Model for Resource Allocation in Decentralized Networks Using Interaction Nets

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Abstract. This article presents the description of a model for allocating resources using Interaction Nets and a strategy for playing public goods. In the description of the model first shows the behavior of the allocation of resources towards the nodes depending on the usefulness of the network and the satisfaction of the agents. Then the generalization of the model with Interaction Nets is described, and a simulation of this behavior is made. It is found that there is an emerging behavior condition in the dynamics of the interaction when assigning resources. To test the model, the interaction of sharing the Internet in an ad hoc network is done. The interaction is shown in the general model obtained.

Keywords: Resource allocation · Ad hoc networks · Interaction Nets

1 Introduction

This article shows the design of a model for allocating resources in a decentralized network to its component nodes. The components of the model are, on the one hand, the computational model of Interaction Nets, which is used to formalize the concept of interaction in the context of computation. The second component is the set of public goods as a vision of allocation of resources to the participants of a specific agglomerate.

The control of decentralized networks is an element that differentiates this type of networks because it is from each of the nodes that make up the network [14]. The application of decentralized networks with more significant potential for the design and implementation of solutions in different areas are ad hoc

H. Florez et al. (Eds.): ICAI 2019, CCIS 1051, pp. 85–101, 2019.
https://doi.org/10.1007/978-3-030-32475-9_7

networks [1,5,6]. The operation of these networks is affected by a change in topology and a change in the number of participants as a function of time; since resources are limited, finite, techniques can be explored to optimize the use of these resources [10].

The analogies shown in the literature for assignment in traditional computational models are based on assignment in stable conditions, with centralized control schemes, or in current applications with distributed control schemes [11,12]. However, the change of paradigm of decentralized control in new generation networks makes it necessary to explore new techniques to perform the resources, such as memory, storage, and processing [2,15].

Decentralized networks have signs of complexity, and adaptability schemes to cope with these signs of complexity use various techniques to cope with this phenomenon. One of the possible ways to construct adaptation schemes is to understand the local interactions between network participants [19]. Thus, details of the functioning of decentralized networks can be covered.

The purpose of this work is to show how to generate a model of resource allocation for decentralized networks, the model is based on the game of public goods and is combined with Interaction Nets, looking for implementation in a computer tool (e.g., a programming language). In the real work, the application of the Interaction Net model is described to carry out a coverage expansion, and the resource assignment is the Internet assignment to the nodes that participate in an ad hoc network.

The distribution of the document is as follows: Sect. 2 presents the theoretical considerations of the model, first presents the concept of Interaction Nets, then describes the concept of the set of public goods and finally this the design of the model. Section 3 explains the simulation of the resource allocation model. Section 4 presents the real work. The description of an ad hoc network is presented, expanding the coverage of the Internet signal between the nodes that make up the ad hoc network. Finally, there are the conclusions and recommendations.

2 Theoretical Considerations for the Model

The purpose of this section is to present the relevant concepts that have been worked on for the construction of the resource allocation model. First, the computational model is presented to represent the elements that are part of the experiment. Then the problem of resource allocation is described using the game of public goods; finally, there is the Interaction Nets model.

2.1 Interaction Nets Model

The Interaction Nets model is a conceptual tool that helps to model different systems in engineering. The purpose of understanding and modeling the interactions of the nodes of an ad hoc network.

Interactions in opportunistic networks are a phenomenon associated with the dynamic characteristics of this type of systems [22]. The resulting emergence of these interactions must be modeled and thus controlled by computer systems [7,18]. The idea of the model is the creation of a computational method that contemplates these actions in highly interconnected systems (Environments where IoT networks are deployed or will be deployed) [13].

The model is represented by a graph, the main port, and secondary ports. The exchange of information between different nodes generates a change in the internal states of the nodes. This action is a definition of interaction. The idea of computation as interaction is the basis of this computational model [8,16].

This model is composed of the following elements:

- A set of symbol elements,
- A collection of interaction rules,
- A network of interactions, and active pairs.

A feature of this model uses several models, graphic, for active and function notation.

2.2 The Linear Public Good Game

The problem of the voluntary provision of resources has been usually analyzed using the linear public good game [9]. Nevertheless, due to the nature of open self-organizing systems, this model presents some limitations that need to be considered before applying it in the context of ad hoc networks. For example, it assumes that the public payoff is equally distributed even when it is possible for the appropriation to exceed allocation; that there is a full disclosure of all information required for the process; that there is no cost related to monitoring; that the utility for all resources are the same no matter if they are needed or not. As a consequence, in order to get a more realistic model, we relax some of these conditions using a variation of this game [17]. In this case, n agents form a cluster in which each agent i owns a quantity of some divisible resource and freely decides if contribute or not to the public good. We assume that agents take their decisions under self-interest analysis, and the game is played in consecutive rounds. In each round, each agent i:

- Determines the resources it has available, $g_i \in [0, 1]$
- Determines its needs of resources, $q_i \in [0, 1]$
- Makes a demand for resources, $d_i \in [0, 1]$
- Makes a provision of resources, $p_i \in [0, 1]\,(p_i \leq g_i)$
- Receives an allocation of resources, $r_i \in [0, 1]$
- Makes an appropriation of resources, $r'_i \in [0, 1]$.

The total amount of resources owned by an agent at the end of the round is given by $R_i = r'_i + (g_i - p_i)$, in which R_i is the sum of resources appropriated by the agent and the ones that it keeps for itself. The contributions of all participants are summed and the payoff u_i for the agent i is given by:

$$U_i = \begin{cases} a(q_i) + b(R_i - q_i) \; if R_i \geq q_i \\ a(R_i) - c(q_i - R_i) \; otherwise \end{cases} \quad (1)$$

where a, b and c are coefficients in $\mathbb{R}$ that represent the relative utility of getting the resources that are needed, getting resources that are not needed, and not getting the resources that are needed.

Furthermore, independent of its utility and the cooperation pattern (the prisoner's dilemma or the linear public good game) each agent i makes a subjective assessment of its satisfaction S_i expressed as a value in $[0, 1]$ according to the relationship between its allocation and its demands. In this regard, we can define the satisfaction level of the agent i in the round $t + 1$ as follows:

$$S_i(t+1) = \begin{cases} S_i(t) + \alpha \left[1 - S_i(t)\right] & \text{if} \quad r_i \geq d_i \\ S_i(t) - \beta(q_i - R_i) & \text{otherwise,} \end{cases} \quad (2)$$

where α and β are coefficients in $\mathbb{R}$ which determine the rate of reinforcement of satisfaction and dissatisfaction of each agent. As a result, choosing different combinations of α and β allow us to model different behaviors in the agents. For example, high values of α and low values β enable us to model agents with a high level of tolerance to situations in which they do not get what they need. On the other hand, high values of β will make the agents be dissatisfied more quickly, and therefore, they would stop following the institutional rules. This scenario is modeled through a threshold value of τ and an interval value of m. If for m consecutive rounds the agent i evaluate $S_i < \tau$ as true, it will stop cooperate. In the case of the prisoner's dilemma, the agents appropriate several resources greater than the allocated (they turn into free-riders). In the linear public good game, the agent leaves the cluster.

2.3 Distribution Model with Interaction Nets

The purpose of this model is to have a notation that serves to generate functionalities in a programming language, a simple representation of the problem and a perspective to analyze a particular situation. Figure 1 presents the situation of resource allocation from a network to a group of agents. Following the convention described in the problem of public goods, in the interaction the set of Σ agents.

- $\Sigma = \{i, g, q, d, r, r'\}$
- Networks U, S.

The rules of interaction are as follows:

- $i \bowtie g \rightarrow \lambda_1$ Determines available resources.
- $i \bowtie q \rightarrow \lambda_2$ Determines the need for resources.

- $i \bowtie d \rightarrow \lambda_3$ Makes a demand for resources to the network.
- $\lambda = \lambda_1 + \lambda_2 + \lambda_3$ The resources of the agent ask to the network.
- $i \bowtie r \rightarrow \mu_1$ Receive a resource allocation.
- $i \bowtie r' \rightarrow \mu_2$ Makes an appropriation of resources.
- $\mu = \mu_1 + \mu_2$ The resources that the network gives to the agent.

The contribution of the agents to the network and the satisfaction of each agent is the result of interactions between the set of agents and networks U and S. So the system that represents the allocation of resources is given by:

- $(i \bowtie \lambda)^* \rightarrow U, S$
- $(i \bowtie \mu)^* \rightarrow U, S$.

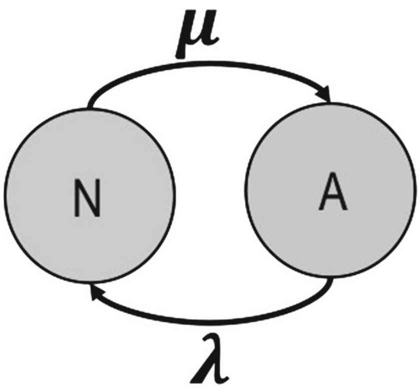

Fig. 1. Model of interactions. N represents the decentralized network, and A represents the collection of agents

Figure 1 shows the concept of interaction for resource allocation. N represents the decentralized network, and A represents the collection of agents. Because a decentralized network has unique features (e.g., decentralized control), it is necessary to review how the model behaves in these cases.

Each interaction between the agents and the network is for a particular scenario. It is considering that there is a variation of nodes in each configuration that varies the time. In each interaction, the usefulness of the contribution of the agents to the network and the satisfaction of the agents varies. Figure 2 shows the variation in the value of the *Utility* and the *Satisfaction* according to the possible configurations that a decentralized network can have. The calculation of each contribution of the participants and the level of satisfaction is exposed. For this we use the model exposed Eqs. 1 and 2.

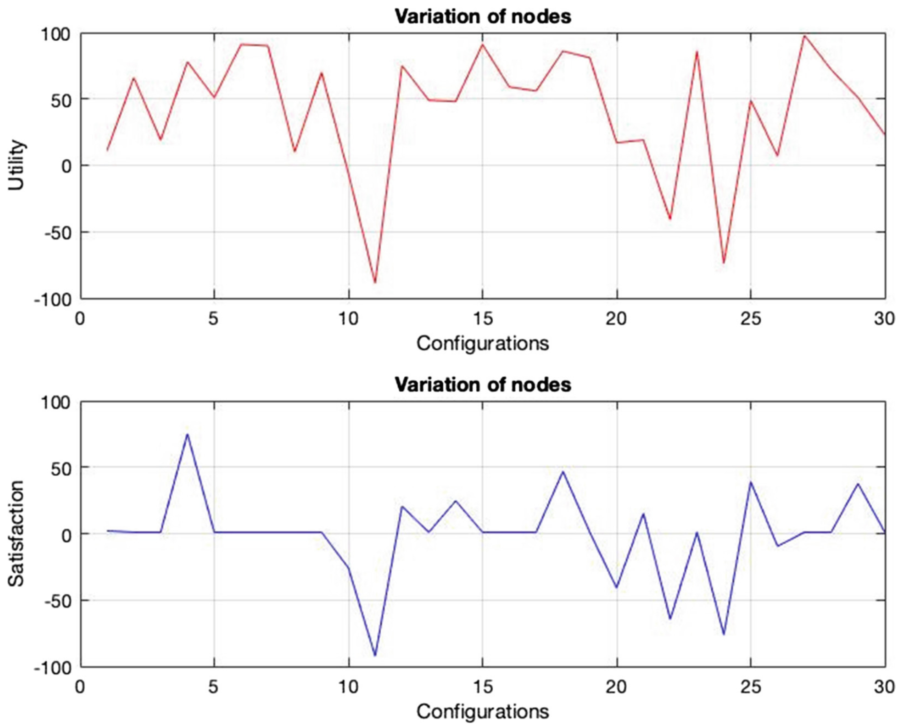

Fig. 2. Utility and satisfaction comparison

The rules of interaction for the general model with different configurations is:

- $(i \bowtie \lambda)^1 \rightarrow U_1, S_1$ and $(i \bowtie \mu)^1 \rightarrow U, S$ Configuration 1
- $(i \bowtie \lambda)^2 \rightarrow U_2, S_2$ and $(i \bowtie \mu)^2 \rightarrow U, S$ Configuration 2
- $(i \bowtie \lambda)^n \rightarrow U_n, S_n$ and $(i \bowtie \mu)^n \rightarrow U, S$ Configuration n.

Figure 3 shows the comparison between the usefulness versus the satisfaction of each agent. It is interesting to note that agent satisfaction is low while network utility is high. This observation indicates that the well-being of the majority is superimposed on that of the individual. One conclusion is that the behavior shown is an emerging characteristic of network behavior as a function of the dynamics of interactions between participants.

3 Tests on the Model

3.1 Simulation

Taking into account the description made in the previous section on the computation model and the resource allocation model, the purpose of this section is to show how to allocate resources from an entity (a network of nodes) to different agents (nodes).

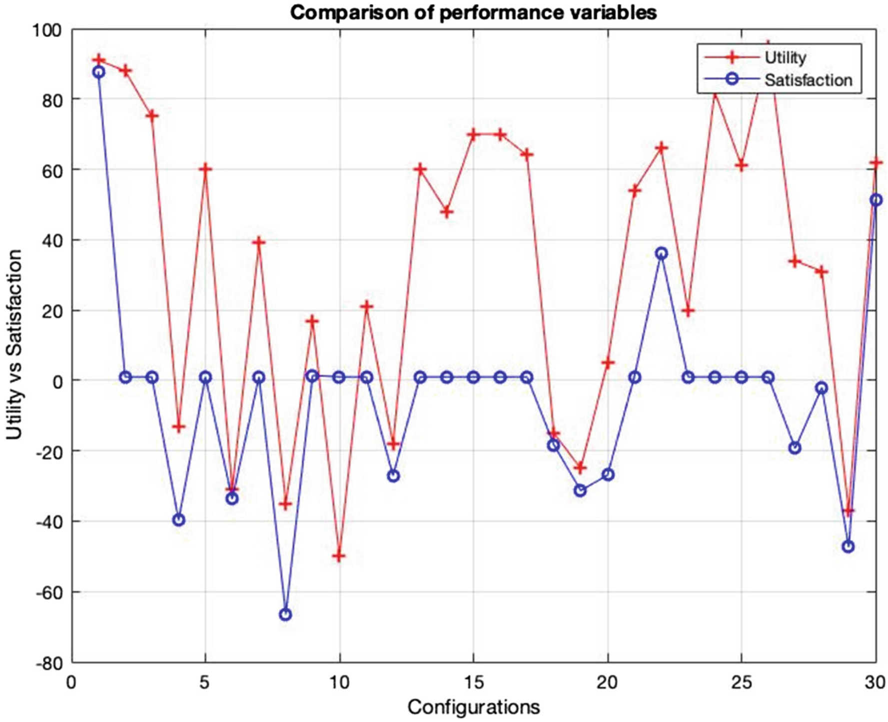

Fig. 3. Comparison of performance variables

NetLogo is used as a platform to simulate, and the variables used are the following: number of agents, degeneration rate, level of satisfaction, agents who do not cooperate.

The purpose of a simulation is to recreate the interactions between agents versus resources. We want to measure in the simulation the evolution of the allocation of resources. The simulation consists of placing a set of agents competing for a resource. The vertical axis corresponds to the amount of resource. The horizontal axis corresponds to the interaction. With the allocation model, resources are guaranteed overtime a necessary feature for performance with quality of service in a data network.

Three scenarios are compared, depending on the number of agents interacting with the network. Figure 4 shows the results of the comparison.

The comparison shows how the allocation of resources is stable from the network to the nodes. Below are the values of the simulation carried out:

– Number of agents: $[10, 30, 50]$
– Rate of degeneration of the resource: $0, 40$
– Scarcity: 1
– Satisfaction level: $S_{th} = 0.1$.

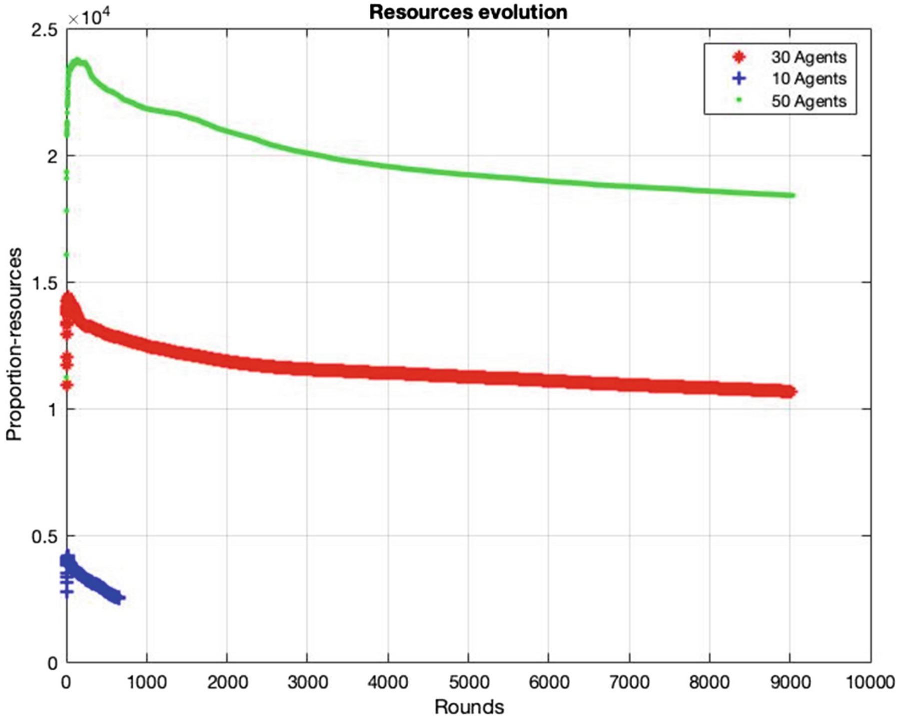

Fig. 4. Model of interactions

The parameter values are used to adjust the simulation to a real situation, for example, an ad hoc network for the generation of a sensor network. In this application, the resource to share in the storage memory.

– Agents equal to nodes.
– The speed at which the power of the nodes decreases (the battery of the devices). The scarcity implies the limit of resources that the agent must maintain.
– The S parameter is the level of times that the node fulfills its function (to take samples with the sensor and to send the information).

3.2 Implementation of an Interaction

The implementation of the interaction is done in the TL language, which is described in [19,20]. Sharing the Internet from one node to the other nodes of the network. This interaction is the most powerful application in the ad hoc network. Several additional services can be offered on the Internet channel to convert the network into a more flexible system and meet the possible user requirements. The code for this interaction is:

```
import mas.__init__
function internet(identifier, description, times)
    x = ExecuteScript()
    x.start()
end
log("test Interaction")
a = internet(1, CycleCallBash, 1000000)
```

For this application, the ExecuteScript agent has been used. In this case the CycleCallBash agent is in charge of executing the native function, which modifies the configuration of the node to create a bridge interface and share the internet service. The graphical view can be seen in Fig. 5.

The interaction is described as follows:

- $internet(A, B) \rightarrow CycleCallBash(A)|ack| \sim (ack)$
- $internet(B, \otimes_n) \rightarrow internet(A, B)|ack| \sim (ack)$
- $CycleCallBash(A, device) \rightarrow ExecuteScript(A, device)$
- $ExecuteScript(A, device) \rightarrow data$

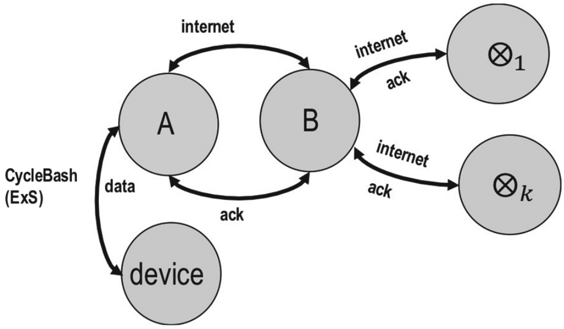

Fig. 5. Agent A shares the Internet with agent B. The interaction of B between the n Nodes of the network is sharing the Internet that comes from the agent A. The function of A is to execute the script as many times as necessary on the device to share the Internet.

The resource that behaves in this application is the Internet (bandwidth). The parameters that intervene in the process are elements described in the previous sections, several nodes of the network, the utility of the network and the satisfaction of the nodes.

- Number of nodes N
- Contribution of the nodes $U(t)$
- Satisfaction of each agent $S(t)$
- Resource: bandwidth, Internet Bw
- WLAN interfaces w_0.

The interaction of this application is:

– $(i \bowtie \lambda)^4 \rightarrow U_4, S_4 : Bw$
– $(i \bowtie \mu)^4 \rightarrow U_4, S_4 : w_0$.

3.3 Approach to Resource Allocation

The purpose of this model is to contribute to understanding decentralized systems as self-organizing systems and how these systems adapt to complexity. The idea of adaptation in self-organizing systems is different from other disciplines like machine learning, statistics or artificial intelligence. In general terms, these disciplines have in mind a single agent acting in an environment that could be unknown, stochastic, partially observable and so on; it could be difficult to find an optimal strategy, but there is a well-defined notion of what an optimal strategy is. In contrast, in the context of self-organizing communication networks, we have systems composed by multiple agents in which everyone is trying to adapt their strategies and achieve their goals at the same time; when an agent adapt its behavior, it is influenced not only by the environment but also by the behavior of other agents. As a consequence, this condition produces a high level of interdependence among the members of the system and makes necessary to provide institutions with adaptive mechanisms that allow them to adjust their parameters in order to react properly to changes in the agents' behavior and the environmental conditions.

4 Real Work

In this section, we will show an implementation of the resource allocation model, expanding the coverage of the Internet signal with an ad hoc network. The purpose is to teach, first, the application using the programming language and second the flexibility of the Interaction Nets model to support different configurations. The resource that is assigned is the bandwidth to route the packets that allow Internet sharing.

The Interaction Nets model considers interactions as computation. In [19,20] there is a definition of this model. A rewriting of the model is done by creating the coverage expansion network. The consideration of the interaction of a network with the following elements:

– A gateway node (Gw)
– Nodes as a proxy server.

Below are the rules of interaction and the graph with which the computational model is represented. This model is carried out by the scripts of the specific programming language for research.

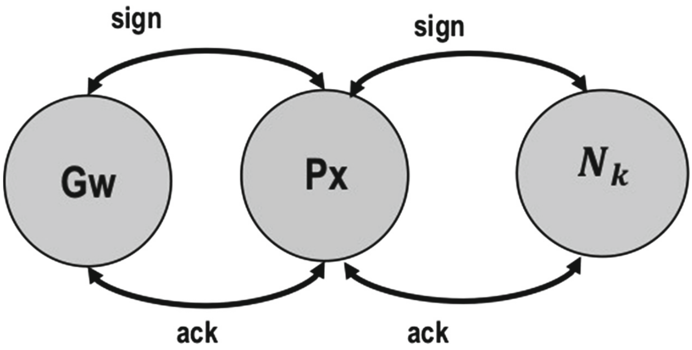

Fig. 6. Interaction graphically proxy

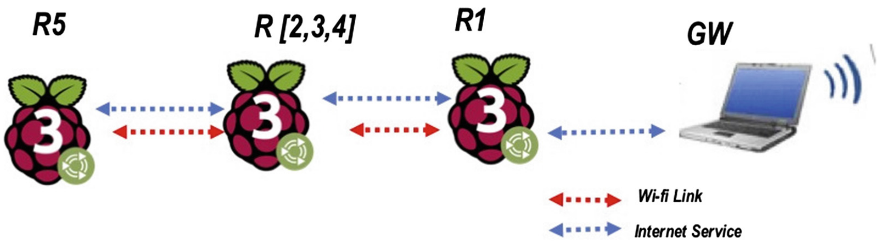

Fig. 7. Straight line configuration

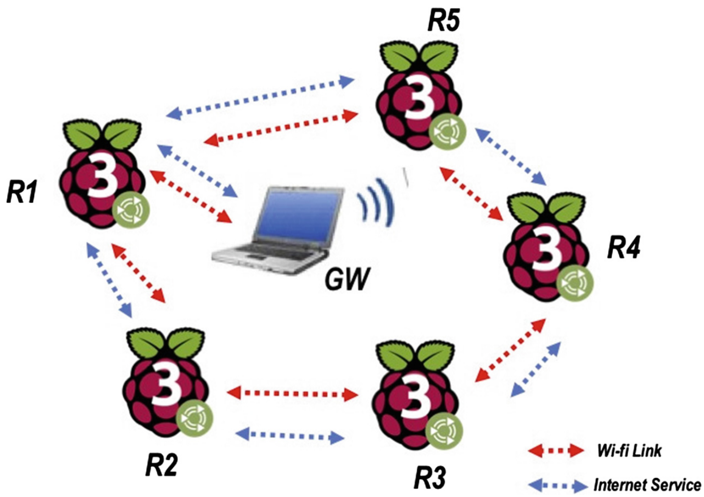

Fig. 8. Radial shape configuration

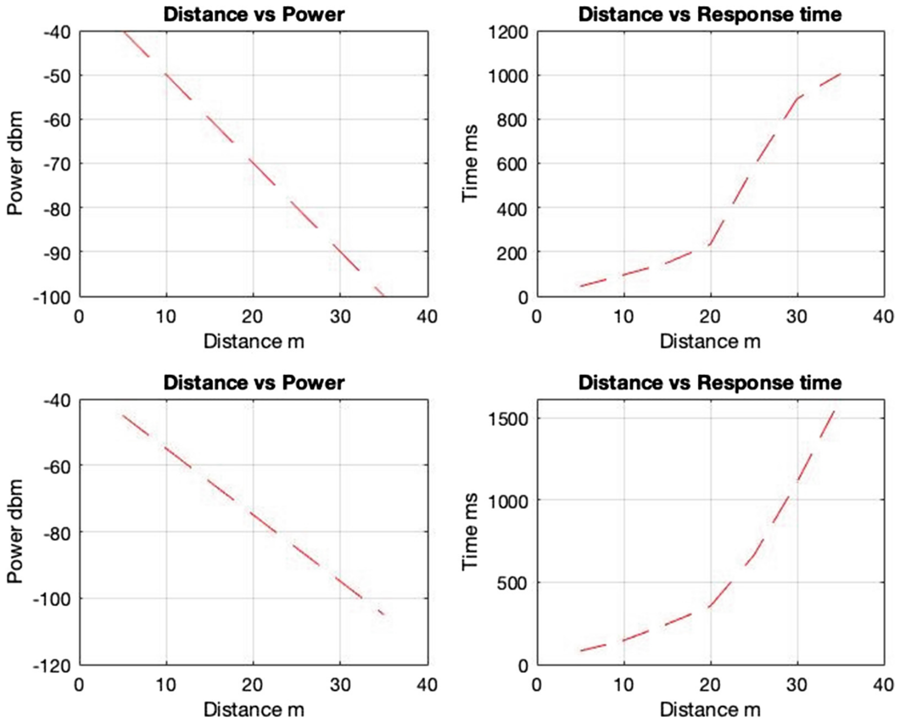

Fig. 9. Results of the 4 scenarios

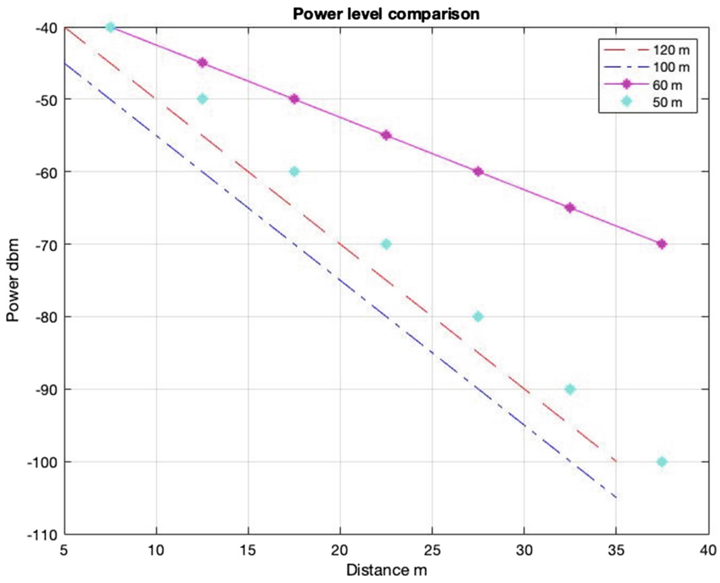

Fig. 10. Power comparison

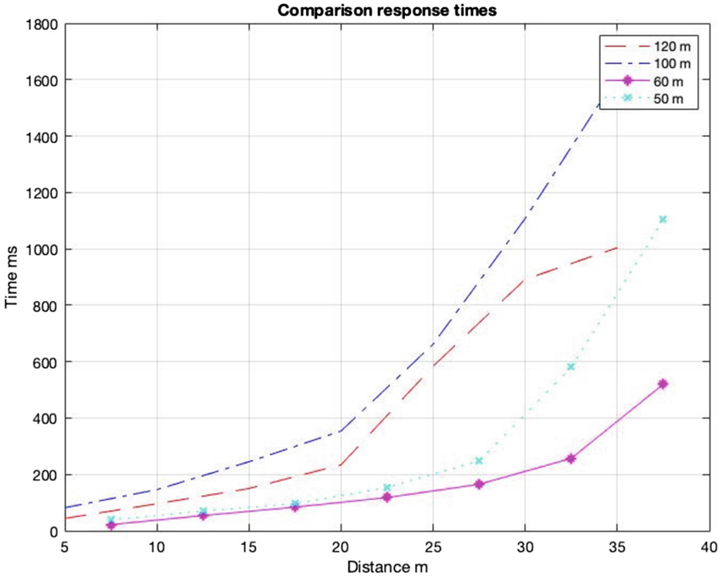

Fig. 11. Lost package comparison

1. $\Sigma = \{G_w, P_x, N_k, sign, ack\}$
2. $G_w \bowtie P_x \rightarrow sign, ack,\ (ack)$
3. $P_x \bowtie N_k \rightarrow sign, ack\ (ack)$
4. $G_w \bowtie P_x \rightarrow P_x \bowtie N_k.$

Figure 6 shows the interaction graphically

From the model, it can be said that item 1 corresponds to the group of agents that make up the interaction. The following agents have been defined for this interaction:

- G_w: agent as Gateway for internet access.
- P_x: agent as Proxy in charge of doing the distribution of the other nodes of the network.
- N_k: agent represents the nodes connected to the ad hoc network.
- $sign$: agent in charge of taking the Internet signal to the nodes of the network.
- ack: an agent with positive or negative response (ack), of the Internet signals in the nodes of the system.

The functioning of the agent modifying the interface of the nodes:

```
#bridge
#!/bin/bash
sudo ifconfig wlan0 down
sudo ifconfig eth0 down
sudo iwconfig wlan0 mode ad-hoc
sudo ifconfig wlan0 mtu 1532
```

```
sudo iwconfig wlan0 mode ad-hoc essid TL_INTERFAZ ap 02:1B:55:AD:0C:02 channel 1
sudo ip link set up dev wlan0
sudo ifconfig eth0 0.0.0.0 up
sudo ip link add name tlon0 type bridge
sudo ifconfig tl0 192.168.2.3 up
```

The previous script is the machine-level operation that is used by the *ExecuteScript*() agent and that allows the configuration of the ad hoc network nodes to expand the internet signal.

Figures 7, 8 show the ad hoc network configuration scenarios – one linear and one radial, with maximum distances of 120 and 60 each. The measured variables are power and response times.

After making the configuration of the ad hoc network, we proceeded to make the measurements of parameters, transmission power, and lost packets. These parameters are contrasted with the distance. The documentation and tests carried out in previous works [3,4] indicate that at higher distances, more lost packets and less transmission power. In the Figs. 9, 10, 11 it can be seen that these behaviours are fulfilled.

The Fig. 9 shows the different power variations against the distance. The four graphs correspond to the evaluation of power level versus distance and response times versus distance. This is for the first scenario where you have a linear configuration. The behavior of the power and response times is expected, the higher the range, the less power there is from the nodes, and the higher the response times.

With the distance 100 m and 120 m, the thresholds for considering services over the Internet [21], such as e-mail, communication between sensors and sending information to the cloud, are allowed with an acceptable quality of service.

The Fig. 10 shows a comparison between the different power levels for the four distances and scenarios explored. The reference to 25 m is found that the configuration with the least power is for 100 linear meters. Take into account the mobility of the nodes and the consumption of the nodes in a bridge configuration.

In the radial configuration, the power consumption is observed to be lower. This is due to the shorter separation distance. The routing of packages is a strategy to consider in the efficiency in the construction of ad hoc networks, with coverage extension capacity.

The expansion of coverage using ad hoc networks is a viable solution. The results obtained, allow applications over the Internet, can have an acceptable performance? applications such as sensor networks, information exchange between nodes or e-mail.

On the other hand, the operation of the mathematical model (for this research Net Interaction), can generate the modifications to the tool (programming language) to have functions that adapt to the needs of specific applications.

In this way, when reviewing the interaction model so that the nodes have the role of bridges and also to replicate the proxy process, it is proposed to modify the rule where the signal distribution action is generated:

- $G_w \bowtie P_x \rightarrow P_x \bowtie N_k$
- $(G_w \bowtie P_x \rightarrow P_x \bowtie N_k)^+$

This operation seeks to replicate from a configuration with a collection of M nodes in an instant of time $\{t\}$, to a collection of N nodes in an instant of time $\{t+1\}$.

5 Conclusions

This article has shown the process of designing a model for the allocation of resources for a decentralized network using two components, a computational Interaction Nets model and a set of public goods. The model is generalized to the situation where the configurations of the network participants change. The measurements made on the utility of the nodes $(U(t))$ and $S(t)$ reflect a behavior where it is obtained that, the satisfaction of the nodes can be minimal, but the utility of the network is useful or high. However, if the utility is below zero, the satisfaction of the nodes is also low. To complement this analysis, in the description of the evolution of resource allocation, it is also evident that this allocation reaches a stable behavior when its allocation process evolves.

Behavior is the result of the interactions present in the network. There are signs of emerging behavior; this means that if the network can guarantee minimum operating resources, regardless of the level of personal satisfaction of the participants, the behavior of the system will be in good operating points.

On the other hand, the model can be coupled with a computational tool (programming language) and thus develop applications to solve problems in ad hoc networks, such as coverage extension or sensor networks. Some application scripts with the TL programming language are exposed. The results obtained in the real work, indicate that the configuration made gives acceptable results in terms of response times and lost packets. An implementation of a sensor network configured with this tool increases quality and service and decreases implementation time.

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