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Game theory-based task offloading in fog-based wireless networks

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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 in contrast to the task execution in independent scenarios, 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 and improve the Quality of Service (QoS) [1]. 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: *Wireless Networks, QoS, Fog Computing, Optimization, FWN*

1. INTRODUCTION

Wireless 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 [2]. 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.

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 [3]. 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 [4].

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 [5]. 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.

Load Balancing can be termed as a solution for networking in order to distribute the network traffic 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 [6].

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.

2. RELATED WORK

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

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 predicting the traffic and	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. A model based on game and resource allocation was

		information about the network.		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	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	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.

	allocation. Proposed solution is a stable one, and reduces interference.		related algorithms.	

3. IDEOLOGY

Independent solution

This module codes the solution to task offloading using an independent approach through CVX programming [15]. 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 cost of the system.

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 cost of the system.

4. DATA FLOW DIAGRAM

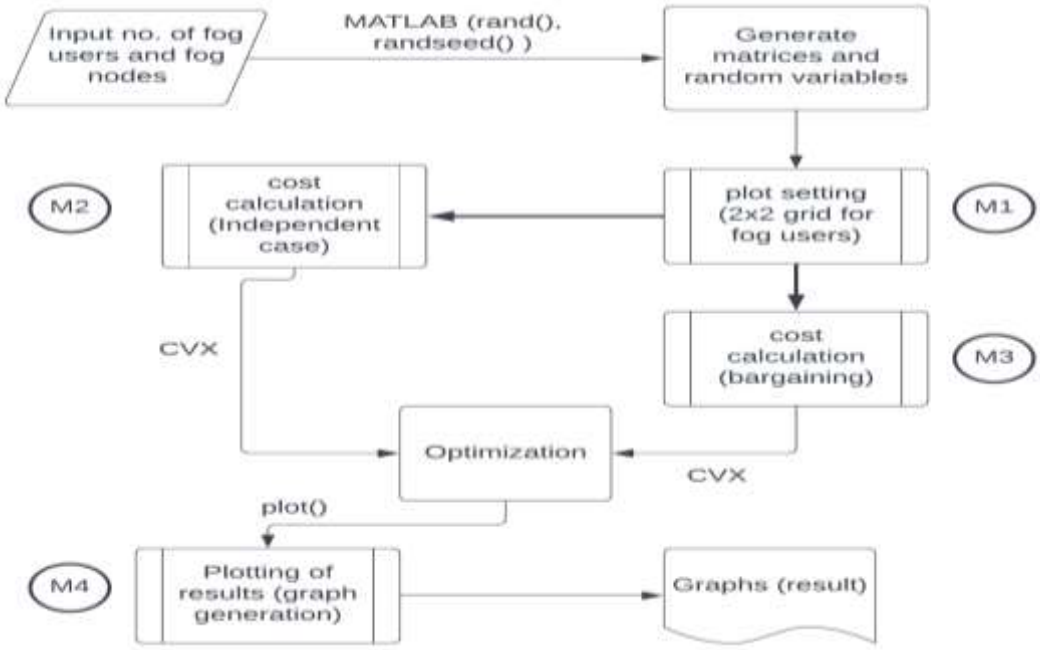

Figure 1: Data Flow diagram for representing approach to task offloading using incentive-based mechanisms.

5. RESULT AND CONCLUSION

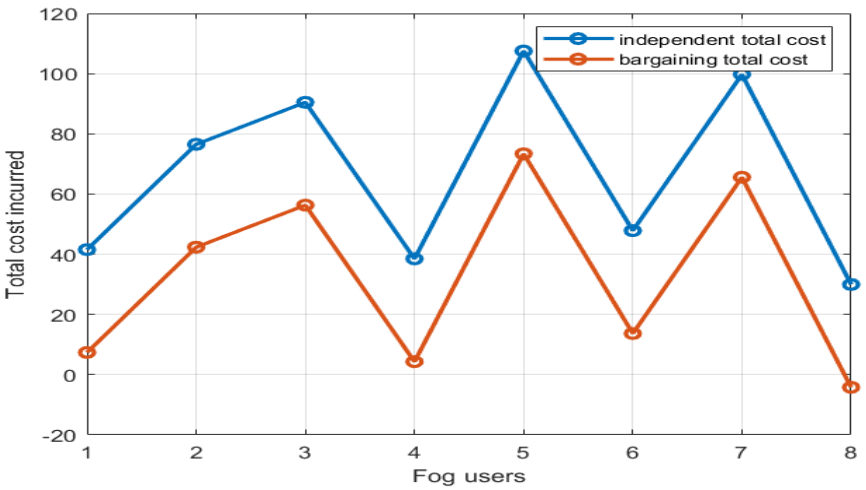

Figure 2: Figure depicting the result comparing the total cost of the system of the independent and cooperative approach for task offloading.

It can be claimed and stated that the total cost of the system is much lower in the case of cooperative and incentive-based task offloading approaches as compared to that in the case of independent task offloading approaches. Although the fog user incurs the incentive costs, the total cost incurred is yet lower than that in case of an independent approach

We simulated the total cost of the system 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 paper.

6. FUTURE SCOPE AND RESEARCH DIRECTIONS

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 [16]. 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 using Artificial Intelligence (AI) and Machine Learning (ML), which can help with improved comparison and analytics.

In addition, the existing research and proposed solution encompasses optimization in resource allocation in a fog-based 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. That is, the above work can be extended further in order with considering more real time parameters while task offloading.

The research in future can also 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. Thus, the paper can be referenced for studying the practical implementation of similar cooperative models. The research can be extended to compare incentive as well as non-incentive based task offloading approaches.

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