Mobility Simulation of Connected Objects in a Heterogeneous Wireless Data Transmission System

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We consider a simulation model of a warehouse with three types of wireless communication links: device-to-device (D2D) links, drone-assisted and infrastructure-based links (via the base station). In all study cases three types of mobile objects are considered: employees (humans), wireless access points in the form of flying robots (drones) and stationary devices (machines). As a result of the conducted research we propose a software tool which provides the graphical representation of mobility of the objects inside the warehouse with given parameters. It allows to assess the network coverage area and allows to study the Internet of Things (IoT) connectivity issues. The developed algorithm and its software implementation allowed to study the impact of different mobility models on the system-level performance of the considered data transmission system in terms of its network connectivity, defined as the ratio of connected devices.

Our evaluation results demonstrate that the use of Reference Point mobility model under the same parameters setting of the system ensures the increase of coverage up to 10%. Therefore the additional area under the RP model is in average less than that under the RW model. Analysis of the obtained graphical results allows to estimate the impact of the number of flying wireless access points in the active state to the coverage area of the considered heterogeneous wireless communication system.

Key words and phrases: mathematical modeling and simulation, reliable Internet of Things (RIoT), wireless communication, heterogeneous system.

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1. Introduction

Unmanned objects' control and industrial robotization are currently the most popular and economically interesting projects in the field of high technology for business. According to analysts, the market of IoT by 2020 will increase up to 1.9 trillion USD. The diagram on the Figure 1 shows that according to Ericsson‘s data by 2021 the number of devices connected to the network will be about 28 billion and more than 15 billion will be machine-to-machine (M2M) devices and consumer electronics [1–4].

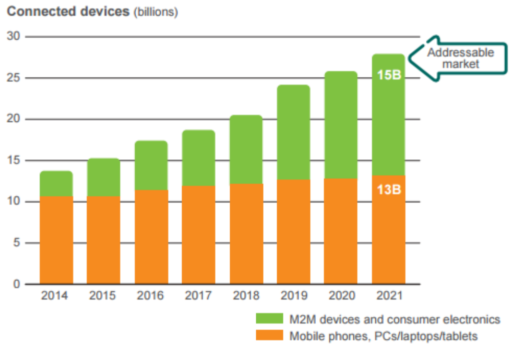


Figure 1. Growth dynamics of IoT

The development of IoT makes it possible to increase the stability for the society and the industry. The implementation of these technologies allows to reduce the resource costs and enhance the efficiency of warehouses. The up-to-date hardware allows to implement this technology in virtually all areas of interest starting from the control of production, transport and logistics up to automatic security systems. The main methods of the data transfer in such networks are the Wi-Fi and Bluetooth (at short distances) technologies, and WAN (wide area networks) in primarily cellular networks that can provide communication at long distances. The use of such technologies creates a number of requirements for the data transmission network simultaneously with new opportunities. The main task is to ensure a stable (reliable [5–11]) connection between the IoT objects with low transmission delays and high availability [12–14].

The goals of this study are the development and software implementation of simulation modeling [15–17] of networked objects' mobility and their interaction through various technologies of wireless data transmission, taking into account the restrictions on the obects' ability to cross the borders of the considered area and the drones' gradual discharging.

2. Description of the problem and the system of interest

As an object of industrial automation for simulation we consider an indoor area (warehouse) of [100,100] meters, where human users and networked M2M devices are allowed to move freely within the considered location according to their specific mobility patterns. There are 100 static machines, 30 mobile warehouse employees and 5 drones within the considered indoor area. Drones provide communication between the humans and the machines, but in the same time the machines can be connected directly with humans and with each other via the D2D interaction [18–20]. This pattern is represented in Figure 2.

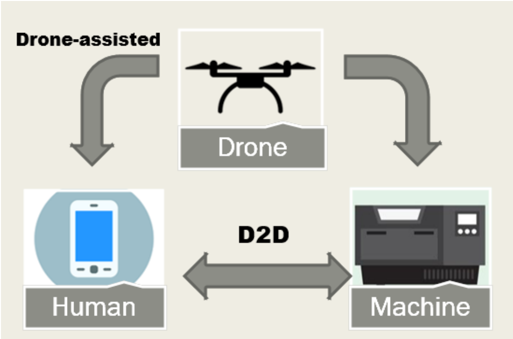


Figure 2. Interaction between devices

Humans are moving according to the Random Walk (RW) model at low speeds and in a random direction. We consider two mobility models of the drones: the RW model and the Reference Point (RP) model [21]. The RP model, contrary to the RW model, assumes that drones are moving in a group with small individual deviations from the general trajectory. At that, drones have a limited battery charge and must be recharged periodically. Drones "repel" from the boundaries of the region, that is, a drone changes its direction when approaching the boundary of the region at a distance of 1 meter, and then "repels" for an equal angle. Besides there is a Long-Term Evolution (LTE) cellular base station (BS) which allows for the devices to be served over the infrastructure-based connections. We assume that the base station coverage is partial within the modeled area, which corresponds to when the network serves challenging environments (e.g., with obstacles for signal propagation, such as walls, in the basements, etc.). Thus we consider that reliable cellular connectivity for the devices is only available over about 70% of the total area of interest based on deterministic modeling [22].

3. The results of simulation modeling

To implement the above task, a program was developed in Python. The solution algorithm is presented in the Figure 3. To define the initial conditions the user is given the opportunity to enter the model time value (number of loop iterations), the step (the distance to which the object can move), the radius of the drones' coverage, the coverage radius of D2D.

As a result of the program, the total number of objects with access to drones is calculated, as well as the number of people and the number of machines that have access to different types of communication at each step. To find the covered area, the total area of the warehouse is divided into equal squares, for each of which is defined its center, then the number of centers of squares included in the coverage area of the drones is counted. The resulting value, multiplied by the squares area, will constitute the area of the general coverage by the drones and the BS.

To assess the quality and efficiency of the model, are calculated parameters such as the total coverage of the base station and drones and the number of devices to which one or another type of communication is available. Also, as a result of the program, a schematic image of the state of the system is generated at each iteration. Figure 4 shows an example of the state of the model. Blue points are cars, reds are drones, green ones are people. Green circles are the active drone' coverage areas, black circle — BS coverage area.

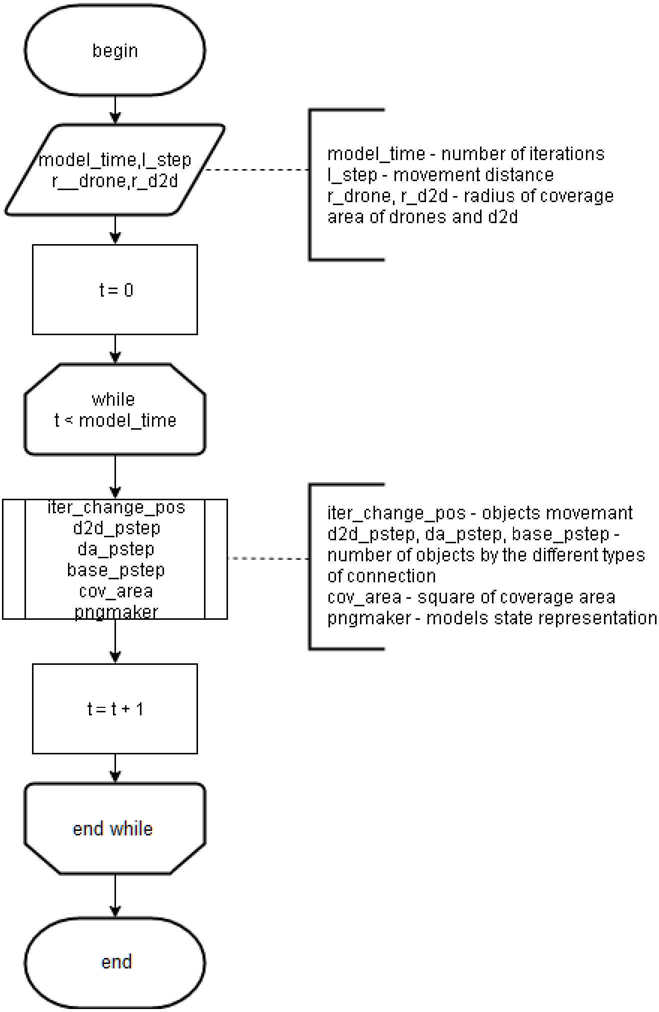


Figure 3. Flowchart of the operation algorithm

The developed software tool also allows to build graphs that show the ratio of different types of communication by the number of objects using them in percentage terms (Figure 5), number of drones in action (Figure 6), coverage area percentage (Figure 7).

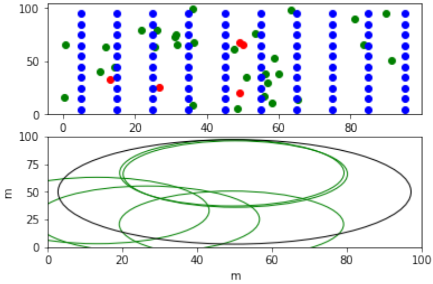


Figure 4. An example of the state of the simulation model

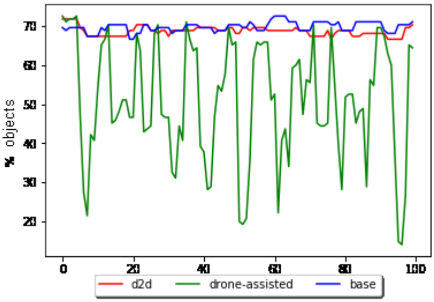


Figure 5. Impact of available radio access technologies to overall connectivity

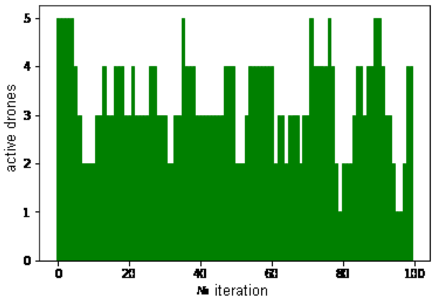
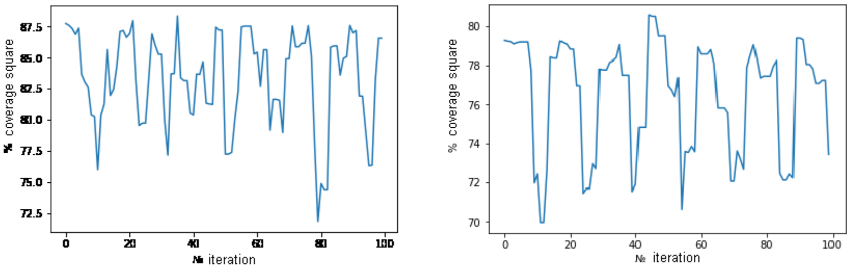


Figure 6. The trajectory of the process describing the functioning of the drones



a) RW b) RP

Figure 7. The square of wireless coverage area of drones and BSs

4. Conclusion

As a result of the work of the developed software tool, there were obtained graphs, which make it possible to estimate the square of the coverage area of connection of the networked objects under consideration. Based on the data showed in Figure 5, we can conclude that for the case when the radius of D2D-connection coverage area equals 20m and the radius of drone-assisted coverage area equals 30m throughout the model time, the percentage of objects to which the device-to-device connection is available and the percentage of objects which are served over the infrastructure-based connections, is approximately the same and fluctuates around 70%. At the same time, the percentage of devices that are available through drones can fall below 20%. The comparison of figures 4–7 allows to estimate the dependence of the wireless system coverage area on the number of drones in the active state.

According to the data represented at Figure 6 and Figure 7, the total square of the summary coverage area of drones and BS fluctuates from 72.5%, with one working drone, to 87.5% with 5 working drones (data calculated for the radius of the drones coverage equal to 30m).

Graphs represented in Figure 7 allow to compare the additional area at different models of movement of drones. The use of RP model with the same parameters of the system ensures the increase of coverage to 10%. Therefore the additional area using the Reference Point mobility model is on average less than Random Walk. The developed software also allows to visualize the state of the system at any time instant, estimate the surplus coverage area of the wireless connection, and calculate the average performance for each type of connection.

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