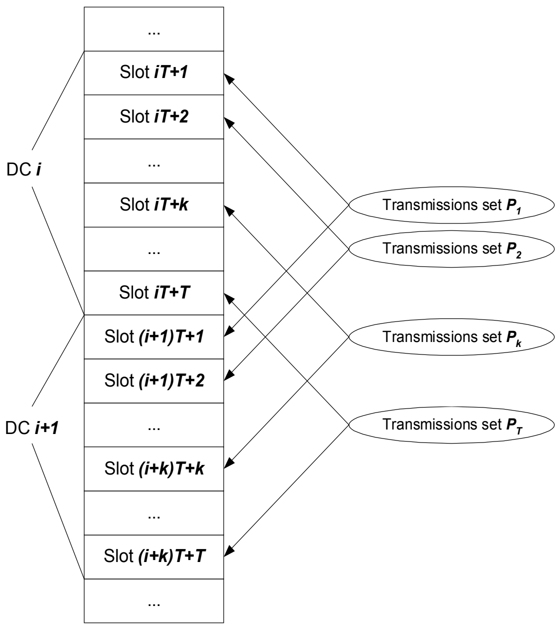

Fig. 2. Duty cycle structure

III. ALGORITHM OF SCHEDULE CALCULATION

Input parameter if developed algorithm is matrix of connectivity, output – the schedule that is instruction: which sensor in which slot is to receive/transmit the message.

Since the network topology can be very branched and have cycles, there can be a few routs connecting sensor with the base station. To minimize the total energy consumption in network the shortest routs are to be chosen. So algorithm of shortest rout calculation is to be a component of algorithm of schedule calculation.

At the beginning of algorithm the following sets are to be arranged:

1) set of sensors for which the transmission is forbidden in current slot (initially it is empty). Mark it as SFT;

2) set of sensors for which the receive is forbidden in current slot (initially it is empty). Mark it as SFR;

3) for every sensor we arrange a set which contains the numbers of sensors which messages it keeps this moment. Then for every *i*-th sensor ($i = \overline{1, N}$) $M_i = \{i\}$, for base station $M_0 = \{\}$.

Matrix of connectivity resorts so that the closer sensor to BS the higher it string in matrix (and more to the left the column). Than the sequential looking through the matrix from top to down beginning from first string (zero string corresponds to BS). Let's consider, that *i*-th sensor is looked, and the next sensor after him on the way to BS is *j*-th. The transmission from i-th sensor to j-th one is included to the schedule of the first slot, if the following requirements are met:

1) $i \notin SFT$;

2) $j \notin SFR$;

3) $M_i \neq \varnothing$.

After that the following procedures are to be carried out:

1) i goes to SFR (sensors are not able to receive and transmit simultaneously [5]);

2) j goes to SFT;

3) one message goes from M_i to M_j;

4) sensors, adjacent to *i*-th, goes to SFR;

5) sensors, adjacent to *j*-th, goes to SFT.

After that next string of connectivity matrix is analyzed etc. When the looking through process is finished the schedule for the first slot is complete. After that SFR and SFT are reset and the next looking through begins. After every looking through the schedule for one slot is carried out. The process goes on until all the messages are gathered in M_0.

IV. SAMPLE OF ALGORITHM WORK

For the explanation of work of the described algorithm, let's make a sample. Let's consider sensor network which is described by graph, shown on fig. 3.

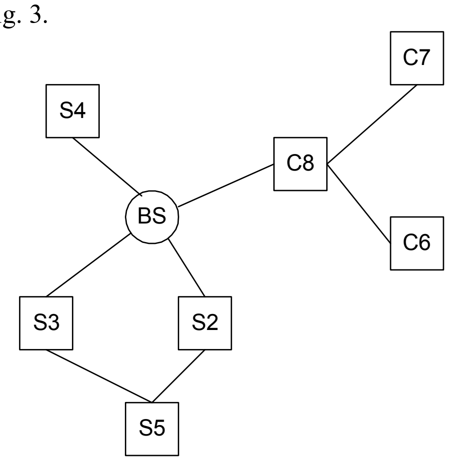

Fig. 3. Sample of the network for algorithm work illustration

In this case $N = 7$. Table of connectivity for this graph is given in table 1.

Table 1

Table of connectivity of graph, shown on fig. 2

Number of sensor	1 (BS)	2	3	4	5	6	7	8
1 (BS)	1	1	1	1	0	0	0	1
2	1	1	0	0	1	0	0	0
3	1	0	1	0	1	0	0	0
4	1	0	0	1	0	0	0	0
5	0	1	1	0	1	0	0	0
6	0	0	0	0	0	1	0	1
7	0	0	0	0	0	0	1	1
8	1	0	0	0	0	1	1	1

The shortest routs, connecting sensors and BS are:

1 sensor: 2–1 (rout length – 1);
2 sensor: 3–1 (rout length – 1);
3 sensor: 4–1 (rout length – 1);
4 sensor: 5–2–1 (rout length – 2);
5 sensor: 6–8–1 (rout length – 2);
6 sensor: 7–8–1 (rout length – 2);
7 sensor: 8–1 (rout length – 1).

Let's sort the table as it was described in previous chapter (look table 2).

Table 2

Sorted table of connectivity for the graph shown on figure 2

Number of sensor	1 (BS)	2	3	4	8	5	6	7
1 (BS)	1	1	1	1	1	0	0	0
2	1	1	0	0	0	1	0	0
3	1	0	1	0	0	1	0	0
4	1	0	0	1	0	0	0	0
8	1	0	0	0	1	0	1	1
5	0	1	1	0	0	1	0	0
6	0	0	0	0	1	0	1	0
7	0	0	0	0	1	0	0	1

At the beginning $M_1 = \{\}$, $M_2 = \{2\}$, $M_3 = \{3\}$, $M_4 = \{4\}$, $M_5 = \{5\}$, $M_6 = \{6\}$, $M_7 = \{7\}$, $M_8 = \{8\}$. $SFR = \varnothing, SFT = \varnothing$.

Let's calculate the schedule for the first slot. Looking through the table begins from the second string (it corresponds to sensor № 2): $2 \notin SFT, 1 \notin SFR, M_2 \neq \varnothing.$

Then, we can include the transmission S2->BS to the 1st slot. After that, $SFT = \{1,2\}$, $SFR = \{1,2\}$. $M_2 = M_2 \setminus 2 = \{\}$. $M_1 = M_1 \cup \{2\} = \{2\}$. Sensor S5 is adjacent to S2, so it goes to SFR. Sensors S3, S4 и S8 are adjacent to BS, so they are to be forbidden to transmit to avoid interfering for transmission S2→BS. After that: $SFT = \{1,2,3,4,8\}$, $SFR = \{1,2,5\}$.

Sensors S3, S4, S8, S5 are in forbidding sets so they cannot transmit in this slot. The seventh string corresponds to sensor S6, which transmits to S8. All the requirements are met:

- $6 \notin SFT$;
- $8 \notin SFR$;
- $M_6 \neq \varnothing$.

Thus this transmission is to be included to the first slot: $M_2 = M_6 \setminus 6 = \{\}$. $M_8 = M_8 \cup \{6\} = \{6\}$. Sensor S7 is adjacent to S8, so it is to be forbidden to transmit its message for not to make an interference for transmission S6→S8.

Looking through the table is finished and the list of transmission in first slot is completed (look table 3).

Table 3

List of transmission in the first slot

Transmitting sensor	Receiving sensor
2	1
6	8

After 6 more scans of table 2, $M_1 = \{2,3,4,5,6,7,8\}$ and schedule calculation is complete (look table 4).

Table 4

Schedule of duty cycle

Number of slot	Transmitting sensor	Receiving sensor
1	2	1
	6	8
2	3	1
	5	2
	7	8
3	2	1
4	4	1
5	8	1
6	8	1
7	8	1

So for the tree, shown on figure 3 duty cycle duration will consist of 7 slots.

V. ANALYSIS OF SCHEDULE CALCULATED BY SUGGESTED ALGORITHM

For schedule quality estimation its necessary to work out criterions of estimation. We consider the duration of duty cycle to be such a criterion. The more quality of algorithm the less duration of duty cycle. Research was done for networks with tree-like topologies.

We developed model providing an ability to estimate statistically mean value of duty cycle for different numbers sensors, different degrees of trees, and the following types of topology:

1) random tree;
2) random tree without linear parts;
3) random tree, every non leaf node of which has equal degree.

We took number of sensors going from $N = 10$ to $N = 50$. Degrees are - 2, 3 и 5. For every mean calculation 5000 experiments were done. Results are represented as plots (look figures 4a – 4b). Boundary values were calculated in theoretical work [6].

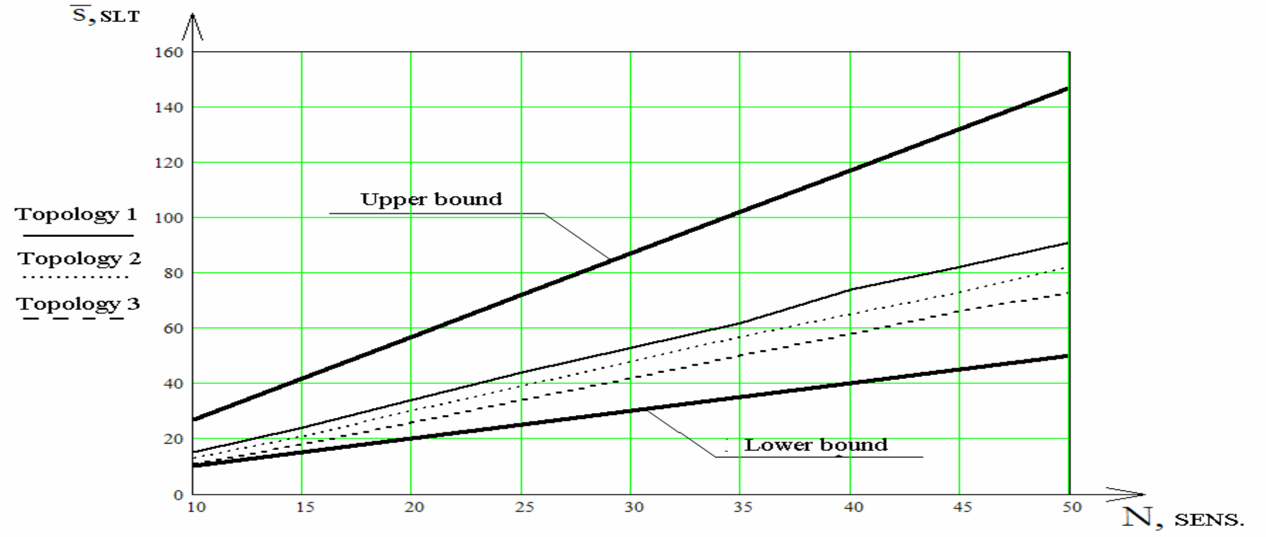

Fig. 4a – Mean duty cycle duration. Trees degree – 5. Three kinds of topology.

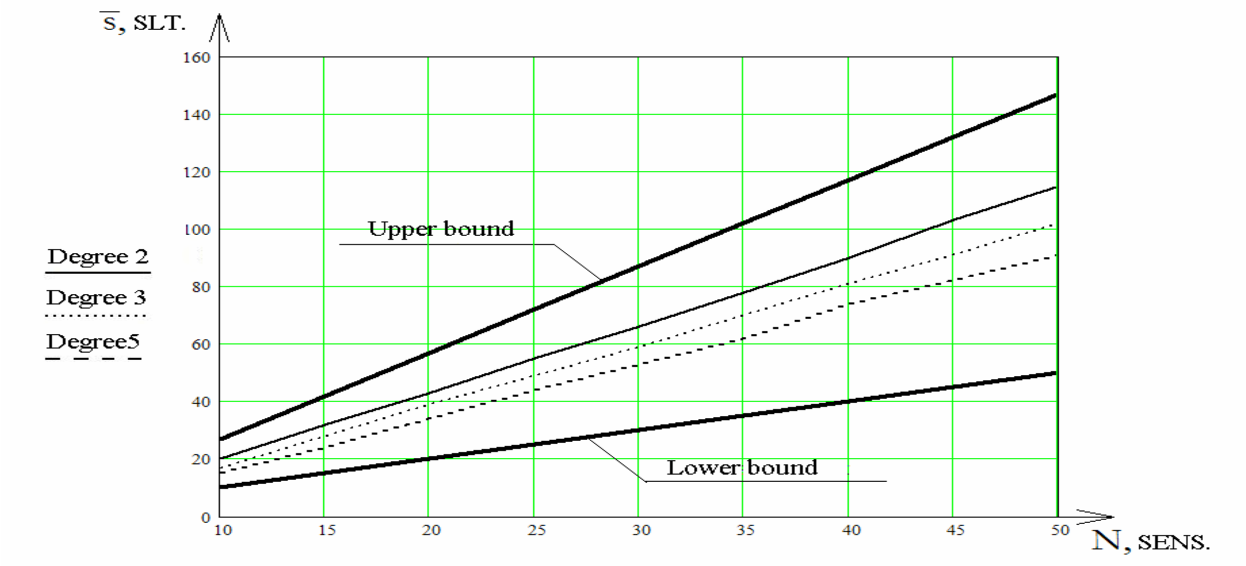

Fig. 4b. Mean duty cycle duration. Topology №1. Degrees 2, 3 and 5.

VI. CONCLUSION

The suggested algorithm calculates the schedule of transmissions in sensor network which duration is in range from N slots to 3N-3 slots, where N – number of sensor. Statistical experiments show, that the network developer should keep the following recommendations:

1) try to avoid linear parts, especially close to BS;
2) each node degree should be as high, as possible.

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