Self-organization of the communication network

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Abstract. The author proposes a model of message delays in the ad hoc telecommunication network of mobile agents, in which connectivity and types of channels between agents change over time. We discuss the problems of the communication maintaining for the agents moving over the terrain with radio-impermeable obstacles and for agents with directed antennae. In the case of directed antennae, agents should choose such a way of movement, that antenna orientation would be maintained during the movement.

1. Introduction
The author has built a model of message delays in a communication network of mobile agents, in which connectivity and types of channels between agents change over time. Agents move around the area with obstacles impeding communication between agents and the movement of agents (figure 1, hatching of different colours indicates obstacles of different permeability, the thicker the hatching, the weaker the permeability obstructions for radio waves). The system of agents shown in the figure is \( q_{ij}, i = 1, 3, j = 1, 4 \), connected by communication channels \( c_k, k = 1, 9 \), can simulate a movement of soldiers equipped with radio stations, groups of interacting robots or unmanned aircraft over rough terrain with impervious to radio waves obstacles.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Changes of the communication system model in the process of agents’ movement.}
\end{figure}

The movement of agents on the terrain is modeled using a cellular automaton [1]. The author
also modeled random movement of agents between given points, taking into account the number and type of randomly distributed obstacles [2].

Agents are vertices of the communication graph. Each agent owns a set of communication devices. The edges of the communication graph are communication channels organized by communication devices of agents located in the vertices of the graph. If there is an obstacle between agents that excludes communication over an existing communication channel, the communication channel is changed to a more suitable one, taking into account the capabilities of the agents. Each agent has a message distribution schedule, and each communication channel has a maximum throughput.

Self-organization in systems of this type may include automatic distribution of radio frequencies between agents, which was studied by the author, for example, in [3]. However, of considerable interest is an agent’s automatic selection of the telecommunication devices in the process of movement based on the permeability of the terrain, the distance of other agents from this agent, and the required QoS. In fact, the solution to such a problem comes down to the development of an appropriate expert system.

2. Agents with narrowly directed antennae
Let us consider the system of mobile agents with narrowly directed antennae. We can study two cases: the case of agents with rotating antennae and the case of agents with fixed antennae. In the first case, agents should continuously change the direction of their antennae to ensure uninterrupted communication while moving. If there is a base station in the network of agents, a constant correction of the antenna position from the base station is possible. However, in the ad hoc network of agents, it is necessary to use algorithms similar to those used for organizing a formation of agents in decentralized systems [4].

In this case, an agent sends a message to the nearest neighbour about the need to change its position and further such information is distributed along a chain of neighbouring agents. In the case of a system of agents with directional antennae, instead of reporting the need to change the position of the agent in order to maintain a formation, it is necessary to transmit a message about the need to change an orientation of the antenna in order to maintain network connectivity. In short, the algorithm for the movement and communication of such agents is as follows:

- All agents are at the initial positions, the antennae are directed so that the necessary connectivity of the agent network is achieved. Each agent has a list \( L \) of agents with which he must keep in touch.
- If one of the agents needs a turn, the agent sends a message to the closest \( a_g N \) agent from \( L \) about the need to deploy the antenna for a specified number degrees.
- After receiving confirmation from \( a_g N \), the agent makes the necessary turn. antennae.
- The agent waits for the duration of the time required for all the agents from \( L \) to turn the antennae.
- The agent continues to move.

Obviously, agents connected with directional antennae cannot move completely arbitrarily and must also maintain a certain order, although not necessarily hard. Rather, such a system can be described using the fuzzy graph previously introduced by the author [5]. The relationship between the degree of rigidity of the graph of building agents and the angle of the solution of the main lobe of the antenna pattern of each agent is the subject of current research by the author.

From the foregoing, it follows that each agent must be able to predict the direction of movement of other agents from \( L \). Prediction occurs based on the latest obtained data on
the direction and speed of movement of agents, i.e. it is assumed that the direction of movement and the speed of the agent will be constant for some time.

If as a result of the prediction, which should be carried out with a certain periodicity, it turns out that at least one of the agents is lost from appearance, then

- A warning message is sent to such agent.
- An additional synchronization of the directions of the agents’ antennae occurs.

In the second case, an agent should rotate itself instead of rotating antenna, so it is necessary to find specific route to maintain connectivity.

We can explain the aforementioned with the example of two agents (figure 2).

![Figure 2. Mobile agents with directed antennae.](image)

The agent 1 moves along the route $r_1$, the agent 2 moves along the route $r_2$. The angle between the antenna ray and the movement direction is $\alpha_1$ for the agent 1 and $\alpha_2$ for the agent 2. For certain time moments $t$, antennae of agents 1 and 2 should be oriented in the way providing the communication between agents. This can be achieved by entering a certain mode of braking when passing a route. Mathematically, it can be expressed as the conditions

$$\left(r_j \circ l_j(t) - r_i \circ l_i(t), \frac{d(r_i \circ l_i(t))}{dt}\right) = |r_j \circ l_j(t) - r_i \circ l_i(t)| \left|\frac{d(r_i \circ l_i(t))}{dt}\right| \cos \alpha_i(t),$$  \hspace{1cm} (1)

where $i, j = 1, 2$, $i \neq j$, $r_i$ is a time-independent parametrization of the $i^{th}$ agent route, for example, the natural parametrization, $l_i$ is the length of the route passed on the moment $t$ for the $i^{th}$ agent, $\circ$ is the operation of superposition. We assume that in the moment $t = 0$ the equation (1) should have a solution.

In order to relax the restriction on the speed of agents, I propose the following.

- The agents 1 and 2 start a message exchange in the moment $t = 0$. As agents know the size of scheduled messages $M_i$, the data transmission rate $v_i$, and the length $l_i(t)$, they can calculate the position $s_{i1} = r_i(l_i(M_i/v_i))$ on their routes which corresponds to the stop of a message exchange. So, the agent $i$ should use a speed regime corresponding $l_i(t)$ until it reaches $s_{i1}$.
- After the end of the exchange of messages, the agents must agree on a point in time $t_2$ to continue the exchange.
- From the moment $t_2$ (or from the point $s_{i2} = r_i(t_2)$) until the end of the message exchange, the agents should use a speed regime corresponding $l_i(t)$ again, and so on.
• When agents 1 and 2 don’t need to communicate and are free to move at any speed, they can adjust their speed so that they communicate with other agents that may be present in the system.

• If an unforeseen obstacle is found in the route of the agent \( i \) at the time moment \( t \in (t_1, t_2) \), then the agent \( i \) should send a message about a possible connection failure to the agent \( j \) \((i \neq j)\). After avoiding an obstacle, the agent \( i \) must increase its speed (i.e. change function \( l_i \)) in order to reach the point \( s_{i2} \) where the next session of the message exchange begins at the moment of time \( t_2 \).

Therefore, if we have \( n \) agents, \( n > 2 \), we should divide the route of each agent \( aq_i \) on parts where it communicates with other agents.

If, for example, \( r_1(l_1) = (l_1, l_1), r_2(l_2) = (l_2, kl_2) \), \( \alpha_1, \alpha_2 \) are constants, and the agents move without returns, then from (1)

\[-2l_1(t) + (1 + k)l_2(t) = \sqrt{2} \cos \alpha_1 \sqrt{|l_1(t) - l_2(t)|^2 + |l_1(t) - kl_2(t)|^2} \]

and

\[l_2(t) = \frac{2}{-1 + 2 \cos^2 \alpha_1 - 2k - k^2 + 2 \cos^2 \alpha_1 k^2 (-l_1(t) + l_1(t) \cos^2 \alpha_1 - kl_1(t) + kl_1(t) \cos^2 \alpha_1 - \cos^2 \alpha_1 l_1^2(t) - l_1^2(t) \cos^4 \alpha_1 - 2k l_1^2(t) \cos^2 \alpha_1 + 2k l_1^2(t) \cos^4 \alpha_1 + k^2 l_1^2(t) \cos^2 \alpha_1 - k^2 l_1^2(t) \cos^4 \alpha_1)^{1/2}). \] (2)

As we can plan near any agent’s route as polygonal chain, the equation (2) describes the most common type of the agents’ movements interdependence.

3. Conclusion

The model proposed by the author and the “Psychohod” software based on it makes it possible to take into account the change in traffic in the systems communication channels when agents are moving along rough terrain and possible channel breaks, as well as simulating the system mobile agents with directed antennae and with automatic selection of the optimal telecommunication devices. The author also plans to study the distribution of random variables, such as the speed of a communication channel as agents move around different types of terrains, depending on the number and distribution of obstacles to the movement and organization of communication agents.

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