DEPARTMENT OF COMPUTER SCIENCE ENGINEERING,

SCHOOL OF ENGINEERING AND TECHNOLOGY,

SHARDA UNIVERSITY, GREATER NOIDA

LOAD BALANCING IN FOG-ASSISTED 5G NETWORKS: AN INCENTIVE-BASED GAME-THEORETIC APPROACH

A project submitted

in partial fulfillment of the requirements for the degree of

Bachelor of Technology in Computer Science and Engineering

By:

SNIGDHA KASHYAP (180101325)

SAAHIL KUMAR SINGH (180101266)

RAJSI SAXENA (180101240)

ABHISHEK ROUNIYAR (180101014)

Supervised by:

Mr. Avinash Kumar

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CERTIFICATE

This is to certify that the report entitled "**Load Balancing in Fog-Assisted 5G Networks-An Incentive-Based Game-Theoretic Approach**" submitted by "**Abhishek Rouniyar(2018015598), Saahil Kumar Singh(2018015052), Snigdha Kashyap(2018003781), Rajsi Saxena(2018005147)**" to Sharda University, towards the fulfillment of requirements of the degree of **Bachelor of Technology** is record of bonafide final year Project work carried out by him/her in the "Department of Computer Science and Engineering, School of Engineering and Technology, Sharda University". The results/findings contained in this Project have not been submitted in part or full to any other University/Institute for award or any other Degree/Diploma.

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Name and signature of Students:

SNIGDHA KASHYAP (2018003781)

SAAHIL KUMAR SINGH (2018015052)

ABHISHEK ROUNIYAR (2018015598)

RAJSI SAXENA (2018005147)

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) is directly involved. In the practical scenario, the ability to cooperate clearly depends on the willingness of fog nodes to cooperate. Hence the prime purpose of this study and project is to design an incentive-based bargaining approach based on Nash Bargaining Solution (NBS) which encourages a cooperative task execution by the fog nodes for the end users in a fog-assisted 5G network. The proposed model encourages the fog nodes to cooperate among themselves by receiving incentives from the end users benefitting from the cooperation. Considering the heterogeneous nature of fog nodes based on their storage capacity, energy efficiency etc., we aim to emphasize a fair incentive mechanism which fairly 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.

LIST OF FIGURES

Table I

GANTT CHART
(PROJECT TIMELINE)

Tasks/Months		**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**
Project Approval													
Literature Survey and Analysis													
Requirements Specification													
Problem Formulation													
System Modelling													
Mathematical Modelling													
Simulation Tools understanding													
Coding & Simulation													
Research Paper writing													
Review													
Editor reviews and changes													

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1. INTRODUCTION

1.1. Motivation

Currently, with a drastic increase in the density of users in a network as well as the number of mobile devices in the network, the usage of mobile devices is also increasing proportionally. Hence, large traffic is experienced in the networks by the nodes, servers and devices connected within it. Specifically, the cloud and fog servers which serve the cloud/fog users also experience high load and traffic which may significantly affect their performance, reliability, availability, latency and response. In wireless networks which are fog-based, multiple fog-based nodes are connected to each other and the devices and further to the main server as well. Due to multiple fog nodes and high density of fog users, there is an overhead increase on fog nodes and the fog server. Moreover, the total cost for executing the tasks increases including the energy, delay and other costs. Hence, it is important to balance the network traffic and the loads among the fog nodes while also focusing on improving the QoS and lowering delay and energy costs. The illustration below depicts a general fog computing architecture (figure 1).

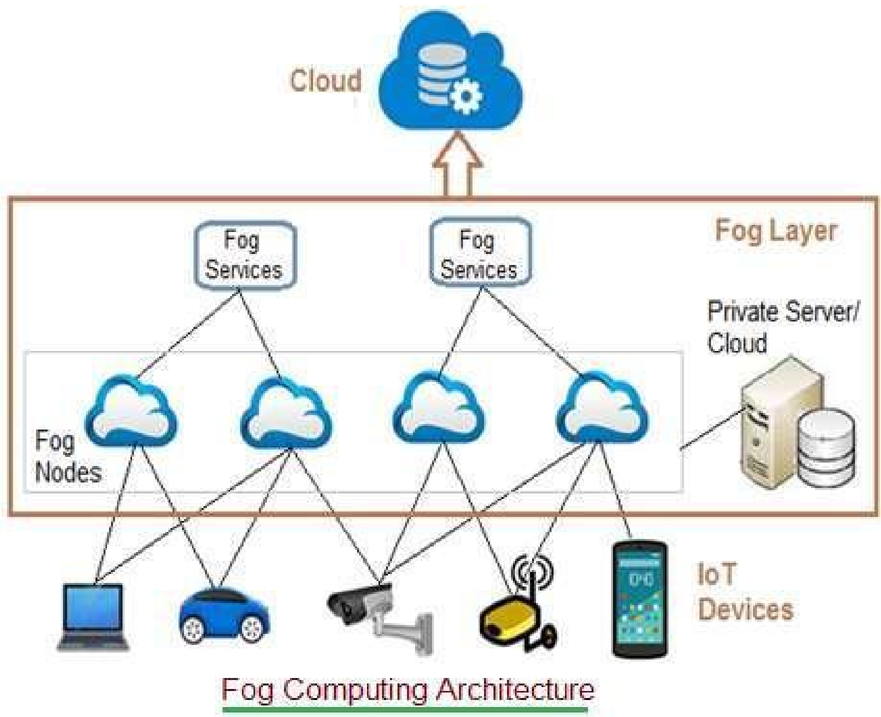

*Figure 1. Fog Computing Architecture

* Figure taken from the source: https://www.rfwireless-world.com/images/Fog-computing-architecture.jpg

1.2. Overview

Resource allocation has been a thing of prime importance within a network. Additionally, when the fog users increase, the services and resources in the network need to be provided to each user, that too in an optimal manner, benefitting every user. Dynamic nature of users and mobile devices within a network is also a priority in current research while pacing up with newer technologies of the future. The newer technologies include 5G network, Light Fidelity (LiFi) and many more for which resource allocation and services provision is being emphasized. In addition, the network is nowadays assisted by cloud computing, which is now enhanced with an extra layer beneath the cloud, known as Fog Computing.

The project aims to design a cooperative approach which enables task offloading for fog users through fig nodes using a bargaining mechanism, basically the Nash Bargaining Solution or NBS. Along with cooperation, the aim is to involve a mechanism based on incentive and rewards which increases the willingness of fog nodes to cooperate and altogether perform the task offloading, instead of following an independent approach.

1.2.1. Wireless Networks

Wireless types of networks are the present and future of communication. It transforms the integrated networks into a reality and gives rise to distributed mobile computing. Wireless networks can be categorized according to the area they encompass, their size and type.

According to the size and area they cover, wireless networks can be classified as LAN, MAN, WAN, PAN and many more are being researched. LAN stands for Local Area Networks. That is, a network which is connecting the devices in a local area such as an office space, building or a home. Secondly, MAN is expanded as Metropolitan Area Networks. MAN is used for connecting the devices and places within a city or metropolitan area. Thirdly, WAN means Wide Area Networks which encompass global coverage. It can be simply referred to the global interconnectivity and the internet and WWW. Last but not least, PAN refers to the Personal Area Networks which are generally private networks with limited coverage and are meant for personal use for an individual or a company.

As per their type, wireless networks can be Ad-hoc or can have a specific infrastructure. Ad-hoc networks are the networks which are spontaneously formed and do not possess a stiff and intact infrastructure.

Since wireless networks are the requirement of digitisation and globalization, hence managing the traffic of unlimited users and devices becomes the need of the hour wherein concepts like load balancing, task offloading, resource allocation and optimisation come into the picture and should be considered a priority.

1.2.2. Future Wireless Networks (FWNs)

Future Wireless Networks (FWNs) are soon going to revolutionize various technologies based on the wireless networks, including cellular technologies, WSNs or sensor networks connected wirelessly, wireless LAN or WLAN, wireless MAN, as well as wired networks which exist traditionally. Also, the IP or Internet Protocol is expected to be considered a common protocol for enabling networking for myriad technologies including the SAE or System Architecture Evolution.

However, there are some challenges associated with the IP, such as; scalability of routing, mobility, privacy of location, preference selection for paths and many more to notice. Thus, the research is going on in this domain to optimize the resource allocation and other related factors using game theory and other effective approaches and schemes.

1.2.3. Load Balancing

Load Balancing can be termed as a solution for networking for distributing the traffic within the network and load across the servers so that excess load is not put on a single server. This in return reduces the overhead on the servers as well as help with reducing delay. In addition, load balancing also assists with increasing the effectiveness and availability of the applications which run on multiple servers. In general, load balancing dedicatedly ensures the availability of resources such as applications, websites, services etc. to the authentic users who need them.

1.2.4. Resource Allocation

It is crucial to allocate necessary resources, services to the needful users across the given network such that they are readily available, and can be fetched and received with least possible delay. Herein, resource allocation plays a vital role and can be termed as a mechanism to allocate and assign the resources to the users via suitable nodes or devices or any other media successfully. Resource distribution and allocation can be fair, uniform or can be specific to a user or group of users. It can be cooperative or non-cooperative in nature. In this research, resource allocation is taken care of with the help of NBS which is derived from economics and is a cooperative resource allocation solution.

1.2.5. Optimization

According to the literal meaning, optimization is the method or process to make the best use of a resource to succeed in a given motive or achieve a target. In terms of networking, optimization can emphasize both maximization or minimization. Maximization can be made for throughput, responsiveness etc. On the other hand, minimization can emphasize latency, delay, costs etc. In general, it can be stated that finding and utilizing an optimal solution for a given problem statement refers to optimisation. In the context of this research, optimization aims at reducing or minimizing delay as well as the total system cost, wherein it aims to maximize the cooperation of fog nodes and availability of resources to the fog users.

Network optimization includes the tools and techniques that assist with maintenance, improvement, or maximization of performance of a network and devices connected to it.

1.2.6. Game Theory

Game theory is a concept of economics and studies models in mathematics relating to interactions among the strategic agents. In this method, users can be treated as players and resource allocation in the network can be formulated as a game. Game theory allows a problem to be formulated as a game and enables players to predict the moves or decisions of opponents and assist in formulating or devising a strategy. NBS is one such game-theory based method of cooperation which is used for fair resource allocation among the users or more specifically, players in a game, to optimize the throughput.

1.3. Problem Statement

As new technologies are introduced, resource allocation poses following challenges, as we progress towards fog computing (being the future wireless network):

- Heterogeneity of users and mobile devices.
- Load Balancing within the fog network among nodes.
- Reduction of response time and latency in providing computational resources.
- Designing incentive and pricing mechanisms for fog nodes as per load balancing.
- Emphasizing Quality of Service..

The problem is to propose a novel cooperative, incentive-based approach to encourage cooperative task offloading such that there is a reduction in costs. Incentive based approach is adopted in order to encourage cooperation. The total system cost to be reduced includes energy consumption, transmission, capacity, delay and latency. In addition, most of the studies and research does not take into account the variable factors which may influence the cost and response time in fog networks. For instance, the willingness of fog nodes to involve themselves in the cooperation process while task offloading is not assumed in this research. The goal is to consider the factors to encourage them to cooperate and eliminate the assumption. It is so because the fog nodes may or may not decide to bargain in a purely rational case. This research emphasizes these variable factors as well.

This, the problem statement is to provide a unified solution to overcome the above mentioned challenges in a fog network.

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1.4. Expected Outcome

The expected result of the above research is to devise a solution to the networking problem of task offloading, resource allocation and load balancing using an incentive-based and cooperative task offloading approach. The approach makes use of the concept of game-theory and economics. The prime outcome of the research is to formulate the problem statement as a mathematical function and derive an optimal solution to the same using mathematical concepts of convex programming and optimization. Secondly, we aim to simulate the results achieved from the solution using effective simulation tool(s) and successfully compare the performance of independent and cooperative or bargaining-based task offloading approaches. The outcome is expected to conclude the betterness of cooperative approach over the independent task offloading approach.

We consider the assumption that fog nodes are characterized by the following factors; delay sensitivity, latency, energy consumption, efficiency of storage and capacity.

2. REQUIREMENTS SPECIFICATIONS

2.1. Hardware Specifications

The minimum hardware requirements for conducting the simulation of the solution are listed below:

- Processors: Minimum AMD x86-64 and recommended AMD x86-64 (having 4 logical cores) and support for the AVX2 instruction set.
- RAM: Minimum required RAM is 4GB and recommended 8 GB.
- Disk: Minimum 3 GB space in HDD for MATLAB specifically, 5 to 8 GB required for installation. The Recommended Disk is an SSD.
- Graphics: Optional. The Graphics Card should support OpenGL 3.3 with 1GB CPU memory.

2.2. Software Specifications

The minimum software requirements for conducting the simulation of the solution are listed below:

- Operating System

  Recommended OS is Windows 10 or higher. Other versions can include Windows 7, Windows Server 2019 and 2016.

- Simulation Tool: MATLAB

  MATLAB is a software tool used for mathematical analysis, modeling as well as visualization of mathematical expressions, plots etc.

- Software Addons: CVX Tool

  CVX tool is an additional library for convex programming in MATLAB, which is used for converting general mathematical functions into convex functions. Specifically, it is used for convex optimization.

3. LITERATURE SURVEY

3.1. Existing System

The existing systems emphasize cloud computing and related technologies and may not take into account all the necessary factors (load balancing, response time, latency, pricing etc) while discussing and formulating network settings for a fog network. Also, the existing systems, being based on cloud computing, lead to a grave disadvantage in cloud-based networks, that is, Network downtime, thereby increasing the response time for resource allocation and further affecting the Quality of Service (QoS) for most of the users within the network. Most of the current systems project disproportionate loads in the nodes thus misbalancing the overall communication flow.

There are several techniques that allow cooperation-based task offloading in the wireless network. The research can be majorly grouped as; incentive as well as non-incentive mechanisms of cooperation or bargaining. The existing approach can include algorithms such as the Heterogeneous Split Caching (HSC), which is based on a reward mechanism and minimizes total cost of content sharing [1]. For computational offloading using reward schemes and edge computing in the networks with wireless connectivity, some approaches leverage the Stackelberg game-theoretic approach [2]. For latency-sensitive applications, studies provide ways for computational offloading among fog nodes with the power of collaboration [3]. The problems above are classified as Quadratic programming-based as well as NP-Hard problems, and they are solved using game theory and Semi-Definite Relaxation methods or SDR. Existing systems also integrate pricing strategies to offer better incentives for wireless ad hoc network node cooperation [4]. One of the cooperative schemes which emphasize offloading tasks onto a single server in case of overloading is given in figure 2. The below model devises a solution for edge computing and local computing devices in clusters.

In this scenario, in case the tasks are overloaded onto the intermediary nodes, the remaining load is offloaded to the main server connected to those intermediary nodes.

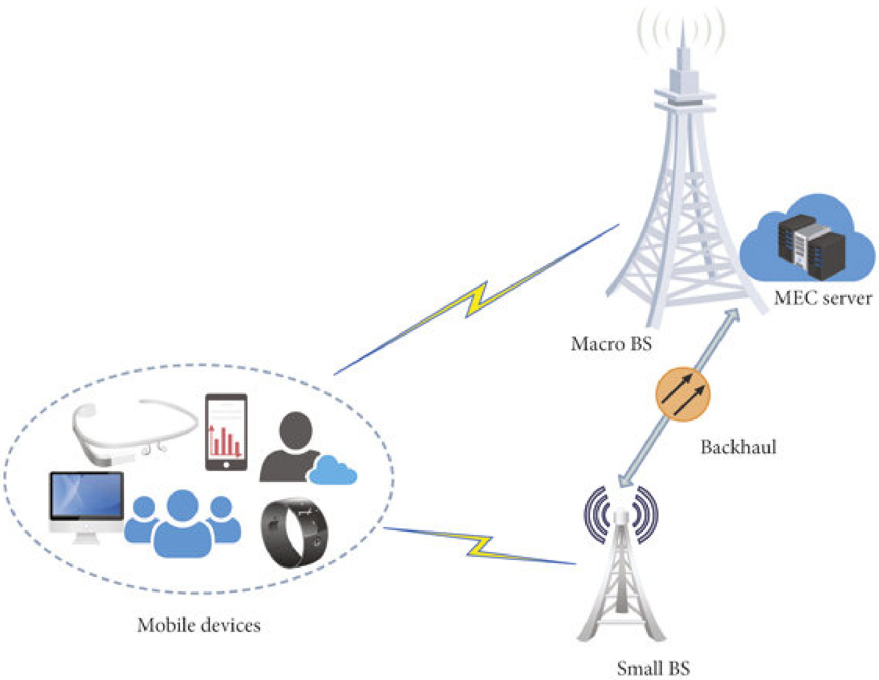

**Figure 2. Existing cooperative approach for task execution for edge computing.

Apart from the incentive-based mechanisms of cooperation, many schemes based on non-reward mechanisms are also proposed. There are schemes which allow inter-cluster cooperation for caching the content in D2D wireless networks [5]. Some systems investigate cooperative load offloading among MDs or mobile devices present in the networks using D2D connectivity and focus on some prominent optimization steps and methods for reduction of system costs; transmission, consumption of energy etc. [6].

**Image source: ResearchGate

(https://www.researchgate.net/publication/341745929/figure/fig1/AS:1084216888561675@1635508858982/Base-station-cooperative-task-offloading-model-based-on-5G-heterogeneous-networks.jpg)

However, above studies overlook the bargaining schemes if the rational case is considered. In the case of a practical network setup, one must consider heterogeneity in terms of energy, cost of task execution etc.

Some additional studies and research related to optimization, wireless networking and game theory in the field of FWNs are summarized in the below Table 2 with their pros, cons and inference.

Paper no.	Pros	Cons	Results	Work Done
[7]	Reduces the problem of exhaustive search for power allocation and high complexity of computation. Considers priority as a parameter to check power allocation for cells in the multi-cell network. Complexity is reduced to very less order.	Fairness becomes an issue in the proposed scheme due to priority 1 cells making choices first. Due to large computation time, exhaustive search allocation results were not calculated.	Proposed scheme was analyzed based on performance, overhead, complexity and fairness. Proposed scheme is proved to have lesser computational complexity. Due to priority concern, the fairness is compromised. Assuming interference as negligible, the system reduces the overhead and doesn't require additional information to estimate interference.	Discussed interference issue in multi-cell environments in D2D Networks. Simulated the approach at system level and compared with existing systems (with single cell schemes) with 100 randomly generated topologies.
[8]	Simulation is done discreetly for various crucial parameters for different areas using the approach.	Performance may get affected as a result of improved call drop probability.	A trade-off is visible between probability of eventual call, when compared with that in existing systems.	Presented game theoretic approach for resource allocation using cooperative games. Developed algorithms for resource allocation, area handover and call admission. Presented proof of concept using simulation of approach.
[9]	Efficient solving approaches are listed in the given research paper related to linear programming. Graph theory is addressed which is efficient to solve resource allocation and optimization problems. Summarizes open research challenges with guidelines in D2D communication.	Detailed solutions to overcome the challenges are partially addressed.	Explored challenges and benefits of integrating social networks using D2D. Research resulted in providing guidelines for researchers to enable social-aware D2D communication. The integration of social-awareness with D2D communication and optimization problems of efficient resource allocation.	Addressed issue of social network integration with D2D and exploring related attributes and network characteristics. Devised guidelines to enable social-aware communication.
[10]	The proposed model emphasizes on QoS and achieves better throughput compared to that in existing systems.	The scalability factor is not considered in the given paper and intelligent learning algorithms are yet to be implemented for	performance enhancement is witnessed in simulation as per the index of fairness and output produced.	formulated the complete problem as a game of stochastic manner and devised the solution to the same effectively.

		predicting the traffic and information about the network.		A model based on game and resource allocation was constructed and methods like method of duality, Lagrangian methods were used.
[11]	Proposed solution helps achieve a higher throughput and satisfaction performance compared to benchmarks. The solution considers a dynamically changing topology, to provide a better user- centric clustering strategy and enhances practicality of design.	The solution does not consider a static network topology. Out of the benchmarks, the Dmin aided system in the proposed model needs to evaluate signal strengths for resource allocation which is a bit complex.	It is inferred that proposed design possesses the property of convergence. Systems using proposed design exhibit higher throughput due to efficient load management. Proposed design is QoE-aware, hence user satisfaction is high, the system has many UEs with QoE index > 0.9, and exhibits a step-like improvement. Also, as UEs increase, the outage rate does not increase drastically.	Formulated the joint design problem as MINLP keeping in mind a dynamic network topology. Conducted comparative study of joint transmission schemes and LiFi technology. Derived a cooperative bargaining solution for networks such as hybrid LiFi and WiFi.
[12]	Proposed model is less complex and more robust compared to the studied reference models. It also takes risk profiles of SPs into consideration. It reduces the number of transactions needed to pair SPs with RPs. Presence of virtual network barriers (VNBs) help to address trust, information protection and incentive issues."The need for specialised entity for resource allocation is fulfilled by VNBs."	Model only takes into consideration the price and fees as factors in the risk profile. It does not focus on all possible scenarios for wireless network virtualisation and discusses one specific case. Surplus values presented in the paper do not include resource payments.	Simulation concludes that SPs having high demand possess satisfaction index high as well. Reputation of a VNB can be predicted by using the probability of rate coverage. VNBs with fewer SP partners have high reputation levels thereby more able to satisfy partners' demands.	Gave an architecture for virtual wireless networks with more than one RP and SPs Implemented a matching mechanism to pair SPs with network builders as per their trading preferences. Proposed a model to characterize SP demands based on data rate, coverage probability etc. Proposed a deferred acceptance algorithm with a stochastic approach for allocation of resources.
[13]	The proposed algorithm is successful in reaching evolutionary equilibrium. It ensures that all players can contribute to resource selection using identical mixed strategy. EGT-based resource allocation algorithm ensures that better strategies gain higher populations.	Proposed algorithm ignores costs as well as delay factors in the communication process using a central controller for the purpose of analysis.	Simulation results coincide with the results from theoretical analysis for the proposed algorithm. Simulations infer that proportion of strategies increase as game progresses thereby reaching an equilibrium and followed by players learning to adopt strategies through iterations of interaction. Eventually they receive the same payoff. This helped achieve better performance.	Proposed system model based on channel, network and interference for RF-based future wireless networks. Formulated a game involving a mixed strategy and conducted a feasibility analysis for its solution to the Poisson Point Processes (PPP). Conducted literature survey and simulated the proposed algorithm to validate theoretical analysis.

[14]	Formulation of prophigh utility of network and the system throughput. Converting given problems into iterative algorithms gives polynomial time complexity for resource allocation. Proposed solution is a stable one, and reduces interference.	The proposed algorithm is not modified according to the algorithms it is compared with, i.e., FFCA and NFCA, due to a different system model.	Discussed and concluded algorithms' characteristics using simulation results. TDCA produced low network utility, high system throughput Discussed NBS and its benefits, its proofs as well as related algorithms.	Authors proposed a system model followed by an algorithm named TDCA for the D2D Networks, and compared it with NFCA, TCFA and FFCA algorithms with the help of simulation and comparative study.

Table 2. Related studies based on game theory, optimization and wireless networks.

3.2. Proposed System

The idea is to formulate the problem statement as a Game-based problem wherein all fog nodes act as players and participate within the game to serve the end users with computational resources or resources instances as per the user demands. The problem will then target on identification of underloaded and overloaded fog nodes. The solution will be propagated to carry out offloading of loads from overloaded nodes to the underloaded nodes.

A cooperative approach will be followed, such as a bargaining approach so as to allow cooperation and communication among fog nodes for deciding service providers for respective end users within the network. Finally, the solution will try to find and set up an optimal path between end user and ideal fog node which will fulfill the criteria of minimum latency and response time.

We build a thorough framework for studying bargaining-based task offloading in wireless networks which are fog based. Specifically in the case of 5G networks, we first try to derive the cost functions of both users as well as nodes in the fog network , on the basis of following; heterogeneity, job demands, experienced delay, etc. Furthermore, an incentive-based cooperative mechanism is derived to foster cooperation among heterogeneous fog nodes, allowing users to pay for task execution as incentives, and fog nodes to get fair incentives for job performance.

The major contributions can be briefed as follows; The proposed system envisions a fog-assisted 5G network with fog nodes that differ in storage capacity, energy consumption, and delay sensitivity. The proposed model also analyzes the impact of these variables on inter-node cooperation. Secondly, the cooperative task execution is modeled as a bargaining situation between various cost-cutting entities. Furthermore, we offer a new incentive mechanism based on the NBS approach that encourages fog users to participate in cooperative task execution. We have tried to explain the model in the detailed manner in the below sections.

4. METHODOLOGY

The idea is to frame the problem statement as a Game-based function wherein all fog nodes act as players and participate within the game to serve the end users with computational resources or resource instances as per the user demands.

The problem will then target on identification of underloaded and overloaded fog nodes. The solution will be propagated to carry out offloading of loads from overloaded nodes to the underloaded nodes.

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Finally, the solution will try to find and set up an optimal path between end user and ideal fog node which will fulfill the criteria of minimum latency and response time.

5. DESIGN CRITERIA

5.1. System Design

To enable network nodes to release and share loads, the proposed system model combines an optimum network cooperation scheme with a realistic reward distribution manner. As per the given figure 3.1 and 3.2, the system model contains a Fog-assisted 5G Network, a BS, a set of fog nodes and end users. Figure 3.1 abbreviates the symbols used for representing the proposed system model. Figure 3.2 depicts the proposed system model. Moreover, the users are connected via dual communication links. The system design focuses on two types of scenarios pertaining to execution and offloading of tasks and analyzes the independent as well as co-operative approach followed by comparison based on different parameters.

The base station or BS serves the fog nodes and enables cooperation within them with the help of suitable algorithms. The fog nodes are the nodes within the fog network which are facilitating the end users within the network range with computational resources or their instances on demand. The user makes requests to the BS for resource instances and the BS is responsible for communicating with the fog nodes contained within the network and allowing them to cooperate using Nash Bargaining Solution (NBS).

The overloaded nodes offload their loads to underloaded nodes. Followed by offloading, ideal fog nodes are then chosen for respective end users and the response is given to the user by the corresponding fog node which has an optimal path to the user device, also keeping into account a fair incentive mechanism.

The below subsection represents the diagrams pertaining to the system model and proposed solution.

5.2. Design diagrams

The design diagrams to justify the problem statement and solution are shown in the below figures 3.1 and 3.2.

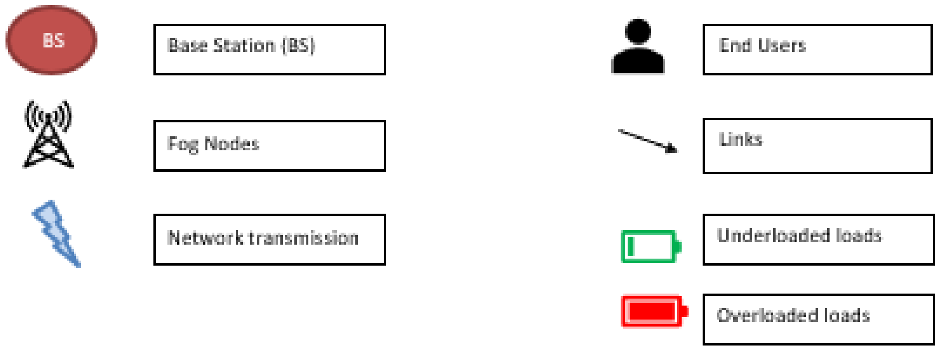

Fig. 3.1. Symbols for the proposed solution model in Fig. 3.2.

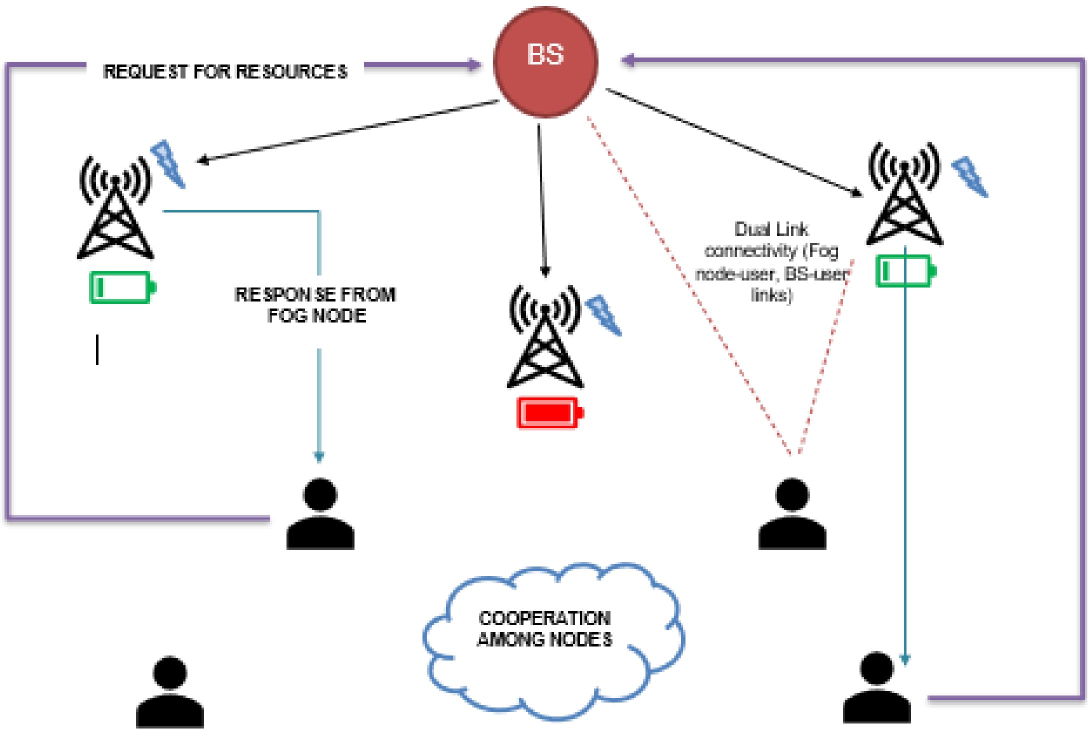

Fig. 3.2. System model for proposed solution. A base station connects the nodes in the fog network. Furthermore, they possess dual link connectivity. Further, the fog users are connected to fog nodes for network communication.

5.3. System Architecture and Cost Modeling

In case the cooperative method is used, fog nodes perform some tasks while the BS, if any, completes the rest. The following are the restrictions that a node must meet:

F:

$$\textbf{task}_{10} + \textbf{task}_{20} + \ldots + \textbf{task}_{r0} <= \textbf{capacity}_{fog\_node}$$

$$\sum \textbf{task}_{fog\_user0} <= \textbf{capacity}_{fog\_node}$$

i.e., work that must be completed for a network user, u, must be completed within the actual capacity of the network nodes. To ensure task execution, the BS is exempted from limitations.

The system design also includes a cost model for fog nodes as well as fog users as per 3.1.1 and 3.1.2.

5.3.1. Cost modeling for node in fog network

The task execution is carried out by the users using either of the execution approaches. Allowing the fog node to expend 'ef' of energy to complete a task.

As a result, each fog node f,

$$\textbf{energy}_{fog\_node} * \textbf{task}_{user} <= \textbf{capacity}_{fog\_node}$$

Using a cooperative task offloading strategy, the tasks can be completed with respect to below constraint:

$$\sum \textbf{Task}^{f}_{coop} <= \sum \textbf{Capacity}^{f}_{ind}$$

$$\textbf{Cost}^{f}_{coop} < \textbf{Cost}^{f}_{ind}$$

Incentive-based strategies can be used to induce fog nodes. For a user, u, let E be the units of energy as a set used as E=ef1, ef2, ef3,... efu. Allow BS to expend energy on completing a fraction of the chores as es. The user u will give the fog nodes incentive 'iu,' which will be evenly dispersed across the participating nodes.

Thus,

$$Cost^{f}_{coop} = \text{Energy consumed by nodes}(e_f) - \text{Total Rewards/Incentive } (i_f)$$

$$Cost^{f}_{coop} = \{energy_{f1} + energy_{f2} + \ldots.\ energy_{fu}\} - \{incentive_{1f} + incentive_{2f} + \ldots + incentive_{uf}\} \text{ (fair split up of incentive)}$$

Profit incurred in the cooperation by the nodes, which is depicted by Pcoop, can also be used to convey the cost.

$$Profit_{coop} = \text{Incentives/reward} - \text{Consumed energy (execution/transmission)}$$

$$\mathbf{Profit_{coop} = (incentive_{1f} + incentive_{2f} + \ldots + incentive_{uf}) - [(energy_{f1} + energy_{f2} + \ldots.\ energy_{fu}) + energy_{s}]}$$

5.3.2. Cost modeling for user in fog network

The cost of fog nodes is calculated using this approach in two scenarios: independent and bargaining based task offloading. When fog nodes cooperate through a mechanism based on incentives, the cost of the independent approach will always be lower.

The delay is represented by Du, while the incentive supplied by the user to fog nodes is represented by iu. As a result, cost may be expressed as,

$$Cost^{u}_{coop} = Delay_{u} + incentive_{u}$$

Furthermore, both nodes (Df) and servers (Ds) may contribute to the delay. As a result, Du can be divided into two parts:

$$Delay_{u} = Delay_{f} + Delay_{s}$$

Every fog node contributes to delay Df by cooperating to execute tasks and unload as well as offload them among themselves via bargaining techniques.

Thus,

$$Delay_{f} = Delay_{f1} + Delay_{f2} + Delay_{f3} + \ldots + Delay_{fu}$$

As a result, the cost of system user can be refined as follows:

$$Cost^{u}_{coop} = Delay_{u} + incentive_{u}$$

$$\mathbf{Cost^{u}_{coop} = (Delay_{f} + Delay_{s}) + incentive_{u}}$$

5.4. Algorithms

5.4.1. *Algorithm for System Modeling*

start

clear existing data

initialize number of nodes, number of users

define empty matrices and random variables

initialize storage capacity of nodes

set energy cost parameters for fog nodes

calculate energy costs

execute independent approach solution

execute Bargaining approach solution

end

5.4.2. *Algorithm for Solution Approach*

start

initialize an identifier for node

initialize payoffs

begin with CVX programming

define empty matrices for use

define storage and energy constraints for fog nodes

calculate delay cost for user

calculate incentive/reward cost

apply maximization optimization function

end CVX

define result structure

display result

end

5.4.3. *Algorithm for simulation*

```
start
    initialize a figure for result 1
        plot independent delay cost
        hold
        plot bargaining delay cost
    initialize a figure for result 2
        plot independent energy cost
        hold
        plot bargaining energy cost
    initialize a figure for result 3
        plot independent incentive cost
        hold
        plot bargaining incentive cost
    initialize a figure for result 4
        plot independent incentive/reward
        hold
        plot bargaining incentive/reward
    initialize a figure for result 5
        plot independent total cost (sum)
        hold
        plot bargaining total cost (sum)
end
```

6. DEVELOPMENT AND IMPLEMENTATION

6.1 Developmental Feasibility

The developmental feasibility of the project can be defined separately in economical, technical and usability terms as given below:

Economically, the coding and simulation requires MATLAB software to be available with the required features. However, trial versions of MATLAB are freely available for 3 months duration and the same were used in order to successfully code and implement the solution design. However, MATLAB being a heavy software requires more data and faster RAM to run and execute the programs contained.

Technically, the project code is written in MATLAB using convex programming. To enable convex optimization, it requires the CVX tool as an add on to be additionally installed and configured on the machine. Simulation on the machine requires minimum 4 GB RAM and recommended to have an 8 GB RAM for efficient execution.

6.2 Implementation Specifications

For implementation, following were the requirements fulfilled:

- Sound knowledge of MATLAB or SCILAB syntax and convex optimization, and familiarity with Disciplined Convex Programming (DCP)
- Windows 10 Operating System Machine with 64-bit processor and 8 GB RAM
- Email ID associated with MATLAB Mathworks to enable a Mathworks account and download the MATLAB trial version.
- MATLAB Trial version installed (R2022b) with optimization tools.
- CVX Package installed and configured.

6.3 System Modules and Flow of Implementation

6.3.1 System Modules

The complete project is roughly divided into 4 modules as given below and are stored as matlab files with '.m' extension):

- *System plot*

This module defines the system plot setting for conducting the simulation. It randomly plots the fog users on a 2x2 grid, where X and Y axes of the grid represent X and Y coordinates of the position of fog users, respectively. The data of coordinates is random and is randomly generated using random functions in MATLAB. There are certain fixed parameters including capacity of nodes etc. which are taken from authentic sources of research conducted in the past.

- *Independent solution*

  This module codes the solution to task offloading using an independent approach through CVX programming. It calculates the following and optimizes using CVX; energy cost, delay cost, incentive cost (0 in case of independent approach) and stores it for later analysis. Also, it sums up all the cost to derive an independent total system cost.

- *Cooperative (Bargaining) solution*

  This module codes the solution to task offloading using a cooperative, bargaining-based approach through CVX programming. It calculates the following and optimizes using CVX; energy cost, delay cost, incentive cost (0 in case of independent approach) and stores it for later analysis. Also, it sums up all the cost to derive a cooperative total system cost.

- *Plotting module*

  This module is responsible for plotting the results and variables inferred from independent.m and bargaining.m. It plots multiple graphs which compare different types of costs and finally the total system cost in two different cases of independent and the bargaining-based approach.

6.3.2 Data Flow

The flow of data among the above four modules takes place in the following manner: Input is taken in the form of numerics stating the total fog nodes and fog users in the network. Random data for the coordinates of nodes is generated in the form of different matrices and variables using randseed() and rand() functions in MATLAB.

The input is then used for creating the general plot setup (i.e., constructing the two dimensional grid of fog users). The variables and constants are defined in this phase.

Followed by system setup, the data is then used for calculating metrics and results of task offloading process in the case of independent approach. The data from the same system setup is used for calculating the metrics and results of the task offloading process in the case of cooperation.

The results are calculated using mathematical functions and then optimized using CVX. The cost variables are stored and transferred to the plotting module in order to generate required graphs for comparison of system costs in both the cases of task offloading. Below is the Data Flow Diagram (DFD) to summarize the data flow (figure 4):

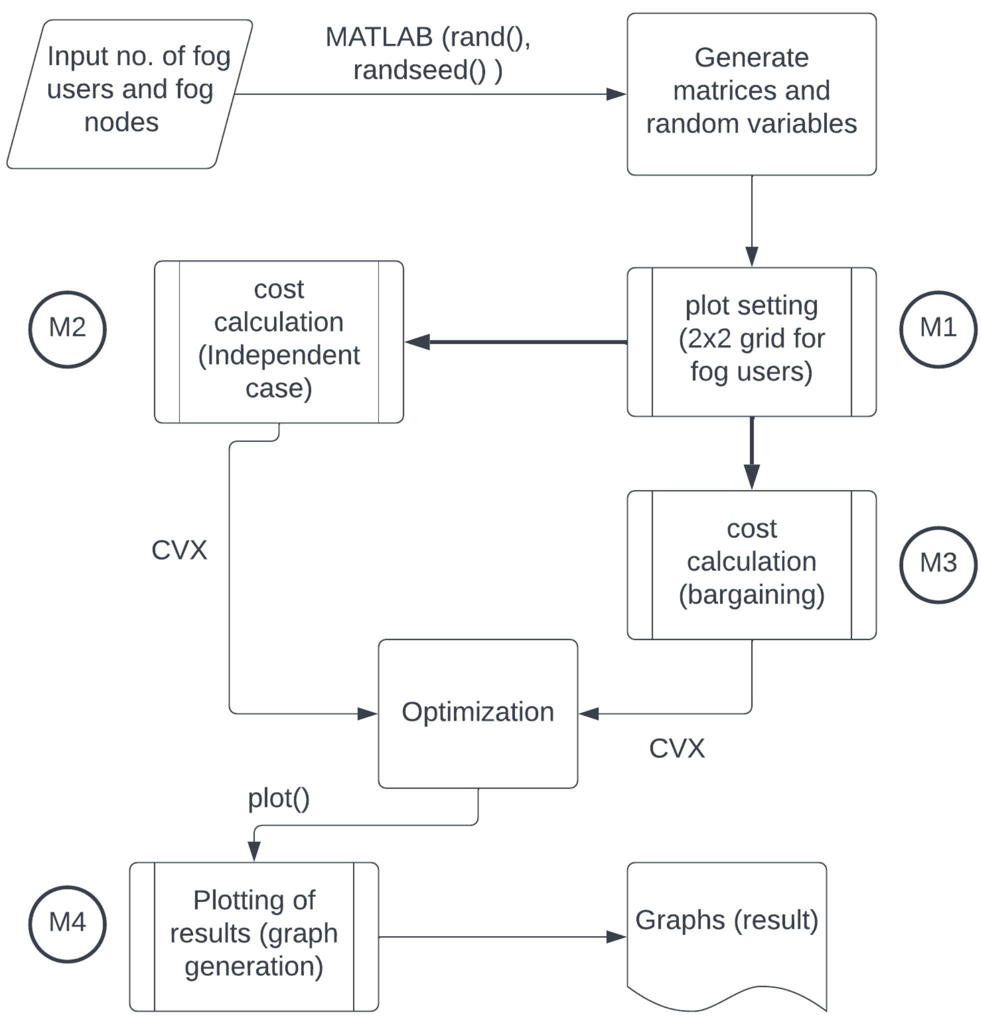

Fig. 4. Data flow diagram for depicting the flow of data among the modules.

7. RESULTS/OUTPUTS

Results are obtained through simulating the implementation of system model and proposed solution as given below:

For obtaining the result, we considered a grid of 2X2 (2D grid) in order to represent the data and relationship between the data. The X-axis represents the x-coordinates of the position of fog nodes randomly scattered on the plot, whereas the Y-axis represents the y-coordinates of fog nodes' positions.

We assume that the nodes in the fog networks are randomly located across the plot, each time the setup is simulated. Figure 5 given below clearly represents the plot setting.

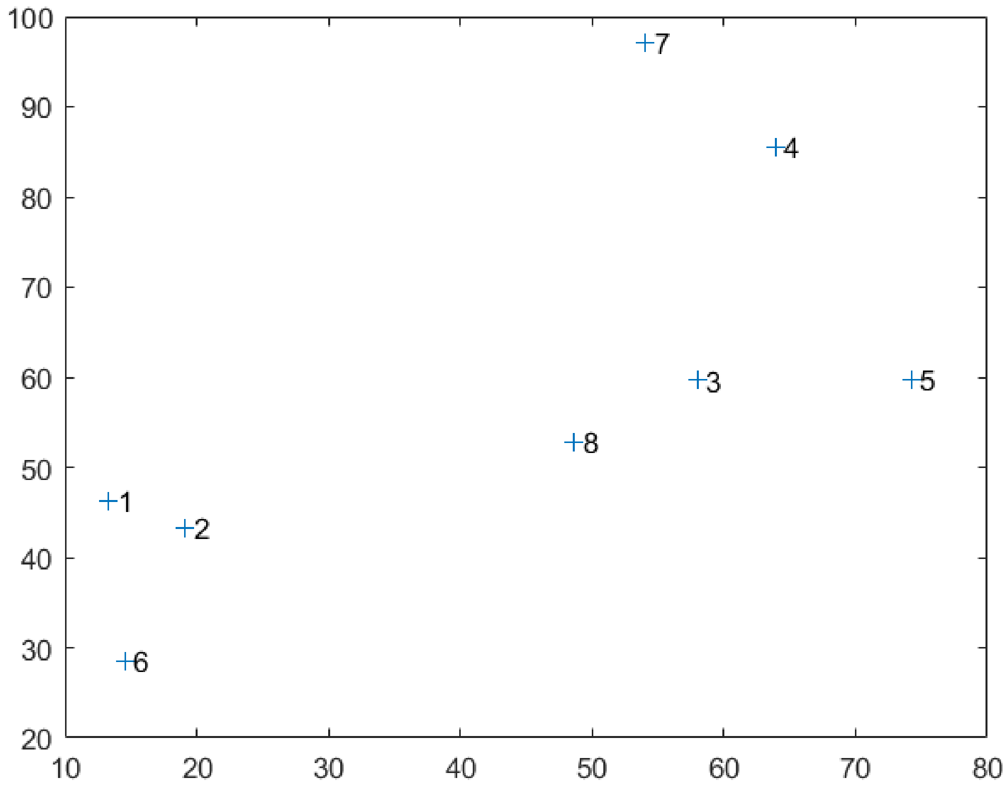

Fig. 5. System setting (2X2 grid of fog users in a plot).

Starting with the comparison of delay costs and factors in independent and cooperative task offloading approaches, a spike can be observed in some cases for delay when fog nodes follow independent task offloading instead of bargaining approach. When the line graph for bargaining approach is observed, we can notice that the delay is highly reduced and is hardly compromised, thereby benefiting the fog users in terms of response time, latency, speed of task execution etc.

Figure 6.1 represents the comparison of delay costs in both bargaining as well as independent task offloading approaches. It claims and proves the bargaining approach being advantageous over the independent one.

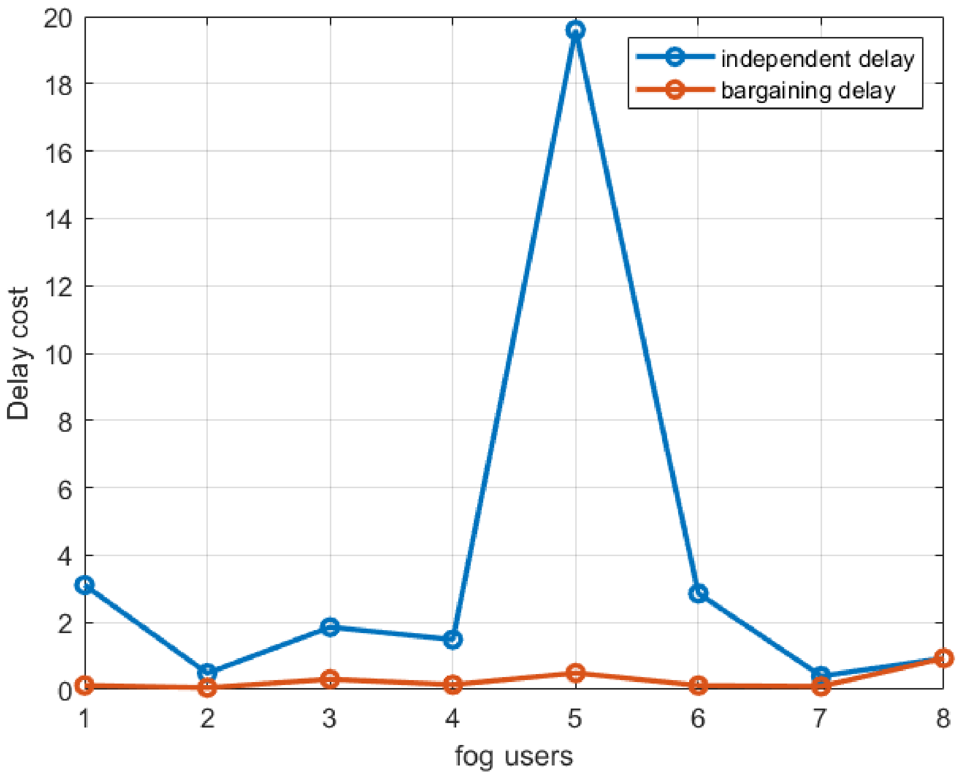

Fig. 6.1. Delay cost comparison for independent and bargaining-based load balancing.

The total energy costs include transmission costs, energy consumed in task execution etc. We sum up all of them and compare individually for both the task offloading approaches.

Considering the energy costs of the fog nodes in both bargaining and independent approaches, the energy consumption is less for fog nodes following cooperative approach than the fog nodes following the independent approach. Hence energy costs (including transmission, task execution etc.) is much less in case of independent task offloading, which is proved and represented in figure 6.2.

In exceptional cases, the costs may seem similar, but are still lower as compared to independent costs.

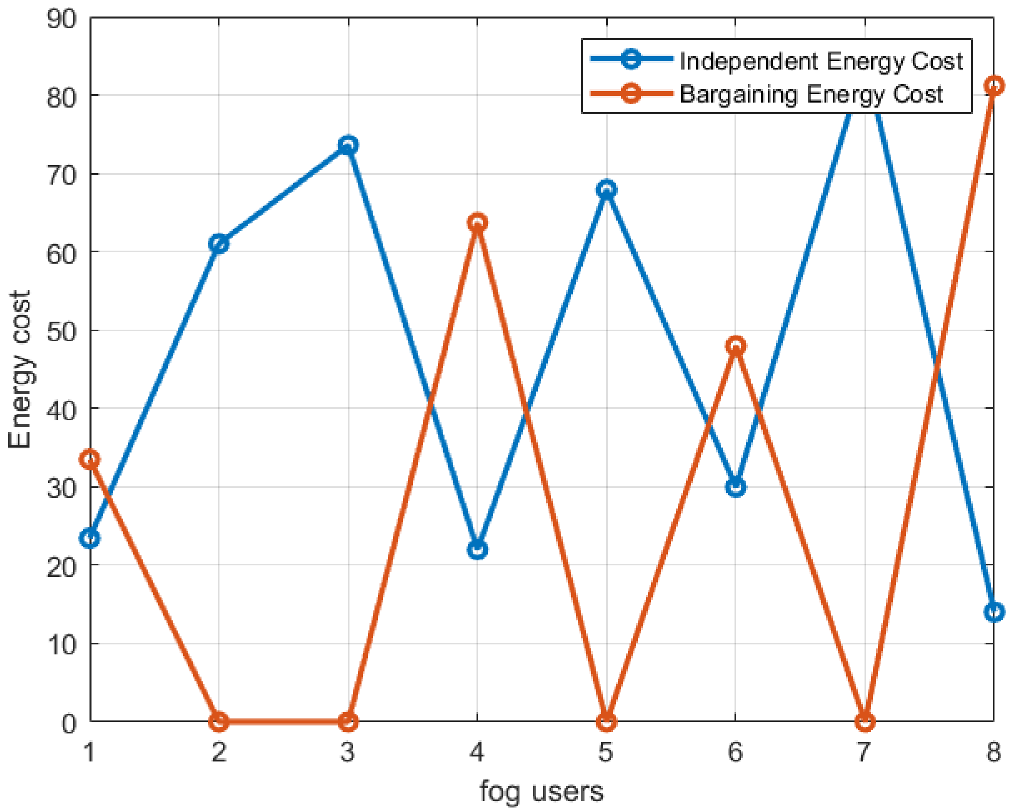

Fig. 6.2. Energy cost comparison for independent and bargaining-based load balancing.

More emphasis is placed on the incentive costs, which are non-zero and contain some value in case of cooperative task offloading approach, as in this case, the task offloading takes place with the help of an incentive-based mechanism, thereby encouraging cooperation.

In the case of independent task offloading, there is no incentive involved, hence it is Zero for all fog nodes involved in task execution. On the other hand, for the bargaining approach, there is some non-zero incentive cost which is incurred by the fog user and spent for the fog nodes.

The same is displayed and presented in the below figure (figure 6.3). The line graph colored in orange depicts the incentive costs for each fog node located on the plot.

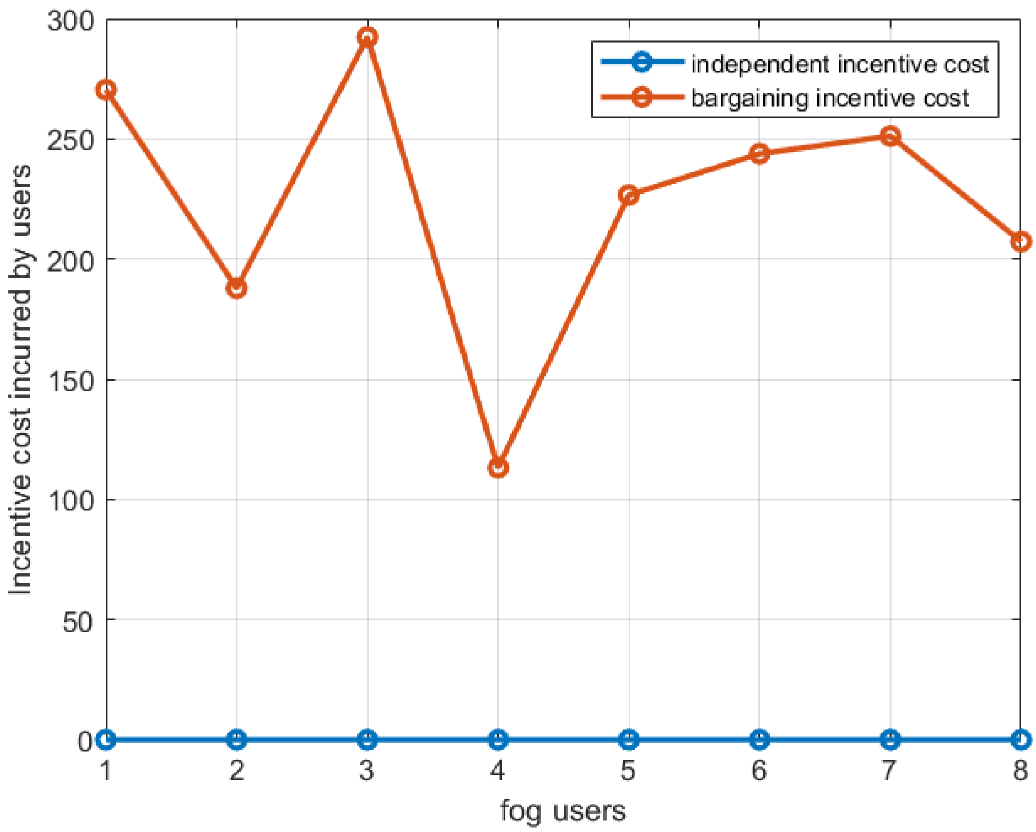

Fig. 6.3. Incentive cost comparison for independent and bargaining-based load balancing.

Following the above result, the figure 6.4, on the other hand, depicts the incentive costs received by the fog nodes from the fog users for which the tasks are offloaded. The fog users spend the incentive as a total which is then uniformly distributed among the fog nodes based on their capacity, usage, contribution to the task execution and other prominent deciding factors. Here is where Nash Bargaining Solution comes into picture and becomes responsible for the incentive distribution among the fog nodes in a uniform fashion.

Similar to the incentive costs, the incentive received by the nodes when they followed independent task offloading, was Zero, wherein it will have a non-zero value in the case of bargaining-based approach, thereby benefiting the fog nodes and encouraging them to cooperate.

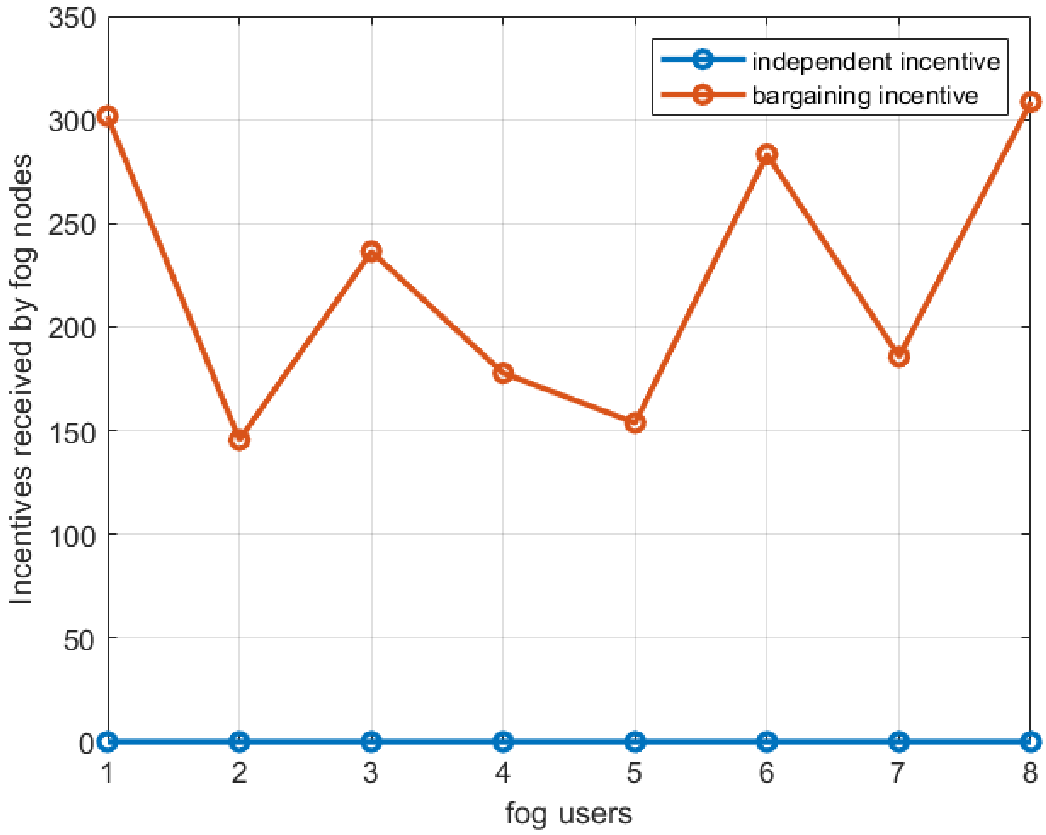

Fig. 6.4. Incentive/Reward comparison for independent and bargaining-based load balancing

The total cost of the system is inferred from the summation of energy consumption, transmission, latency or delay, and the incentives incurred by the fog users.

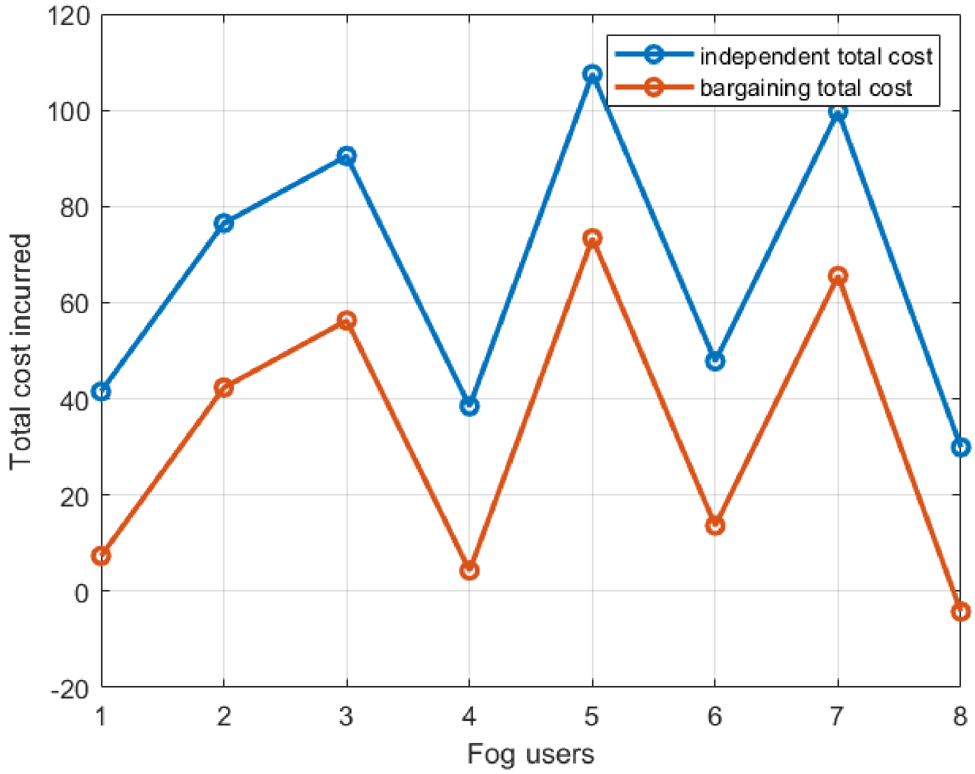

Fig. 6.5. Total, overall cost comparison for independent and bargaining-based load balancing

It can be claimed and stated that the total cost of the system is much lower for the cooperative and incentive-based task offloading approaches in contrast to the task offloading approaches which follow independent cases. Although the fog user incurs the incentive costs, the total cost incurred is yet lower than that in case of an independent approach (figure 6.5).

We simulated the total system cost considering all mandatory parameters and reassured the statement by simulating multiple times with random values of coordinates of fog nodes. The result achieved proves the objective of the research.

8. CONCLUSION & FUTURE IMPROVEMENTS

8.1. Conclusion

In a fog-assisted wireless Device-to-Device (D2D) network, we presented the configuration of fog nodes and fog users and defined a task offloading problem. We used NBS to simulate an effective job execution, and we created a bargaining or cooperative strategy. We took into account elements including the node capacity, and added the various expenses experienced by the users and the nodes in the fog networks, such as transmission latency, energy costs, and rewards. Finally, we demonstrated the NBS-based bargaining approach's efficiency and cost-effectiveness. NBS is summarized as a concept of economics and is a game-theory based mechanism to devise solutions to game-theory formulated problems and helps find fair and optimal solutions to the same. We have used NBS i in our system model in order to minimize the cost of the system including energy, latency, response time, etc. From this research and simulation carried out, it was found that optimal task offloading can be efficiently achieved in the case when fog nodes are encouraged to cooperate and thus cooperate by offloading and taking up tasks from the neighboring nodes which take part in the offloading of tasks. Compared to the independent approach, the cooperative task offloading approach was found better as the independent approach did not consider the variable factors which may influence the task execution. Consideration of such factors led us to include a mechanism based on rewards which motivates the fog nodes to allow cooperation and hence helps achieve the desirable results as per the practical scenario. Incentive-based mechanisms promoted cooperative task execution without assuming the fog nodes were willingly participating in the process. Also, cooperative approach, along with consideration of variable factors, emphasize load balancing and keep latency, response time and fair task allocation in view.

This paper suggests a mechanism based on bargaining for task offloading among the fog nodes in order to reduce consumption of energy as well as latency. In addition, it includes the incentive-based approach (that is, NBS) for the same to encourage nodes and the fog networks to co-operate for an optimal task execution and resource allocation. The approach is implemented mathematically in the form of cost models, individually for fog nodes as well as users. Also, the independent task offloading models are effectively compared with cooperative task offloading models in the project.

8.2. Usability of the research

The research can possess multiple uses in the domain of research, networking, optimization and control, resource allocation and load balancing. The system model devised in this paper and the results inferred can assist with further research in the field of load balancing and resource allocation. The paper contains a literature review of the related existing systems which propose or implement the solutions and models to similar problems, and can be used for referring to various ideas of devising solutions for real time networking and optimization problems.

In addition, the above research can be used as one of the bases for conducting a survey and analysis to implement solutions for networking problems including task offloading, resource allocation and load balancing in the domain of edge computing, mist computing and many other newer technologies.

The system model and conducted research can be suitably treated as an application of convex optimisation and Disciplined Convex Programming (DCP) which are generally used for formulating, solving and simulating mathematical optimization problems.

We have formulated a networking problem as a mathematical optimization problem and devised a solution to it accordingly using effective simulation tools and techniques and concepts of game theory and networking. Hence, it can be inferred that this paper can help in formulation of any related networking and optimisation problem as a mathematical problem. This in return, can assist with the mathematical modeling of the solution(s).

Furthermore, the research can be effectively used to consider practical and real time scenarios for devising solutions to similar networking problems without having many assumptions before reaching the solutions. This is so because of the fact that the paper considered and included real time factors such as willingness of cooperation, minimum latency incurred and many more.

8.3. Limitations

The above research successfully achieves its objective, however we can find open scopes which can be considered to overcome the following limitations:

The solution in the research is currently restricted to convex optimisation. We have formulated the problem statement as a mathematical, convex function and devised the solution accordingly. However, we can find solutions other than specifically convex optimization to extend the scope of solution. We can formulate the networking problem as some other mathematical function as well and reduce the dependency of the solution.

Currently, the research compares two kinds of approaches to increase the willingness of nodes to co-operate in order to offload the tasks and balance the loads. Thus, the paper limits this comparison to the two approaches, that is, Independent task offloading, and Cooperative or Bargaining-based task offloading. In future, the research can be extended to comparison and analysis of Incentive versus Non-incentive task offloading approaches in order to overcome this limitation.

8.4. Scope of Improvements

The paper contains open scopes which can be refined with improvements as listed below:

Currently, the paper contains the system model as well as the solution to task offloading in wireless networks, specifically the fog-based wireless network, multiple fog nodes being connected to each other and to the base station in the network, and the devices of fog users being further connected to the fog nodes. This paper is restricted to fog assisted networks. There is a scope of improvement in many other future wireless networks. The research can be extended to include latest technologies in networking and propose solutions to basic networking problems such as the one solved in this paper including resource allocation, load balancing and task offloading. The newer technologies which can be encompassed under the research in future may include edge computing, mist computing. Also, the solutions can be upgraded with the help of Artificial Intelligence (AI) as well as Machine Learning (ML), which can help with improved comparison and analytics.

In addition, the existing research and proposed solution encompasses optimization in allocation of resources in a fog network. The problem statement is formulated as a convex optimization problem as discussed in the above subsections. Furthermore, in the future, we can extend the research and use it for conducting surveys and research in the field of mathematical optimization and control.

At present, the solution is proposed with the help of the Nash Bargaining approach, which is a game-theory based concept of economics. However, we can approach other optimization and fair resource distribution schemes other than the NBS in order to achieve a few more feasible solutions to the above problem statement.

Also, the current research emphasizes an incentive-based mechanism to propose the task offloading solution, which helps with the consideration of practical scenarios which the users in a network practically experience. In future, we can focus on non-incentive based methods and mechanisms as well which may consider practical factors. This in return, will widen the domain of our future research and will help with proposing and devising even better optimal and feasible solutions.

The research in future can be used in order to practically implement the networking solution and help optimize current networking control and processes in cloud and fog computing -based networks. As a result, this article can be utilized to research the implementation of such models in practice. The research can be extended to compare incentive as well as non-incentive based task offloading approaches.

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10. APPENDIX I: Abbreviations

D2D	: Device-to-Device
NBS	: Nash Bargaining Solution
M2M	: Machine-to-Machine
DFD	: Data Flow Diagram
BS	: Base Station
FWN	: Future Wireless Networks
QoS	: Quality of Service
LiFi	: Light Fidelity
WiFi	: Wireless Fidelity
LAN	: Local Area Network
MAN	: Metropolitan Area Network
WAN	: Wide Area Network
PAN	: Personal Area Network
WWW	: World Wide Web
IP	: Internet Protocol
SAE	: System Architecture Evolution
CVX	: Convex Programming tool
DCP	: Disciplined Convex Programming
AMD	: Advanced Micro Devices
GB	: Giga Byte
RAM	: Random Access Memory
SSD	: Solid State Disk
HDD	: Hard Disk Drive
CPU	: Central processing Unit
OS	: Operating System
SDR	: Semi Definite Relaxation
MD	: Mobile Device

VNB	: Virtual Network Barriers
QoE	: Quality of Experience
UE	: User Equipment
RF	: Radio Frequency
PPP	: Poisson Point Processes
FFCA	: Furthest First Coalition Algorithm
NFCA	: Nearest First Coalition Algorithm
TDCA	: Two-stage distributed Channel Allocation
TCFA	: Two-stage Coalition Formation Algorithm
OFDMA	: Orthogonal Frequency Division Multiple Access
HSR	: High Speed Railway
UDN	: Ultra Dense Network
LN	: Long Range Nodes
SF	: Spreading Factor
MSN	: Mobile Social Networks
ADMM	: Alternating Direction Method of Multipliers
IOT	: Internet of Things