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# OPTIMAL INFORMATION TRANSMISSION SCHEDULE FOR NETWORKS WITH TREE-LIKE TOPOLOGY

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**Abstract**

The article deals with tree sensor networks integrated intelligent multi-information-management systems. For each of the subsets of a tree network the lower limit of the length of time gathering information is calculated and an algorithm of optimal routing is purposed in the form of knowledge that can be used for any tree of the sensor network.

Rapid transfer of information is one of the most important characteristics of modern communication systems and information processing, working under severe time constraints, for which the response time to external stimuli is critical. Intelligent multi-functional integrated information management system (IMIUS) are hard real-time systems, which causes the specifics of their algorithmic support. Systems that used to transmit radio messages have a special appeal. The miniaturization of components and the progress of communication technologies have created the prerequisites for the emergence of a special type of wireless data transmission systems – sensor networks. This network consists of a plurality of autonomous elements – sensors. The sensor includes a sensitive element detecting the change in a physical parameter of the environment, a processing unit and a battery. Each sensor can be as a source of messages and it could relay messages from other sensors. Thus, using sensor networks can transmit information at a considerable distance using low power transmitters. The final destination of the message delivery is a base station (BS) as part of IMIUS.

Developed and presented evaluation and algorithms in this article allow the following conclusions:

1. You can always schedule for any tree of the sensor network with duration $K$ € [$N$, 3$N$-3] slots;

2. The duration of the schedule depends on the number of sensors in the first and second tiers of the tree and the network of distributed sensors to subtrees of the graph network.

The developed algorithms increase the efficiency of information transfer in the form of knowledge in sensor networks integrated intelligent multi-information management systems, as well as allow you to schedule a minimum duration for any tree IMIUS sensor network. It should be noted a special attraction of the developed algorithms for systems operating in hard real-time response when time is a critical parameter.

## INTRODUCTION

Rapid transfer of information is one of the most important characteristics of modern communication systems and information processing, working under severe time constraints, for which the response time to external stimuli is critical. Intelligent multi-functional integrated information management system (IMIUS) are hard real-time systems, which causes the specifics of their algorithmic support. The system used to transmit radio messages has a special appeal. The miniaturization of components and the progress of communication technologies have created the prerequisites for the emergence of a special type of wireless data transmission systems – sensor networks. This network consists of a plurality of autonomous elements – sensors. The sensor includes a sensor detecting the change in a physical parameter of the environment, a processing unit and a transceiver battery. Each sensor can be as a source of messages and relay messages from other sensors. Thus, using sensor networks can transmit information at a considerable distance at low power transmitters. The final destination of the message delivery is a base station (BS) as part IMIUS.

## ALGORITHM *D*1 (*AD*1)

For the sensor network topology (1,1)-tree duration of the collection of information (DCI):

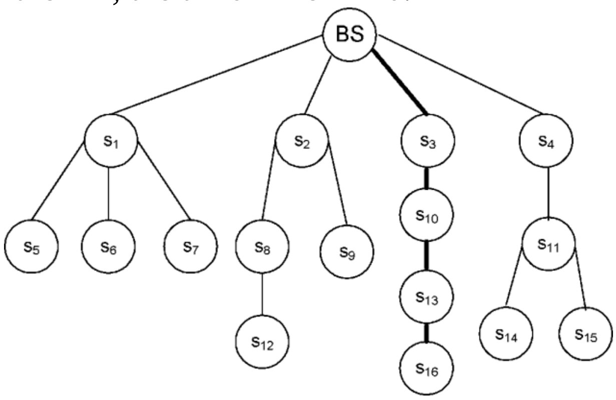
$$K \geq 3N-3. \qquad (1)$$

The sensor of the first tier during DCI must perform $N$ transfers (its message and all of its descendants). The sensor of the second tier during DCI must perform $N$-1 transmission. Sensors third tier – in the amount of $N$-2 transmission. Since this tree sensor of the first tier, second tier sensor and sensors third tier can not transmit simultaneously (otherwise there is a collision), it would take at least $N + (N-1) + (N-2) = 3N-3$ slots.

We formulate an algorithm that generates a schedule for optimal (1,1)-tree. We formulate the notion of iteration of the algorithm $D1$ ($I_{AD1}$). During one $I_{AD1}$ prepared schedule for three slots DCI. Select an arbitrary tree in the active route connecting the root node and any leaf of the tree.

Sensors on the selected route divided into three sets. To the set $Ms$ ($s$=0,1,2) we put sensors located on the line, the number of which is equal to $s$ mod 3. If the number of sensors on the route is less than three, then the set $M3$ or $M2$ and $M3$ sets are empty (picture 1).

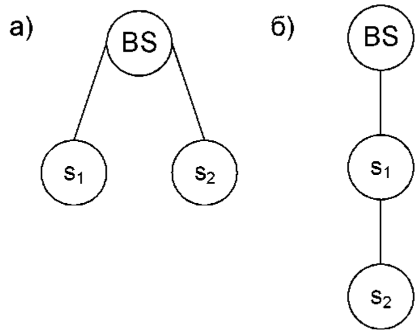
Suppose that in the first slot iteration will give messages of sensors $M1$, the second – from the $M2$, the third – from $M0$.




*Pic.1. Tree with the selected route*

In each of these three slots multiple transmissions will be without conflict, as both conditions are met (in each slot each sensor or transfers or receives a message, each receiving sensor hears only one transmitter). Then at the end of the three slots posts all sensors of the route will be transferred to the tier above, and the BS will be one message. As a result, the network will iteration in pseudo starting state, and the list sensor selected route will be deleted from the active tree.

When repeating iteration reduced active tree for another node in the network will run in pseudo starting state BS gets another message and so on. After 3($N$-2) to the BS gets $N$-2 message and the active tree will have 2 sensors. There are two types of tree containing the two sensors when the sensor adjacent to both the BS and the adjacent BS when only a single sensor (picture 2). The maximum duration of the collection of information generated by $AD1$, is equal to $3(N-2) + 3=3N-3$ slot.




*Pic.2. Two kinds of trees, consisting of two sensors*

Let us analyze the inequality (1) and the algorithm *D*1:

– When working with *AD*1 on BS every three slots message arrives.

– Schedule drawn up by *AD*1, is optimal for (1,1)-tree.

– *AD*1 allows you to schedule, in which the duration of the DCI is strictly equal to $3N$-3 slots for any tree network.

Consider a network with the topology of the «star» when BS is within earshot of all sensors, and each sensor only hear the BS. For such a network the following schedule can be offered – to the slot which number is equal to $i$ mod $N$, the BS transmits a sensor with number $i$. Then DCI will have a duration of $N$ slots, which is almost 3 times less than is provided by the algorithm *D*1.

The disadvantage of *AD*1 is that it is not considering a tree structure and, therefore, the duration of the DCI can significantly exceed the minimum achievable.

Given a sensor network topology $(1,v)$ - tree ($v \geq 2$). We select $v(1,1)$-subtrees formed from the BS, is the root of each of these subtrees, the sensor of the first tier, and many descendants through each of the nodes of the second tier. Assume that a larger subtree contains $n_1+1$ sensor, a smaller, respectively, $n_v+1$ the sensor ($\sum_{k=1}^{v} n_k+1=N$). For such a sensor network length of DCI is: $K \geq \max(2N-1, N+2n_1-1)$.

The sensor of the first tier for DCI must perform $N$ gears (its message and all of its descendants). Sensors of the second tier for the DCI must implement $N$-1 transmission. Since this tree sensor of the first tier and second tier sensors can not transmit simultaneously (otherwise the sensor of the first tier would be both a source and recipient of the message), it would take at least $N + (N-1) = 2N-1$ slots. On the other hand, the sensor of the second tier of the first subtree should obtain from their descendants $n_1$-1 message and pass the first level sensor $n_1$ messages. The sensor of the first tier must pass the BS $N$ messages. All of these transmissions can not occur simultaneously, otherwise there is a conflict. Therefore, the DCI can not be less than $N+n_1-1+n_1=N+2n_1-1$ slots.

Now we formulate an algorithm that generates a schedule which is optimal for (1,$v$)-tree ($v$≥2).

**ALGORITHM *D*2 (*AD*2)**

By analogy with the *AD*1 we formulate the notion of iteration of the algorithm *D*2 ($I_{AD2}$). During one $I_{AD2}$ schedule is drawn up for 4 slots DCI.

1. Select two subtrees, the active part of which contains the largest number of nodes.
2. In the selected subtrees pave the route connecting the BS and one of the vertices of the active leaf of the tree.
3. For the set $M_s^1$ ($s$=0,1,2) we put sensors belonging to the first subtree and are on the line, the number of which is equal to s mod 3. To the set $M_s^2$ ($s$=0,1,2) we put sensors belonging to the second subtree and are on the line, the number of which is equal to s mod 3. Then will be formed following sets: $M_0^1=\{s_3\}$, $M_1^1=\{s_1\}$, $M_2^1=\{s_9\}$, $M_1^2=\{s_1,s_{10}\}$, $M_2^2=\{s_6,s_{11}\}$.

Distribute formed multiplicities on 4 slots of iterations.

The sensor of the first tier receives and transmits two messages during iteration. Two top sheet in the selected route is transmitted one message and, accordingly, do not take any. Other sensors take one message and transmit one message. Consequently, at the end of $I_{AD2}$ active tree network will be reduced by two leafy tops, and the network will go into pseudo starting state.

Next, consider the work *AD*2 in two cases:

Case 1. $n_1>\sum_{i=2}^{v} n_i$ .

Clearly, in this case, each part will $I_{AD2}$ first subtree and one of the other subtrees. Then through $\sum_{i=2}^{v} n_i$ all iterations subtrees with numbers $i=\overline{2,v}$ will be excluded from the active tree, and in the active part of the first subtree remains $1+n_1-\sum_{i=2}^{v} n_i$ nodes. Active tree degenerates into (1,1)-tree. For it, the schedule can be compiled from *AD*1 and has a duration of $3(1+n_1-\sum_{i=2}^{v} n_i)-3$ slots. Then a full schedule will have a duration of $4\sum_{i=2}^{v} n_i+3(1+n_1-\sum_{i=2}^{v} n_i)-3=3n_1+\sum_{i=2}^{v} n_i=2n_1+\sum_{i=2}^{v} n_i\ 2n_1+N-1$.

This is the lowest attainable duration DCI.

Case 2. $n_1\le\sum_{i=2}^{v} n_i$ .

If the sum is $n_1 > \sum_{i=2}^{v} n_i$ even, then after $\frac{1}{2}\sum_{i=2}^{v} n_i$ iterations through active tree 1 sensor (first tier) will remain active. The total duration of the DCI will then be equal to $4(\frac{1}{2}\sum_{i=2}^{v} n_i)+1=2\sum_{i=2}^{v} n_i+1=2N-1$. If the sum $\sum_{i=2}^{v} n_i$ is odd, then $\frac{1}{2}(\sum_{i=2}^{v} n_i -1)$ iterations active tree degenerate into (1,1)-tree containing 2 sensor. Then the total duration of the DCI will be $4*\frac{1}{2}(\sum_{i=2}^{v} n_i -1)+ 3 * 2 - 3 = 2\sum_{i=2}^{v} n_i +1= 2N-1$. $(2N-1)$ is the minimum attainable for the duration of DCI $(1,v)$-tree.

We introduce the following notation: $C_i$ – $i$- th slot in the DCI; $C$ – the set of slots in the DCI; $F$ – a lot of empty slots (it is not carried out any transfer) in DCI; $V$ – a lot of vacant slots (there is no transmission of messages to the BS) in DCI; $V_{i,j}$ – a subset of $V$, containing slots whose numbers belong to the interval $[i, j]$; $M$ – set of slots, which are transmitted to the BS; $M^{i,j}$ – a subset of $M$, containing slots whose numbers belong to the interval $[i, j]$. It is clear that $V \cap M$ € ø, $V \cup M=C$, $F \subseteq V$, and $|M|=N$.

Suppose we are given two trees $D_{N_1}(1,v_1)$ and $D_{N_2}(1,v_2)$, for which the duration of the scheduling $R_1$ and $R_2$, compiled by $AD2$ respectively, are $K_1$ and $K_2$ slots ($K_1 \geq K_2$). hen, for these trees, there are always schedules $R_1$ and $R_2$ with lengths $K'_1$ and $K'_2$, respectively, such that the following conditions:

$$M'_1 \cap M'_2 \text{ € ø};$$
$$\text{For } \forall C_i, C_j \text{ € } (V_1^{'1,K_2} \cap V_2^{'1,K_2}),\ i=j \bmod 3; \qquad (2)$$
$$\max(K'_1, K'_2) \leq K_1+1.$$

There is no such slot, which would have both trees transferring message to the BS, and the number of slots vacant in both trees and having a number in the range $[1, K_2]$ are equal mod 3.

For any tree $D_N(1,v)$ and any given $k$=0,1, 2 you can always make a schedule for $AD2$ $R$ such that:

$$\text{any } C_i \text{ € } M \text{ if } i=k \bmod 3 \qquad (3)$$

Path given tree $D_N(u,v)$ $(u \geq 2)$. Lets allocate $u$ subtrees containing BS, is the root of each of these subtrees, and many descendants through each of the nodes of the first tier. Formulations for these subtrees by $AD2$ schedules $R_i$, $i=\overline{1,u}$. We arrange the subtrees to reduce the duration of the schedule. Then the first subtree will be the longest schedule containing $K_1$ slots. Number of sensors contained in subtrees are respectively $N_1, N_2,..., N_u$ [1]. For the duration of such a tree DCI satisfies (4).

$$K \geq \begin{cases} \max(K_1, N), K_1 > K_2 \\ \max(K_1+1, N), K_1 = K_2 \end{cases}. \qquad (4)$$

Duration of timing can not be less than $N$, and can not be less than $K_1$. If $K_1=K_2$ the $K_1$-th slot two subtrees shall transmit on BS. In order to avoid conflicts of one of the two subtrees should move this transfer to another slot. Moving to an earlier slot isimpossible, because timetable is drawn up by $AD2$ is optimal. Hence, this transmission can be transferred only to a later slot, which means that the duration of the schedule will not be less than $K_1+1$.

## ALGORITHM *D*3 (*AD*3)

Let's arrange the subtrees by theirs descending duration schedules drawn up by $AD2$. Consider 3 cases.

Case 1: $u=2$.

Let's compose schedules $R_1$ and $R_2$, or two subtrees, satisfying the conditions set forth in (2) in this case $R=R_1\cup R_2$ schedule is conflict-free. It is clear that if $K_1>K_2$ the duration of the schedule is $K_1$. On the other hand, if $K_1=K_2$, then $R_1$ will be inserted into an empty slot and $R$ will have a duration of $K_1+1$. Thus, when $u=2$ $AD3$ provides optimal schedule.

Case 2: $u=3$.

Let's compose schedules $R_1$ and $R_2$, for two subtrees, satisfying the conditions set forth in (2), and for the third subtree – schedule $R_3$, satisfying the conditions laid down in (3).

In order to transfer the third subtree to the BS did not make collisions lets allow only those that are located in the slots belonging $M_3^{'}=M_3\cap(V_1\cup V_2)$. Based on the properties of schedules can be seen that $V_1^{1,K_3}\cap V_2^{1,K_3}\subseteq M_3$. Then $M_1^{1,K_3}\cup M_2^{1,K_3}\cup M_3^{'}=C_1^{1,K_3}$, that is, each slot numbers $[1, K_3]$ on the BS receives one message. In the sensor of the 1st tier of the third subtree at the end of the slot number $K_3$ is accumulated remaining $N_3$-$|V_1^{1,K_3}\cap V_2^{1,K_3}|$ messages. These reports this sensor should produce to BS in any vacant slot [2].

If $(N_3 - |V_1^{1,K_3}\cap V_2^{1,K_3}|)\leq|V_1^{K_3+1,K_1}\cap V_2^{K_3+1,K_1}|$, then part of the vacant slots of the plurality $V_1^{K_3+1,K_1}\cap V_2^{K_3+1,K_1}$, will be filled, and the duration of the schedule will be equal to $K_1$.

Otherwise, all vacant slots will be filled from $V_1^{K_3+1,K_1}\cap V_2^{K_3+1,K_1}$ and more $N3$ - $V_1^{1,K_3}\cap V_2^{1,K_3}$ - $|V_1^{K_3+1,K_1}\cap V_2^{K_3+1,K_1}|=N3-|V_1\cap V_2|$ slots sensor of the first tier of the third subtree will transmit each slot on the post. Then the length of the DCI will be equal to $K_1+K_3-|V_1\cap V_2|=(N_1+N_2+|V_1\cap V_2|)+N3-|V_1\cap V_2|=N_1+N_2+N3=N$. Thus, when $u=3$ $AD3$ also provides an optimal schedule.

Case 3: $u\geq4$.

In the first three subtrees set order of transmission of messages as well as in the case 2. Then, in slots numbered 1 through $K_3$ transmission of these messages to the BS subtrees carried out every slot. In other subtrees messaging should be carried out by *AD*2 randomly with the only difference that the sensors of the first tier they do not convey the message to the BS, and accumulate them. For subtrees numbered $i \geq 4$, $K_i \leq K_3$ it to the slot number $K_3$ in their sensors will be the first tier are clustered all messages with these subtrees. They should be transmitted to the BS in any slot, the remaining vacant after the first three subtrees. Then, if $\sum_{i=4}^{u} N_i > |V_1^{1,K_1} \cap V_2^{1,K_1} \cap V_3^{1,K_1}|$, all vacant slots in the interval [1, $K_1$] and length will be filled in the DCI will be equal to *N*. Alternatively, only a part of the vacant slots to be filled and the length of the DCI is equal to $K_1$. In both cases, the lower bound is achieved (4), then the algorithm *D*3 generates an optimal schedule for any arbitrary tree sensor network.

## CONCLUSION

Analyzing the information, evaluations and algorithms given in this article allow the following conclusions:

1. For any tree-like sensor network, you can always schedule, duration *K* € [*N*, 3*N*-3] slots;
2. The duration of the schedule depends on the number of sensors in the first and second tiers of the tree and distribution of the sensors to the subtrees of the graph network.

The developed algorithms increase the efficiency of information transfer in the form of knowledge in sensor networks integrated intelligent multi-information management systems, as well as allow you to schedule a minimum duration for any tree IMIUS sensor network. It should be noted a special attraction of the developed algorithms for systems operating in hard real-time where response time is a critical parameter.

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