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Load Balancing and Resource Allocation in Fog-Assisted 5G Networks: An Incentive-based Game-Theoretic Approach

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Response to the comments:

Sir, thank you for the acknowledgement, I have reviewed your comments and have made the following corrections to my manuscript:

1. added CONFLICT OF INTEREST
2. verified and synced email in both submission and manuscript.
3. corrected minor grammatical errors

Load Balancing and Resource Allocation in Fog-Assisted 5G Networks: An Incentive-based Game-Theoretic Approach

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Abstract

Fog-assisted 5G Networks allow the users within the networks to execute their tasks and processes through fog nodes and cooperation among the fog nodes. As a result, the delay in task execution reduces as compared to that in case of independent task execution, where the Base Station (BS) or server is directly involved. In the practical scenario, the ability to cooperate clearly depends on the willingness of fog nodes to cooperate. Hence, in this paper, we propose an incentive-based bargaining approach which encourages the fog nodes to cooperate among themselves by receiving incentives from the end users benefitting from the cooperation. Considering the heterogeneous nature of users and fog nodes based on their storage capacity, energy efficiency etc., we aim to emphasise a fair incentive mechanism which fairly and uniformly distributes the incentives from users to the participating fog nodes. The proposed incentive-based cooperative approach reduces the cost of end users as well as balances the energy consumption of fog nodes. The proposed system model addresses and models the above approaches and mathematically formulate cost models for both fog nodes and the end users in a fog-assisted 5G network.

Keywords: Fog computing, cooperation, task offloading, incentive, NBS

I. Introduction

In the present scenario, along with increasing end users, there is a proportional increase in the number and usage of mobile devices. Due to this fact, huge traffic is witnessed and experienced by the network nodes and cloud or fog servers which are responsible for serving the end users. In fog-assisted wireless networks, there are multiple fog nodes which are connected in a wireless network to the fog server. When multiple users directly request the fog server or independent fog nodes to serve the task execution, the delay is introduced as well as the cost of task execution increases due to energy spent by the server [1]. Thus, it becomes necessary to ensure balanced traffic loads over the fog nodes and simultaneously focus on enhancing the quality of service (QOS) and cost reduction. QOS can refer to various performance and other factors, including latency, task offloading efficiency, optimality and availability of services [2]. Thus, as per the recent research and studies, cooperative approaches for task execution and offloading in fog-assisted wireless networks are a suitable option, which consider the QOS parameters as well as cost factors. Fog nodes can be connected via direct d2d links or are in proximity with neighbouring nodes [3]. Hence, it enables interaction among the fog nodes. Cooperative task offloading makes use of the interaction and hence distributes the tasks among the fog nodes and offloads the tasks from overloaded nodes to the underloaded nodes [4]. Thus, the performance and efficiency of task offloading and load balancing schemes majorly depend on the way fog nodes cooperate. In order to encourage cooperation among the fog nodes, efficient fair incentive mechanisms can also be inculcated within the cooperative task offloading approaches [5]. Once the tasks are executed for users, the incentive from users can be fairly distributed among the fog nodes.

A. Motivation

The existing models emphasised cooperative approaches for load balancing among the fog nodes and improved Quality of Service (QoS) including service delay, response time, cost minimisation, energy efficiency etc [6]. However, the existing studies take into consideration the assumption that the fog nodes are socially bonded and are willing to cooperate in order to execute the user tasks. In the rational scenario, fog nodes may not agree to cooperate due to energy and transmission costs. This discourages the fog nodes to cooperate and offload the tasks to neighbouring fog nodes. Moreover, the characteristics of fog nodes may vary as per their storage capacity, energy sensitivity and delay factors [7].

The mentioned reasons motivate us to propose a cooperative mechanism of task execution among fog nodes in fog-assisted 5G networks to serve the fog users. We aim to use a game-theoretic approach to enable cooperation among fog nodes. Moreover, we propose a scheme for fair distribution of incentives to encourage cooperation and achieve Nash Bargaining Solution or NBS [8]. This model computes the energy and delay costs, as well as profits gained by fog nodes through cost modelling. Technically, given the fog users and their characteristics, we aim to find out answers to the below questions: *i) What portion or percentage of tasks need to be executed by fog nodes and cloud server, ii) How much incentive should the fog users pay for task execution? iii) How is the fair distribution scheme implemented for multiple fog nodes serving a fog user?*

B. Contributions

For analysing the cooperative offloading in fog-assisted 5G networks, we design a framework wherein we begin with modelling the cost function of both fog nodes and fog users based on certain parameters; heterogeneity, task demands and delay of different kinds. Moreover, in order to encourage fairness and cooperation among the fog nodes for task execution, an incentive-based, cooperative approach is proposed, under which a fog users pay an amount as an incentive to the fog nodes participating in tsk execution. This, in turn, also claims to reduce overall cost of task execution for the fog users. The major contributions can be briefed as follows:

- We assume and simulate a fog-assisted 5G network including fog nodes and fog users as the participants characterized by the following characteristics; sensitivity of delay, energy, and storage efficiency. Additionally, we analyse and infer observations of effect of above listed characteristics on the task execution in cooperative manner.
- We frame the problem statement of cooperative task execution as a game, more appropriately as a bargaining situation between fog users and the fog nodes. We treat both users and fog nodes as players who try to balance the profit. On the basis of bargaining game and solution found, we aim to propose a highly cooperative and incentive-based task execution and offloading approach which maximises throughput and minimises cost.

The remaining paper is organised in the following manner; Section II discusses the literature review and related work conducted to study fog-assisted networks and incentive as well as non-incentive-based resource allocation schemes. Section III defines and explains the system model representing the problem statement and assumptions taken into consideration. The system model is discussed with cost modelling with an overview to NBS. Section IV evaluates the given system model with the help of results fetched from a simulation tool. Finally, Section V concludes the paper providing a summary of research and mentioning the future research directions.

II. Related Work

There are various schemes that exist to enable cooperation among nodes in a wireless network. The studies herein are grouped into two categories; incentive-based and non-incentive-based cooperation schemes. Firstly, the incentive-based schemes can be discussed as per the existing research.

Wang et al [9] proposed an incentive-based Heterogeneous Split Caching algorithm which aims to minimise the cost of provision of electronic content with the help of cooperative caching policies. Liu et al [10] made use of the Stackelberg game-theoretic approach for incentive-based computational offloading using edge computing technology, in a wireless network. Sarkar et al [11] emphasised latency-sensitive applications in a fog network and suggested a strategy for computational offloading among the fog nodes through collaboration. The problem was treated as an NP-Hard and Quadratic programming problem and it was solved using semidefinite relaxation (SDR) method. Froushani et al [12] combined reputation-based as well as pricing methods in order to generate higher incentives for enabling cooperation among the nodes within a wireless ad hoc network.

In addition to the incentive-based cooperation schemes, various non-incentive-based schemes have also been proposed. Bennis et al [13] proposed a scheme to enable inter-cluster cooperation in wireless D2D networks for content caching. As per the scheme, popular content can be cached and users are able to share the content in the cellular network through cellular transmission or direct D2D links. Ronen et al [14] focused on the generic low payment mechanisms for task allocation and proposed a non-incentive mechanism along with a learning-based approach for decentralised task allocation in a network. Deng et al [15] focused on optimisation of retention-aware caching specifically in vehicular networks, which refers to paying attention to the time for which the content is stored as cache. The authors formulated a problem of retention-aware caching and analysed the complexity. Post analysis, a retention-aware multi-helper caching algorithm using dynamic programming (DP) and concept of polynomial time complexity was proposed. Wu et al [16] analysed and studied traffic offloading among mobile devices (MD) in cooperative D2D networks and focused on a novel joint-optimisation scheme to reduce transmission costs for contents as well as the energy consumption for MDs.

Synthesis: The studies discussed in the above subsection emphasises the cooperation among the nodes, either fog or cloud, in wireless networks, but with an assumption that users within the network are socially bonded and nodes are willing to offload the loads to other neighbouring nodes. Thus, the studies do not consider cooperation as per the rational case.

In a practical scenario, the energy constraints and task execution costs limit the nodes to execute the tasks for the users. Moreover, some of the existing works also overlook the heterogeneity of users and nodes, which may not enable an efficient cooperation among the nodes. Hence, we propose a novel scheme to overcome the above limitations of existing cooperation schemes. We aim to design an optimal network cooperation scheme with a fair incentive distribution approach in order to motivate the fog nodes to offload and share the loads.

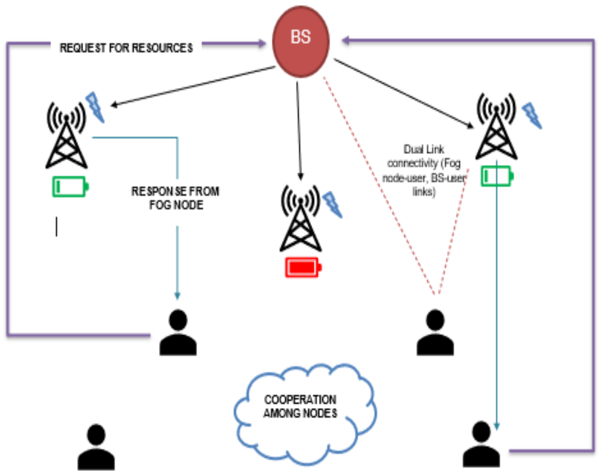

Fig 1: Fog-assisted 5G Network with dual link connectivity

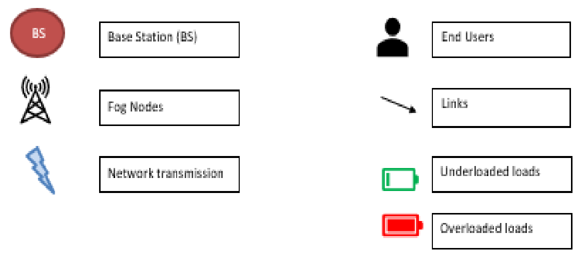

Fig 2: Symbols corresponding to the system model in Fig. 1.

III. System Model

A. Overview of the proposed model

The fog-assisted 5G network in the proposed model constitutes the following; a single Base Station (BS) and multiple fog nodes to assist multiple end users in the network. 'n' represents the number of total users in the fog-assisted network. The model along with assumed symbols and their reference are depicted in figures 1 and 2 respectively. Here, we represent the set of fog users as U= $\{u_1, u_2, u_3, \dots u_n\}$. Each user u ∈ U can be characterised by their certain characteristics. The users lie within the coverage area of the BS and hence are connected to each other and the fog nodes via dual communication links. The set T= $\{t_1, t_2, t_3, \dots t_r\}$ represents the tasks of a user, where 'r' relates to the number of total tasks. Each task can be categorised based on the medium of execution; execution through fog server or BS, and fog node(s). Thus, t_r= $[t_{r0}, t_{r1}]$ denotes the breakdown of a user task and thus assists task offloading. The set of fog nodes can be denoted as F= $\{f_1, f_2, f_3, \dots f_z\}$, where 'z' is the number of total fog nodes present in the 5G fog-assisted network. Each fog node has a capacity c, which can be represented as a set C= $\{c_1, c_2, c_3, \dots c_z\}$. Moreover, the system model emphasizes two kinds of scenarios for task execution and offloading and compares them to infer the results; independent and cooperative task offloading. If the cooperative approach is followed, some portions of tasks are executed by fog nodes, and remaining by the BS, if any. Below are the constraints which need to be met by a fog node, f:

$$\mathbf{t_{10} + t_{20} + \dots + t_{r0} <= c_f}$$
$$\mathbf{\sum t_{fu0} <= c_f}$$

i.e., The tasks to be executed for a user, u should be executed within the capacity corresponding to the fog nodes.

The fog server or BS is set free from constraints in order to assure the task execution.

B. Cost model of Fog node

The users carry out the task execution with the help of either independent or cooperative task execution. Let a task t belong to user u, and c be the capacity of a fog node f. Let the energy spent by fog node to execute a task be 'e_f'. Thus, for fog node f,

$$\mathbf{e_f * t_u <= c_f}$$

Case 1: If the tasks are executed through an independent approach,

The total cost for execution of a task is,

$$\mathbf{\sum T^u_{coop} = \sum C^u_{ind}}$$
$$\mathbf{C^u_{coop} = C^u_{ind}}$$

Where C^u_{coop} is the cost of task offloading through cooperation, and C^u_{ind} is the cost of task execution through fog server.

Case 2: If the tasks are executed through a cooperative task offloading approach,

As per [17],

$$\mathbf{\sum T^u_{coop} <= \sum C^u_{ind}}$$
$$\mathbf{C^u_{coop} < C^u_{ind}}$$

Hence, the cooperative model is more optimal compared to independent approaches.

The fog nodes can be encouraged using incentive-based mechanisms. Let E be the set of energy units spent for task execution as E= $\{e_{f1}, e_{f2}, e_{f3}, \dots e_{fu}\}$ for a user, u. Also, let energy be spent by BS to execute a portion of tasks as e_s. The user u will provide incentive 'i_u' to the fog nodes, which is fairly distributed among the cooperating fog nodes. Hence,

$$t^u_{coop} = \text{Energy spent}(e_f) - \text{Incentives received } (i_f)$$

$$t^{u}_{coop} = \{e_{f1}+e_{f2}+\ldots.\ e_{fu}\} - \{i_{1f}+ i_{2f}+\ldots + i_{uf}\} \text{ (fair distribution)}$$

The cost can also be expressed in terms of Profit incurred by fog nodes, which can be represented by P^{u}_{coop}.

$$P_{coop} = \text{Incentives received} - \text{Energy spent or consumed}$$

$$\mathbf{P_{coop} = (i_{1f}+ i_{2f}+\ldots + i_{uf}) - [(e_{f1}+e_{f2}+\ldots.\ e_{fu}) + e_{s}]}$$

C. Cost Model of Fog user

This model calculates the cost for fog nodes in two separate cases, independent and cooperative task offloading.

Case 1: If user allows task execution through independent approach, he needs to pay s one-time subscription cost to the user. Let $T^{u}_{coop\_f}$ and $C^{u}_{ind\_f}$ represent total cooperative cost of fog user and total independent cost of fog user. Then,

$$\sum T^{u}_{coop\_f} = \sum C^{u}_{ind\_f}$$

Case 2: If cooperation is followed by fog nodes using an incentive-based mechanism, the cost against the independent approach will always remain less.

Along with the incentive the user distributes to fog nodes, the user also incurs some delay while getting the tasks executed. Thus, the delay can be represented as D_u and incentive given by user to fog nodes is i_u. Hence, cost can be represented as,

$$C^{u}_{coop} = D_u + i_u$$

Furthermore, the delay can be contributed by both fog nodes, represented as D_f and the fog server, represented as D_s. Thus, D_u can be split as,

$$D_u = D_f + D_s$$

Delay D_f is contributed by every fog node which cooperates to execute the tasks and offload and underload the tasks among them using bargaining approaches. Thus,

$$D_f = D_{f1}+ D_{f2}+ D_{f3}+ \ldots + D_{fn}$$

Hence, the cost incurred can be further derived as per below derivation:

$$C^{u}_{coop} = D_u + i_u$$

$$C^{u}_{coop} = (D_f+ D_s) + i_u$$

Breaking down the delay and incentive costs,

$$\mathbf{C^{u}_{coop} = [\ (D_{f1}+ D_{f2}+ D_{f3}+ \ldots + D_{fn}) + D_s] + (i_{if}+i_{2f}+i_{3f}+ \ldots + i_{uf})}$$

D. Nash Bargaining Solution (NBS)

NBS is a cooperative optimising technique to maximise throughput and minimise costs. NBS is used here in the fog-based resource allocation model to minimise the total cost including delay, energy and other factors. Additionally, NBS helps to fairly distribute the incentives among the fog nodes participating in the task offloading and execution. The incentive can be distributed in the form of a virtual currency. The system model is modelled as a bargaining game, which is solved using NBS, treating fog nodes and fog users as players. The game can be represented as:

$$\mathbf{G = \{U, F, S\}}$$

Where U and F represent the set of fog users and fog nodes respectively, and S represents the space in the form of a 2X2 grid where users are randomly present.

IV. Performance Analysis and Results

In this below subsection, we analyse the results of the proposed algorithm and cost model fog-assisted 5G networks. Visualisation and mathematical tool called MATLAB is used for computing the mathematical solutions of the solution approach proposed in the model. We have considered a fog-assisted 5G network with 8 users and 20 fog nodes. We are comparing and analyzing the efficiency of the independent task offloading approach with that of the cooperative Nash Bargaining approach. Mathematical formulation of the problem statement and representation of the efficiency of cooperative approach for task offloading with the help of cost parameters is done. Figure 3 demonstrates the setting of users randomly scattered in a plot in a 2X2 grid.

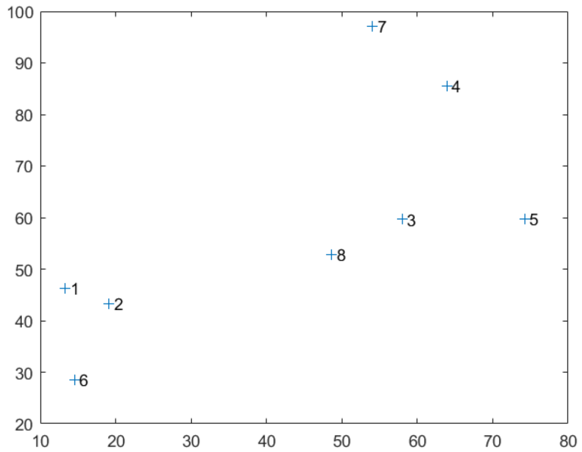

Fig 3: Plot setting for fog users in a fog-assisted network.

The given figures in this section compare different types of costs incurred by fog users in order to offload and execute their tasks. Fig 4(a) claims that the delay cost incurred in case of bargaining approach is less than that in independent approach. Hence it can be stated that delay faced by fog users when fog nodes cooperate, is always less as compared to the delay faced in independent approach.

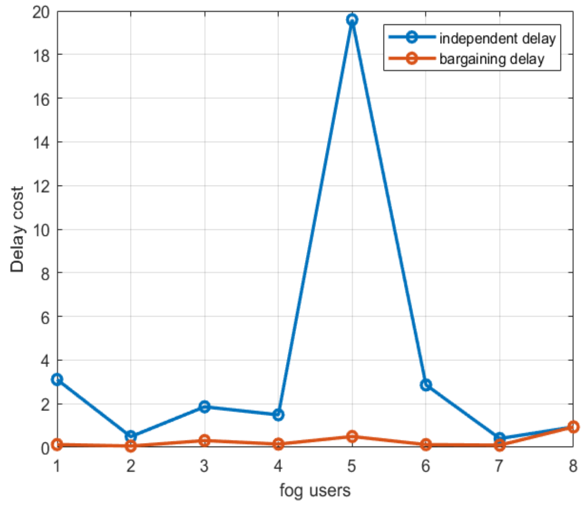

Fig 4(a): Comparison of delay cost or delay incurred by fog users in bargaining and independent approach.

Additionally, the energy cost, including transmission and task execution energy spent by fog nodes and BS, is always less in the case of a bargaining approach as compared to an independent approach. This makes the bargaining approach more efficient in terms of energy efficiency (fig 4(b)).

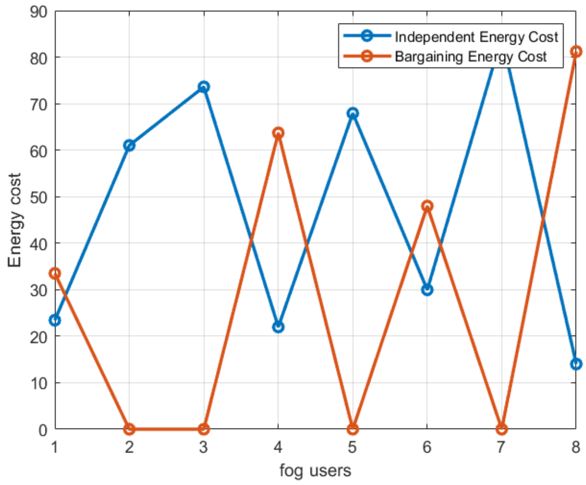

Fig 4(b): Comparison of energy cost by fog users in bargaining and independent approach.

For an independent approach, we do not use any incentive scheme to promote task offloading and load balancing among the fog nodes. Hence, the fog nodes do not receive any incentive sum in order to execute the tasks and is thus 0. Thus, the total incentive cost incurred by the fog users in case of independent approach is also 0, as represented in figure 4(c) and 4(d). On the other hand, to promote task offloading among the fog nodes, an incentive sum is distributed among them using NBS. Hence a non-zero amount is received by each fog node as an incentive.

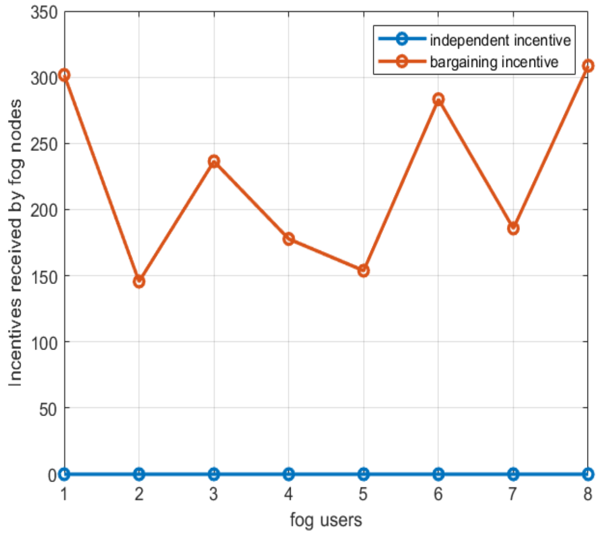

Fig 4(c): Energy cost by fog users in bargaining and independent approach; comparison of costs incurred by fog users as incentives.

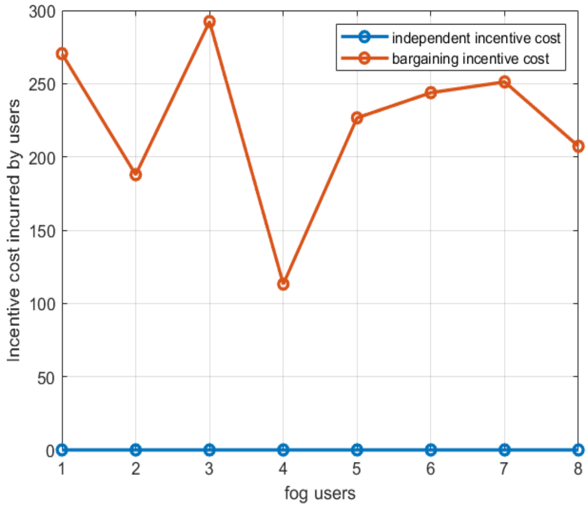

Fig 4(d): Energy cost by fog users in bargaining and independent approach; comparison of costs incurred by fog users as incentives.

Finally, the total cost calculated by summing up all the costs incurred by the fog users is also very less compared to the total cost incurred by fog users in the independent task execution. As per the figure 2(d), it can be seen that the line graph for total cost in the case of bargaining solution lies below the line graph for total cost of independent solution.

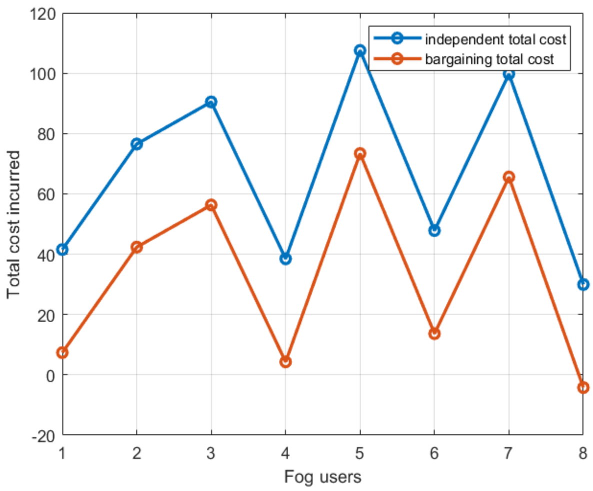

Fig 4(d): Comparison of overall, total cost incurred by fog users in bargaining and independent approach.

Overall, the above system model successfully compares and analyses the efficiency of cooperation among fog nodes for executing task in a fog-assisted network. The MATLAB simulation proves that in terms of efficiency and cost, cooperative NBS approach is better compared to the independent task offloading approach.

V. Conclusion

We have demonstrated the setting of fog nodes and fog users in a fog-assisted wireless D2D network and formulated a task offloading problem. We devised a bargaining or cooperative approach using NBS in order to model a more efficient and cost-effective task execution and load balancing among fog nodes for the fog users. We have taken into consideration the factors such as fog nodes' storage capacity, as well as the different costs incurred by the fog nodes and users including delay in transmission, energy cost, incentives. Finally, we simulated the comparison of total cost incurred in case of an independent and bargaining task offloading approach and proved the efficiency and cost-effectiveness of the NBS-based bargaining approach. The above work can be extended further in order with considering more real time parameters while task offloading. The paper can also be referenced for studying the practical implementation of similar cooperative models.

Data Availability Statement

The authors declare that all the data supporting the findings of this study are original and generated through the tool used for research and simulation. The data is available within this paper and its supplementary information files.

Conflict of Interest

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript. The authors have no financial or proprietary interests in any material discussed in this article.

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Figure 1: SYSTEM MODEL

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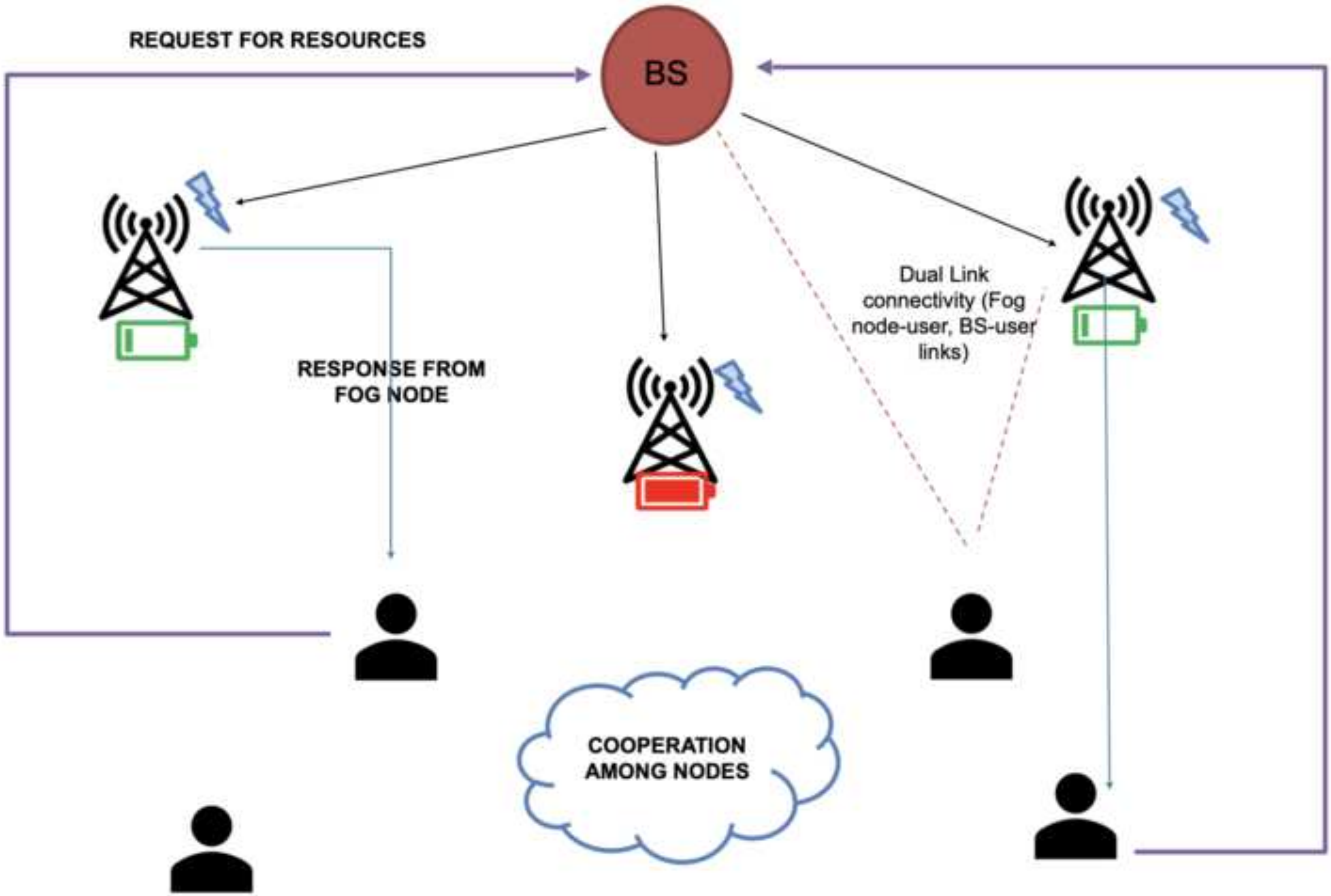

Figure 2: symbols to SYSTEM MODEL