Game Theory in Edge Computing: a Survey

Muhammad Umair Khan

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Muhammad Umair Khan (14849)
Department of Computer Science
Riphah International University Lahore, Pakistan
Email: umairkhan8120@gmail.com

Abstract—Edge computing is gaining its fame as the IoT is becoming the state of the art now. The limitations of IoT that prompted the need of edge computing were energy consumption, latency and signal strengths. To overcome all those limitations, Edge computing was introduced. Game theory is a special type of critical thinking that was developed by military in order to train their soldiers. Later on it was being used in almost every aspect of life, from politics, economics and computer science. In this paper we are going to cover how game theory is used in edge computing. Many models have been presented in different papers showing that how game theory can help in learning algorithms as well as spontaneous decision making algorithms.

Index Terms—Edge computing, game theory, Multi access Edge Computing

1. Introduction

Internet of things is taking over the field of computer science in which every electronic device can be converted in to a smart device to save energy and many other resources. All of these devices need computational as well. As most of these devices are the devices of everyday use like mobile phones, watches, home appliances etc. So they have a limited battery power source, and the computation that is being done by them is huge and power consuming. All the data from devices is forwarded to a main cloud or data center where it is being processed upon and to draw the conclusions for the future use of those smart devices. Transmission of all that data to the cloud is more power consuming for them, as well as it decreases the performance of the cloud as it has to collect the data along with performing all the computations. Edge Computing provided the solution for this by designing a new scheme which suggested that the computations should be done by a local computing resource and then only the processed data should be forwarded to the main cloud.

Edge in edge computing refers to an infrastructure of computing that resides near the source of the machine, which is a responsible for collecting all the data from the machines and then performing all the computations on the data. It helps to improve the stream of data along with minimizing the latency so it can provide real time processing upon data. The data that is being collected by the sensors on the devices is mostly unnecessary and is in a huge quantity, so without having a filter on the data, to purify it and only the necessary information is being passed to the cloud, it is just pointless to send and store all that data to the cloud. Sending or receiving of data on cloud is optimized in order to avoid disruptions by the edge computing. Most of the IoT devices are deployed in such areas where getting connection is no reliable. Decreasing the amount of time it takes to store and process the data can be a big help in such cases, which is being provided by the edge as all of the data is processed before sending to the cloud.

All the computations that edge has to perform are mathematical and mostly algorithms of big data and data mining. For all those computations, Game Theory (GT) is being used now a days. GT is playing a vital role in performing tasks like formulation and designing and optimizing. Can also be used in many scenarios of networking as well. It is also known as the theory of strategic thinking [1]. Many types of game theories are used in solving the problems which were tedious to solve before it. Moreover, game can be used in learning environment which are referred to as evolutionary games which will be discussed later in detail.

The rest of the paper is divided into the following sections. Section 2 will discus about the background. Detailed discussion about the game theory and its types are discussed in section 3. Section 4 summarizes the key technologies that uses game theory following by their limitations in section 5. Section 6 describes about the possible research directions for game in edge computing and section 7 concludes the paper.

2. Background

Edge computing was designed for the reduction of energy consumption and latency with the help of task offloading along with carefully managing and keeping track of resources. Changsheng and Huang. [2] devised a policy of offloading which helps in minimizing the latency and energy consumption of the devices, since the execution time of devices is below a mentioned threshold

TABLE 1. CROSSOVER OF GAME

	1 payoff	n payoffs
1 player	Optimization	Multiobjective optimization
n players	Team theory	Game theory

and data percentage is determined simultaneously. Chen, Xu and Jiao [3] was responsible for the proposition of a computation model that was effective enough to join computation with communication together to improve the systems performance. Many algorithms were proposed to improve the performance of Edge Computing. Among all these works, allocation for communication channels along with the control of CPU capability has been variously addressed. The work on the control of transmission power is also done by some of the researchers. Rodrigues et al. [4] has tried to control the transmission power in order to reduce the latency of the cloudlets.

Table 1 describes that Game theory is an intersection among many disciplines and usually it involves more than one players and each player is assigned with it own payoff. So it is not like optimization where, there is only one player and the player has to only improve its own payoff. Although, in 60s, one more discipline related to game theory was devised which has multiple players (decision makers) and was known as team theory. To sum up what game theory actually is we can say that, it is a systematic way to use mathematical tools in such a way that they can model and analyze situations where multiple decision makers (players) are involved. It is a strategic process, so not only it is used in edge computing, but also it is used in several other aspects of life as well.

2.1. Mental and physical games

Every game whether mental or physical admit a mathematical model which is described via game theory where the actions of players belong to a set called action set and the payoff is the probability to win which every player is trying to maximize. Every game has some tactics and the player chooses to act upon those tactics if the opponent is playing a certain set of tactics, in order to overcome the opponent.

2.2. Marketing and finance

Some marketing strategy is needed in order to maximize the sale of a new product, which is the payoff, for a company who just launched their new product into the market. They have to predict the response of market before they let their product hit the market.

2.3. Political influence

Game theory can be used to measure the successful ratio of parties that are involved in ruling or the parties that are trying to attain the power. Also, in predicting and analyzing of a specific social policy that a governing party is going to design for the public.

2.4. Social Networking

Game theory could be used in analyzing and predicting the opinions on social media. Learning games are used to devise algorithms that are being used by the social networking experts to analyze the statistics and patterns of the users for their types. Those learning algorithms are also used to generate what to show to a specific user based on their likes and dislikes.

3. Game theory

Game theory is an application of mathematics which is utilized in the analyses of strategies used by different players while making decisions which results in enhancement of payoff among them and of the individual player. J. von Neumann and O. Morgensterns were the first one to use game in zero-sum games, this is the category of games in which one players [5]. Cooperative game theory is referred to a class of games in which there are group of players and players actions and their formation determine the result of the game. On the other hand, non cooperative games do not have joint actions of players to determine the outcome of the game. Each player can take their own actions and the end results are dependent on the actions of individual player [5]. Moreover, the set of rules are available to each player in non cooperative games to choose from.

3.1. Definition of Game

To describe a simple game, there is an assumption of three tuples, (N,A,u), in which:

- N describes a set of n finite players, which will be indexed by i and these players will make the decisions while the game is being performed.
- A defines a set of finite actions and have $A = A_1 \times ... \times An$ where A_i is the set of actions that are available to player i.
- u is defined as a real value utility (payoff) with $u = u_1, ... , u_n$, for each player i.

Figure 1 shows the representation of prisoner's dilemma. Each player has two static strategies; cooperate or defect. Each player has the knowledge of the matrix but is unaware of the choice that other player has made. If both the players have choose to defect then the matrixs value dd would be theirs. [6] proposed an algorithm for admission control which was based on cooperative game that meant to solve the problems of allocation and admission of resources. This resource allocation issue arise due to the advancements in fourth generation mobile networks that provided with mo- bile station to connect with multiple WAN simultaneously. This came up with the issues of resource allocation as each

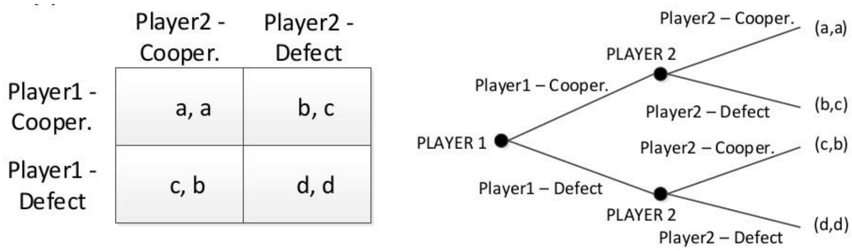

Figure 1. Representation of prisoner's dilemma

TABLE 2. CLASSICAL VS EVOLUTIONARY GAMES

Classical Game	Evolutionary Game
Players	Individual organisms
Payoff	Fitness
Static strategies of players	Player's learn and their strategies evolve
Focus on rationality	Focus on survivablity

WAN tend to have its own resources and all the WANs that are connected to a mobile network have their own. So for the coalition of all those WSN, the resource managers need to be intelligent in order to save resources.

3.2. Game Types

In this section, we are going to discus the two main representation of games found in the literature which are organized in two different perspectives; classical and evolutionary [7]. A set of predefined set choices are given to the users in the classical GT and users have to choose from those set of static choices in order to perform in the game. On the other hand, evolutionary GT does not have a static set of choices and players are not rational. The players have limited information about the choices they can make and the consequences they will have in return. When a players starts deviating from the equilibrium of the system, in classical game the player is penalized in its payoff and in fitness in evolutionary game.

Table 2 shows a big picture of how classical and evolutionary games differ from each other. The classical game is further divided in to two categories, named Non-cooperative and cooperative games which are discussed in detail in the next sub section. As for the evolutionary game, the players have evolving strategies and the mechanism that are associated with it are mutation and selection. The payoff is to survive because the less dominant solutions are taken out from the set of actions and only those survive which have a higher fitness values. The fitness value will decide what information will be passed on to the next generation. More fit a solution is, more chance it has to be passed on to the next generation.

3.2.1. Non-cooperative vs. cooperative. [1] States classi- cal games are divided into two main categories depending upon the type of choices players have and their outcome. In non-cooperative game theory, every player strive to choose their best response in order to maximize ones own payoff. There is no connection between the players and no joint actions response. By far non-cooperative games are being widely used and many text books can be found describing about it. While Cooperative games, which is further divided into two categories; transferable utilities (TU) and non-transferable utilities (NTU), the players have to find optimal joint actions NTU or cost and reward sharing in TU. Furthermore, players can have communications before playing in cooperative games. Prisoners dilemma, discussed in the last section, is an example of classical games and has both cooperative and non-cooperative conditions in it.

3.2.2. Simultaneous vs. sequential games. [1] States The second major distinction of the games is based on simultaneous and sequential games. First for the simultaneous games, as the name suggests the decisions are made once and are not changed afterwards at the same time by all the players. The players have partial knowledge and no strategy or planning is used to make their decisions. Prisoners dilemma is an example of simultaneous games. However, sequential games are those in which they have an specific order of events which effect the results and the game collects the results of previous actions to decide what action to take for this set of events. So ultimately the players may know partially or fully that what is the state of the game. Finally the decisions are made with the knowledge of state and what was the results of previous decisions. This type of games are mostly represented in the form of trees.

3.3. Automatic learning using game theory

When it comes to the learning and evolution, genetic algorithms (GA) tend to be known as the best option for this. GA uses operators like crossover, mutation and natural selection to find the best solutions from the population and then pass them to the next generation which will evolve more in the next generation and thus the best solutions can be found from all the search space. Due to the convergence time in GA, it is not recommended to be used in the learn- ing of a network like routing and localization. Reinforced learning (RL) performs better in this scenario than GA. RL is a learning mechanism in which every object learns only by its own experiences with the outer environment.

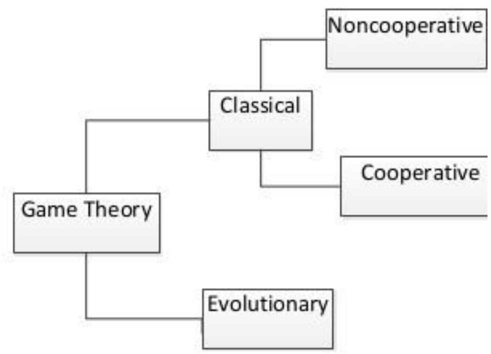

Figure 2. Types of Games

No previous knowledge is stored or used in the making of decisions. It is what our routers do in routing and it can be labeled as unsupervised learning. Despite of this fact, evolutionary game theory is used in some of the network selecting algorithms.

4. Key technologies of Game in Edge

In this section, we are going to discus what are the applications of game in Edge computing.

4.1. Game Theory in Multi Access Edge Computing

[7] In optimization of parameter configuration along with their modeling and their analysis, game theory, which is enhanced with the help of learning algorithms, plays an important role. Firstly we are going to discus the advantages that can be obtained by NC in many fields of wireless networks. In network resource sharing, NC helps to enhance the approach of using a common pool between set of consumers that want to use a set of constrained resources in a fair way. This implies that NC provides with the elastic and scale able managing of the resources. In power control, the main problem was to distinguish the interference between signals and limiting it. Energy consumption was a huge in this scenario without NC, and NC helped to solve this problem. While in Medium Access Control (MAC), scheduling of single channel of communication, which is to be shared by several users, is improved by NC. Multi rate opportunistic routing with NC is done to steer the traffic through a network for the purpose of maximization of end throughput. For security NC game theory is used to maximize the lifetime of network along with low power computation and communication of IoT. Along with all these, the wireless nodes compete with each other in a limited shared resource, so an algorithm which solves the problem of robustness as compared with the centralized approach which was being used before that. Moreover, MEC provides the computational capabilities which are inside a small cell and in close range, specifically radio access range, to provide the user with best experience [8].

4.2. Game theory to enhance QoS of Cell Edge users

[5] States the QoS for the signals that are being transmitted matters while talking about the latency of the system. The data that is being transmitted from the base station and through multiplexing is based up on the frequency along with the domain that is being selected, for combining the beam formation to Low Power Station (LPS), which is responsible for providing the plane that is dedicated for transmission. Which can help in reducing the noise interference and source station calls can be prioritized. The link between Base Station (BS) and LPS have very low latency for communication in them. Frequency that is being divided by a fraction can be used in combination of soft and hard frequencies, soft frequency for the inside network users and hard for the outer ones. For the formation of beam, adaptive beam former is used. Adaptive beam former can be defined as a systematic way to perform spatial signal process, along with the dealings of communication on network signals. The main things that separates adaptive beam former from conventional is that it can adjust the performance provided accordingly to the change in the environment in which it is operated in. The time, frequency and time frequency domains are explained in Figure 3.

Time domain works by putting and managing time delays in reception and sending of signals, explains how time beam former works. It adds up a delay of a specific amount of time delay in the receiving signal of each array element and then sums them all up in the end.

Frequency domain can be further divided into two types of frequency beam former. First one operates by dividing the received signals frequency into multiple bins. After that, different delays and sums are of beam former are applied to the individual bin which causes different signals in different multiple directions for each of the frequencies received. On the other hand, second type deals with same way of distribution of the frequencies but during doing so, multiple different phase shifts are introduced into the each bin. This method can be used to optimize and increase the strength of a particular needed signal in order to send it to LPS which will help in drop and low rate of signals of that particular signal in the LPS.

Third one, as mentioned earlier, is time frequency domain. As it is clear from its name that it is a combination of both time and frequency distribution. This combination is done in the following manner: during the data transmission frequency is divided in to several bands and then those bands are divided further internally in different time domains in order to get more throughput of the network. The cooperative behavior of the BS, they are connected with each other and communicating simultaneously, is the main aspect of a network while dealing with the real time communication. If by any means, one of the BS is

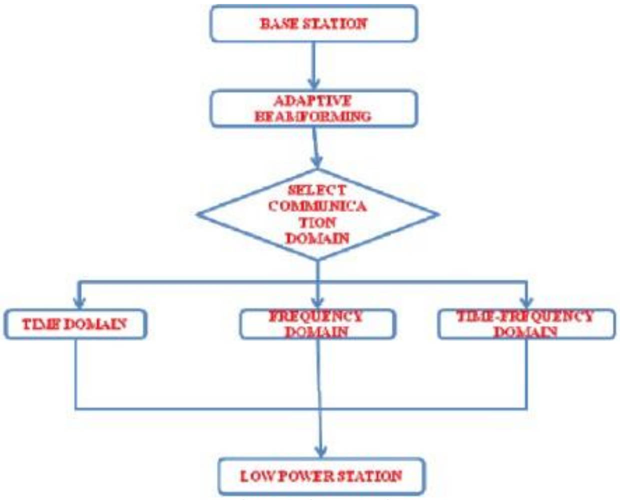

Figure 3. Working of Beam formers, from BS to LPS

overloaded or stops working then its load can be distributed to the other BS depending upon their availability, access , connection and workload .This is the cooperative approach of game theory that learns with the help of previous decisions that how cooperative game theory can help in increasing the QoS of signal to the edge users. Coalition, which is used in this, is basically a subset which is derived from the set of all players in order to work together and work accordingly. They have to agree upon a set of rules that will lead to the division of pay off among all of them. Cooperative game can have multiple coalition and values of every coalition is specified for each of them. The characteristic function of N finite players in a single coalition can be defined as c: 2_N R. The value of coalition for an empty coalition set would be zero and the players profit from entering into a coalition. Along with that, game is also used in analytics and learning skills for the small drones which will use game theory and MEC offloading techniques to solve energy efficiency and QoS issues [9].

4.3. Using game for interference aware multi user mobile edge

[10] The main purpose of Multi access Edge Computing (MEC) is to reduce the power consumption and latency of the nodes and devices along with their task offloading and properly managing their resources. Due to the interaction of mobile users and along with the disruption in the power control, MEC is distributed and game theory is used to solve this challenging situation. The system model that is used for this in [10] implies, a MEC system which comprises of N users. Every user have some tasks that need computation, that computation could be done locally or this data could be offloaded onto the MEC server. All of the desired region is divided into cells and each cell has a Base Station (BS) and every user can be connected to a BS based upon its signal strength and distance from the BS but one user can connect to only one BS at a time. The task offloading decision is simple and binary. Spectrum that is available is divided into k sub channels and the decision of offloading is 0 or the a single channel that was responsible for its delivery; for a user a = 0 or a = s_{ck}. This problem is solved using games Nash equilibrium.

4.4. MEC offloading with Game theory and Reinforced learning

[11] Problems that are being faced by MEC are activation of server, load balancing, management of requests, proper allocation of the critical resources along with scheduling problems. These problems can be avoided using the cooperate game in MEC. With the combination of reinforced learning, the lack of knowledge before making decisions and being uncertain issues can be resolved. Using MEC for increasing the wireless network might affect the radio distribution of resources. To keep the energy consumption of the server to minimum will cause uncertainty as all the resources have to consume and share most of the resources over the network. This problem can also be solved by the game theory with reinforcement learning. While talking about the resources that need computation and allocation of them, offloading is done on the server side of MEC. The devices themselves are responsible for the decision whether to offload the data on server or not, while some intelligent servers also have the capability of decision. There could be a competition between the devices for the access of resources and on server as well for increasing the number of offloaded tasks on them. All these type of problems can be solved with the help of games that involve competition and economic models from the market. After being inspired from the caching mechanism in the operating systems, information centric MEC are designed which uses the approach of saving the data of needing services to various locally available servers in order to access it very quickly. The need of the users or devices can be changed hence the data that is being stored for fast access can be changed, same as that of cache. The servers are needed to be designed by keeping in mind the need of data and how much data they can store at one time for fast accessing. Moreover they need to interact with each other in order to get the clear picture of data, hence cooperative game theories can be used to address all the problems in this. Large number of players competing for a limited available resource can be modeled using Monitoring Game (MG). In MG, algorithm is used by the agents to learn the best action that could be played in the next round from a set of strategies. Agents use their strategies and then score them, the strategy with highest score will be used in the next round. This is how MG evolves. Many of these algorithms are based on reinforcement learning which let the agents to balance exploration-exploitation trade off in order to get the maximization of their scores for their strategies. Agent choosing and scoring its strategy is know as exponential learning. Since the MEC servers are not homogeneous as they are composed of numerous small base stations along with large base stations and wireless access points, so the

resource allocation is a difficult task. The appropriate game theories can be used to avoid these kind of problems.

4.5. Game in one to one contract VM migration

[12] As the MEC has to deploy edges within the radio access range to serve real time applications that need minimum latency to provide them with latency free services. Virtualization is becoming an important part of todays network along with in the MEC as well, where VM are used to share the physical resources across several different applications and facilitate many applications on a shared physical resource. Virtual Machine (VM) migration is a main issue in MEC as have to move VM from from one edge node to the other. A model is developed by [] in which Edge Nodes (EN) act as players and each EN has a payoff to maximize their own profit. The players have to take actions which include: 1. make a decision about migration of VM, 2. conclusion of contracts of VM for their migration and 3. having to adjust the prices of EN. Each player has to do one to one contracts with each other in order to be able to migrate the VM. The MEC architecture for this is composed of multiple highly performing EN which are fully connected with each other in a well manner. Each EN receives data from wireless network and have to perform real time computation and then share that data with each other. The major part of the data which is composed of remote tasks is assigned to the EN which can help in more expansion of the MEC. The Mobile Users (MU) are connected to one EN and they are moving so in near future they are going to be connected to the next EN. The VM on one EN which is running the application required by this MU will have to be transferred to the next EN, which is done by the VM migration from this EN to the next. Due to this working schema, the computations and calculations become very difficult to handle. So in this situation, EN and MU take decisions to increase their own profit whether cooperatively or by competing with each other. While entering in the range of new EN, a MU announces itself to the new EN and EN compensates it with a new contract depending upon the resources it has available and current number of MU connected to it. The figure 4 summarizes the working and architecture of MEC for this.

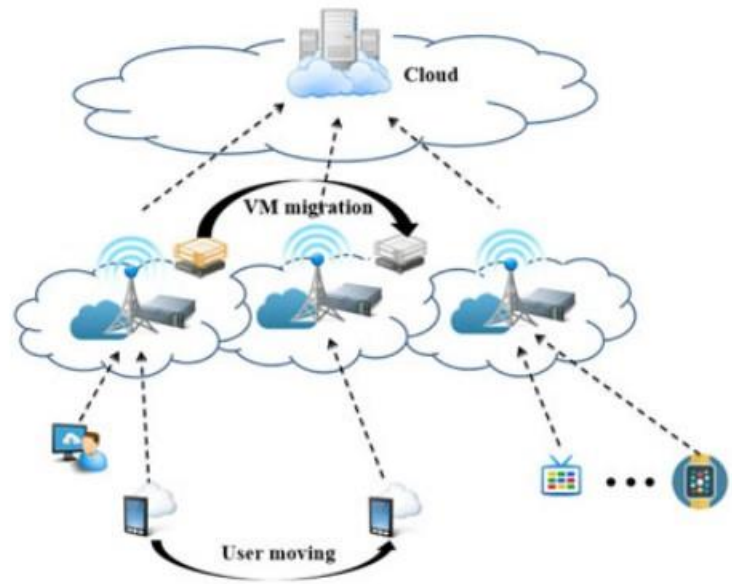

Figure 4. General Architecture of MEC

5. Limitations

The limitations of the technologies, that were discussed in the above section are discussed in this section.

5.1. Game Theory in Multi Access Edge Computing

Non-cooperative(NC) game could be chosen for the support of in performing the wireless operations correctly, however it should be kept in mind while choosing NC that it could also have some disadvantages. The very first con that we are going to discus of NC is that the learning curve is not present in it because of the players are taking actions simultaneously along with the lack of information about what other players decisions were.

5.2. Game theory to enhance QoS of Cell Edge users

The QoS of cell edge users is enhanced with the help of cooperative game which helps them to work along with each other. The limitation to this system would be that they are unable to take decisions which will affect in their own benefits. In other words we can say that the Base Stations (BS) cannot help themselves to maximize their throughput as they have to sometime take decisions to benefit the other BS. But as we can see it is a trade off between QoS for the Low Power Stations (LPS) and maximization of the throughput of BS, so in order to improve QoS, it is necessary to do that. It is the opposite of Non cooperative game theory in which every player has to make decisions for its own benefit, referred to as selfish actions.

5.3. MEC offloading with Game theory and Reinforced learning

The algorithms discussed in the cooperative games need to learn in order to perform well with the help of reinforcement learning. Learning can be difficult if the set of strategies is too large and need to devise some other algorithms in order to speed it up. As the cooperative game has players that are depending upon each other and one of them has latency in it due to this slow learning procedure then it can cause the whole system to perform badly or even worse than the conventional systems. Although conventional systems are not equipped with these kind of technologies but the failure of these state of the art systems can cause them to perform even more badly then those old school systems.

5.4. Game in one to one contract VM migration

As it uses one to one contract for the EN and MU, this process is totally interactive in every step. Due to this continuous interaction, it might have a bad impact on the battery life of the mobile devices. The scheme proposed by [] performs well than the state of the art technologies but there is no analysis of this new systems energy consumption.

6. Future research directions

Some interesting research directions have been identified by [7] which will help in covering Augmented Reality (AR), virtual allocation of resources and congestion control. Sensor and actuators are needed for assistance like location tracking and picture sensing in AR along with cognitive assistance. Energy consumption is the bottle neck for the resources allocation whether fair or dynamic. Game theory can be used in these as they are open to learning and efficiency can be increased using the learning process in game. Intelligent Agents (IA), which is a combination of performance along with learning, can also be designed for the intelligent resource allocation process. IA depends on raw data that it receives from the sensors and after perform- ing a set of computations that were based on the policies defined by it, with the help of which it can determine the environment. The policies or set of rules that were defined for the IA will determine the performance of IA and after measuring the performance of IA those policies could be modified if not found satisfactory. Controlled congestion could be defined as a system which helps to keep a check on the network along with looking out for any near future possible breakdowns and avoiding them.

7. Conclusion

Edge computing came into the picture when the increasing devices in IoT started having issues of energy, memory and latency. Then in Edge computing issues like fair resource allocation, maximization of throughput and minimizing the latency were faced. Game theories are used to solve these issues in Edge and Mobile Edge Computing. Game provide many models in almost every aspect of life, cooperative and evolutionary games are used in scenarios where the system has to learn and non-cooperative games could be used where simultaneous decisions are to be made with minimum latency. Moreover issues regarding range, intelligent resource allocation, handling users and increasing the QoS of wireless signals can also be increased using game based models.

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