A Battle for a Forest: 3-Layered Model of Fire-Fighters Actions Based on Limited Information Gathered by a Wireless Sensor Network

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Abstract

We describe a simulation model concerning a scenario of a burning forest and fire-fighters battling with blaze. The simulator addresses three layers of the scenario. We model spreading of the fire, a network of sensors gathering temperature data from the forest and fire-fighters actions taken automatically on the basis of sensors data. We also provide initial simulation results showing how the precision of the sensors data affects the fire-fighters efficiency.

1. INTRODUCTION

While forest fires computational aspects were thoroughly studied and numerous solutions have been developed [1-2] until now, we would like to discuss the other side of the coin: fire-fighters battling with blaze in a burning forest. In this short paper, a 3-layered discrete event computer simulator is presented that properly addresses this scenario. First, we are adopting, with slight modifications, a percolative cellular automata forest fire model [1] that shows the fire spreading in a forest. Second, we are simulating a network of tiny wireless sensors, deployed in the forest and gathering temperature data. Finally, we are considering fire-fighter teams that use the sensors data and choose specific locations in the forest in order to extinguish the fire there. As the number of sensors is limited, fire-fighters have only partial knowledge about the fire and their choices (where to extinguish the fire) can be incorrect. We focus on modeling the interaction between three layers of the simulator showing the relation between the precision of the sensors data and the efficiency of fire-fighter actions.

2. FOREST FIRE

We assume that the forest is divided into a hexagonal grid. Each forest site (a hex with height of 30 m) has six neighbors. The fire starts from an ignition of a single tree in the middle of the forest. Then, the fire is spreading according to the model presented in [1] and adopted, with some modifications, in this paper. The model can be shortly described as follows.

Each forest site can be in one of three states: (a) there can be some trees there, (b) the site can be burning or (c) it can be burnt out to ashes. In each discrete time step, sites can change their states according to the following rules. A site with trees will start to burn with ignition probability P_I, but only if it has a neighbor site that was burning in the previous time step. A burning site will turn into ashes with burning probability P_B. Finally, all sites with ashes remain in this state until the end of the simulation (see Fig. 1).

3. SENSOR NETWORK

As a second layer of the simulator, we model a certain number of sensors that are distributed randomly in the forest. Additionally, in four forest corners, there are control stations that can freely contact with each other. The sensors can send the temperature data in a multi-hop way to one of the control stations, however they have limited connection capabilities. Sensor transmission parameters are based on MICAz motes [3] working in 2.4 GHz frequency band and commonly used in environmental applications. The wireless channels between the sensors are modeled according to the attenuation in vegetation model developed by International Telecommunication Union [4] with channel fadings as suggested in [5] on the basis of measurements performed for sensor networks in outdoor environments. Thus, it can happen that a sensor is isolated, being located too far from the control stations and other sensors and unable to transmit its data.

The sensors gather the temperature data informing about their distance to a fire. We assume the following simple rules about sensor readings:

a) in a distance smaller than 15 m from a fire, the sensor is burning and sends no data;
b) if the sensor is farther than 150 m from all burning sites, it reports only the ambient temperature, thus gives no information about the fire;
c) if the distance from the sensor to the nearest fire is in the range (15,150) m, the sensor can exactly calculate this distance on the basis of the measured temperature.

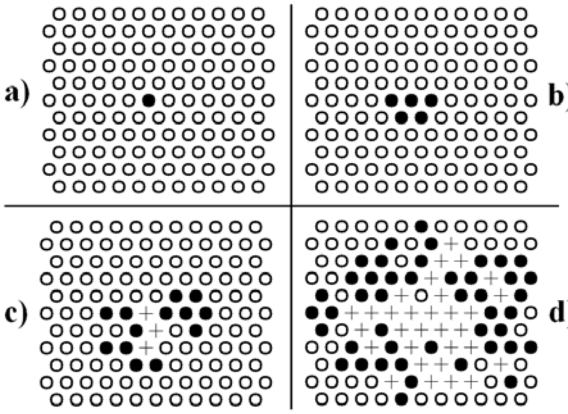

Figure 1. An example of the forest evolution, the steps 1, 2, 4 and 8 are shown. There are three possible site states: with trees (o), under fire (•) or covered by ashes (+).

The data that reaches the control stations is then merged in order to obtain a map of the fire. The forest is analyzed to decide which sites are burning. For each site, the data from sensors located in the range of 150 m is analyzed. A site is regarded as under fire if and only if each considered sensor reports the distance to fire closer that the distance between the sensor and the site. Otherwise, the site is regarded as covered by trees or ashes. These two states are distinguished from each other using the memory of the previous state, as after the fire there can be only ashes, no trees. Finally, it is possible that the system cannot detect the state of a site, if there are no sensors in the range of 150 m. It should be noted that, when fire is growing, the network topology is reduced, as some sensors are burning and become unusable.

4. FIRE-FIGHTERS ACTIONS

The third simulator layer describes the actions of fire-fighters. In every time step, each fire-fighter is working in a single forest site, extinguishing the fire there, preventing its spreading to neighbor sites and changing the site to ashes.

The decisions where to send the fire-fighters are taken on the basis of the fire map. We choose the burning sites that have the maximum number of neighbors with trees. This approach is similar to basic strategies for preventing the viruses or epidemics propagation in communication or social networks [6]. If we consider the forest as a network, the sites can be regarded as nodes. In the forest before the fire, the degree of all the nodes (sites) is the same, equal 6, as the forest is modeled as a hexagonal grid. However, in case of fire, a node degree can be reduced. A burning site can spread the fire only to its neighbor sites with trees. Thus, the fire-fighting approach can be seen as an attempt to protect the nodes (sites) with the highest degree (having the large number of neighbor sites with trees).

It can also happen that, because of errors on the fire map, the fire-fighters are sent to a site without fire. We assume that such an action is wasted and has no effect.

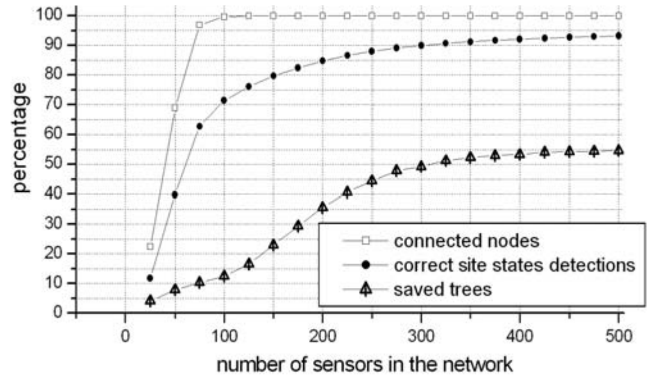

Figure 2. Connected nodes, correct detections of the site states (in first 30 simulation steps) and saved trees.

5. SIMULATION RESULTS

According to the rules described above, a C++ simulator was built and we have obtained initial results. We investigated a case of a 1260 × 832 m^2 forest (42 × 32 hex sites). We adopted the probabilities P_I = 0.5 and P_B = 0.3 and assumed 6 fire-fighters. We analyzed the precision of the created fire map and efficiency of the fire-fighters actions for the number of sensors ranging from 50 to 500. In each case, we run the simulations 10.000 times.

In Fig. 2, the obtained results are documented. For a very small number of sensors (below 75), many of them are not connected with control stations and cannot send their data. For larger number of sensors (100–250), the majority of them is connected, but still their density is too low to locate the fire precisely and effectively use the fire-fighters. With 300 sensors, we can save about 50% of the forest. More sensors results only in a slight improvement of fire-fighters efficiency.

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