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Game Theory-based Routing for Software-Defined Networks

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Abstract: ***Software Defined Networking is an emerging paradigm that allows the separation of the control plane from the forwarding plane. This shift in paradigm towards plane separation provides various advantages as compared to the traditional networks. Routing is one such benefit that allows more controlled, predicted, and dynamic routing in the network due to its centralized paradigm. The global network view is available at the controller. It can take optimal decisions compared to distributed systems where a global network view is impossible to create, as many message exchanges are required. Dynamic routing is one of the notions where the decisions are made in real-time by viewing traffic in the network. Inspecting the current traffic, an optimal path is chosen. This practice of selecting an optimal route is possible in different ways. Game theory is a model for strategic decision-makers applied in another field to make the results more effective. In this paper, the game theory for traffic light control is studied in detail, and the mechanism is applied for efficient routing in the network. Simulation results show improvement over traditional methods of routing.***
Keywords: Software Defined Network, Routing, Game theory, Control plane, Scalability

I. INTRODUCTION

Software Defined Networking is an architectural approach that simplifies network operations by providing global network view and programming capabilities from a central location. A controller in a software-defined network (SDN) facilitates interactions between applications and the forwarding devices [1]. Open network foundation (ONF) has bound the definition of SDN to the OpenFlow protocol [2], which is one of the mainly used communication protocol between the controller and the forwarding devices. The centralized design allows a global network view of the topology and traffic network to compute and end to end path. The global perspective must include all network elements and resources existing in the infrastructure, whether they are actively used or not. The separation of the control plane and forwarding plane can benefit the consumer by changing the software release model to enable innovation in either plane to proceed independently from each other. More relevant to the control and forwarding plane separation would be its ability to support network hardware in the forwarding plane without having to iterate the control plane. By separating the planes, the forwarding elements become more stable by having less coding and limited functionality. In a traditional network, the configuration is manual, and the command-line interface (CLI), based on a device by device basis. Network management consists of using the script as a way to solve manageability problems. Dealing with multiple routers, switches, and servers working as a system, the control and management state need to be applied across the network as an operation. It doesn't provide flexibility and agility or the notion of dynamicity. SDN allows centrally managed and distributed control management and data plane where the policy-making process is centralized while rule processing is distributed among multiple forwarding devices [3]. The QoS, access control, security, etc., are managed centrally and pushed to the switching nodes. This allows more flexibility, control, and scalability of the network itself. The combination of dynamic routing and signaling with the centralized view is a compelling concept of SDN.

Traffic policy and rerouting, based on network conditions or regular shifts are typical applications of any network. When we apply SDN and a centralized management plane, more quickly decisions can be made about where to reroute the data traffic, and this can occur programmatically with software interfaces. Routing protocols used to construct loop-free paths in a network are mostly implemented in a distributed manner, i.e., each device has a common control plane that decides the policy and an independent forwarding plane that implements the protocol [4]. Both planes communicate with each other, which leads to communication path construction at the control plane. The centralized control plane is prone to failure due to scalability issues.

Similarly, in SDN, large traffic and control signals towards the controller create their scalability challenges and reveal the scalability limitations. The control plane's availability is to provide a flexible environment to affect the outcome of forwarding decisions. It should make the network more elastic and efficient based on additional knowledge above and beyond the optimality's algorithmic determination. Routing policies have limited scalability in most of the implementations. The control plane supports multiple applications.

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This proposal's motivation is to facilitate the scalability of the control plane by restricting the number of messages and providing the best route to packet delivery. At present, the control plane addresses the issue of scalability by installing multiple controllers. Efforts are still required to provide scalability by designing a new routing algorithm that routes so that fewer events are generated towards the control plane for delivering a packet from its source to destination [5]. Undoubtedly, the scalable path may not follow the shortest one, but it provides scalability to the controller, a more desirable property of any centralized network.

The remaining paper is organized as follows. Section II discusses background work on which the proposal is based upon. Section III provide detail design and implementation of proposed model. Section IV presents experiment results followed by a conclusion in Section V.

II. BACKGROUND

This section starts with discussion on different research proposals that are provided for modelling solutions to traffic light problems in an urban area. Cooperative and non-cooperative both solutions are discussed with emphasis on the solutions using game theoretic approaches. The discussion on game theory solutions are followed by routing solutions that are available in literature for increasing the scalability of SDN.

Game Theory is a science in which strategy and optimal decision making, is done by independent and competing actors in a strategic setting. In such a setting, each player has some small number of possible choices to be made. Game Theory deals with situations where a participant's decision affect their outcomes as well as the outcomes of other players. Each actor has well-defined objectives that drive their decisions and results in payoff to them. Different approaches such as network flow approach, reinforcement approach and game theoretic approach, for traffic light management system are used. Applicability of Non-Cooperative Game Theory model in the transport system is analyzed in [5]. It presents insight into the relation of transport model and games, and it claims that non-cooperative games well suits for transport system where the gain of one may prove congestion to others.

In "Urban traffic control problem: A game theory approach" [6] author propose to use signal lights as finite controlled Markov chains. Non-cooperative games are used to represent an intersection and solution is provided using Nash Equilibrium. Game theory and extra-proximal method are used for realization. Each player at intersection want to minimize its queue and therefore a conflict occur. The payoff for each player depends on player's strategies. Each player wants to minimize his penalties i.e. number of waiting cars. Both aims are in conflict which is solved by Nash Equilibrium concept. The solution is based on game theory and Markov chain model. At each iteration a game is solved by extra-proximal method to find a Nash equilibrium point. The approach is applied to simple isolated intersection in the paper.

In "A distributed approach for coordination between traffic lights based on Game theory" [7], author proposed a neural network based Q learning approach with fuzzy reward designed for online learning of traffic light behavior. In past few years, multi-agent systems have become famous technology for effectively exploits the increasing availability of diverse, heterogeneous and distributed information sources. Researchers are using different tools and techniques to implement multi-agent system for different problem domain. Multi-agent system is aggregation of agents, where multiple agent communicates and coordinate with each other. As urban traffic system is very complex system where entities and relationship among them are complicated, therefore author apply multi-agent system into the simulation of traffic system. Reactive cognitive and hybrid agents are used in the system. Every agent controls all the phases of an intersection only. The control agent coordinates all the phases of intersection base on game theory. The Q-value is used that influence the control strategy. The use of neural network reduces the number of traffic. The study concludes that Neural network based Q-learning can be applied into the control of the traffic signal light and coordination mechanism is required. The learning time should be reduced to optimize the performance.

A game theoretic approach for traffic management at intersections is introduced in [8]. The concept of game theory that captures the interplay software independent decision making and centralized control is the notion of a correlated equilibrium. Correlated equilibrium is used in the model and the action of agents are put to external entity who decides the property that it is not in the interest of any agent to deviate from the recommendation of this external entity. Vehicle to vehicle infrastructure communication protocol is assumed in which vehicle communicate their intended paths and the system send permission of approval. A generalization of Nash equilibrium that more accurately reflects situation where centralized controller is used is called coordinated equilibrium. Correlated equilibrium can be computed in polynomial time. The author shows that game theory traffic model based on delay and safety reduces to independent set games. Through simulations it is proved that connected vehicle allow more throughput than standard control mechanism.

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With the development of IOT intersection controller are called smart agents that can communicate with each other. A cooperative game theory approach is proposed in [9] to improve the traffic flow in large network. A distributed manage and split algorithm for coalition formation is presented. As the number of vehicle are increasing day by day, intelligent traffic control become very important issue for future. Transportation research is focusing on optimizing the flow of traffic. Cooperative game theory between agents are proposed to optimize the stability. The experiment result shows that the proposal improves traffic flow in both uniform and non-uniform. By coordination among controllers the waiting time of vehicles at intersection can be reduced from 15 % to 25% comparing with previous methods like green wave coordination.

The article [10] provide decentralized flexible phasing scheme for traffic signal control using Nash bargaining game theory framework. Each phase is modelled as a player in a game that cooperate to reach a mutually agreed outcome. The controller adapts signal timing dynamically to changing traffic conditions without using historic data which tends to inaccurate and results is inefficient traffic signal plans. The developed controller is decentralized which increase both scalability and robustness of the system. Decentralized system are easy to establish and operate as no such reliable and direct communication network is required. Also the decentralized does not sacrifice in system wide performance and compute network wide Nash optimum solution. Finally, the model reduces unnecessary stop and go vehicular movement which reduce fuel consumption and air pollution.

Scalability issues remains prevalent in SDN due to its centralized architecture. Various solutions are there in the literature to increase the scalability of the network [11][12]. Handling scalability through routing protocols is one of the main solutions to the problem. The routing protocols routes the packets in such a way that less number of control plane events are generated. The path is selected in such a way that it remains valid for longer period as any invalidation of the path create unnecessary packet forwarding towards the controller. Reducing the number of events towards the control plane reduces the load of the controller and it can handle other important events in the network. Overloaded controller is not able to handle all the requests or it may handle it with large latency. No doubt increasing controllers in the control plane is one of the solutions to increase the scalability, but routing protocols can also do its part of work by reducing the events towards the control plane. Pure OpenFlow switches are totally dependent upon the controller and for every event that did not find a rule in its flow table is forwarded to the controller. Reactive nature for flow installation of OpenFlow is a concern to scalability of the controller. Table 1 presents different routing protocols that provide scalability to the network in one or the other way.

Source	Type	Objectives	Strategy
M. Soliman et. al. [13]	Source Routing approach	Controller scalability and performance issues in SDN	Reduction is state distribution by the controller to network devices by using variation of Source Routing
H. Owens II et. al. [14]	Explicit Source Routing approach	Controller scalability in SDN	The scheme is used to reduce the number of events in the control plane.
A.R. Curtis et. al. [15]	Modified OpenFlow model by shifting some responsibilities to data plane.	To make SDN capable to the needs of high performance networks.	It provide a modification of OpenFlow model to break the coupling between control and global visibility.
M. Yu et. al. [16]	Shift functionality towards data plane.	To increase scalability of the control plane.	Keep all the traffic in data plane by directing traffic from intermediate switches.
A.R. Curtis et. al. [17]	Management of Elephanta flows	To utilize traffic for better bandwidth utilization.	Detect Elephanta flows at the end hosts.
R. Wang et. al. [18]	Proactive approach	Traffic distribution and load balancing in the network.	Proactive install wildcard rules in switches to direct requests without involving controller
J. Zhang et. al. [19]	Hybrid approach	Load balancing for multiple traffic matrix with low complexity and good scalability.	Complement destination based routing with explicit routing, take advantage of both routings.

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III.PROPOSED GAME MODEL

To explain our game model, we must first discuss how the model for traffic light control works in an urban city. In one case, the traffic light control in a city works independently of the other intersections lights. They have fixed timings for red and green lights. This system is not suitable to handle the traffics in the city as they are not adjustable and cannot tune to handle the traffic. Another traffic control system that has centralized view is more suitable to handle the traffic as the overall traffic flow is visible to the central server. In case of high traffic at the intersection, the traffic light system may consult the server. The server after considering the traffic of the nearby intersections, directs the traffic light system to increase or decrease the green light timings for a particular direction. In this way, the traffic can be diverted to other direction based on the traffic in the nearby area. Figure 1 shows such intersection.

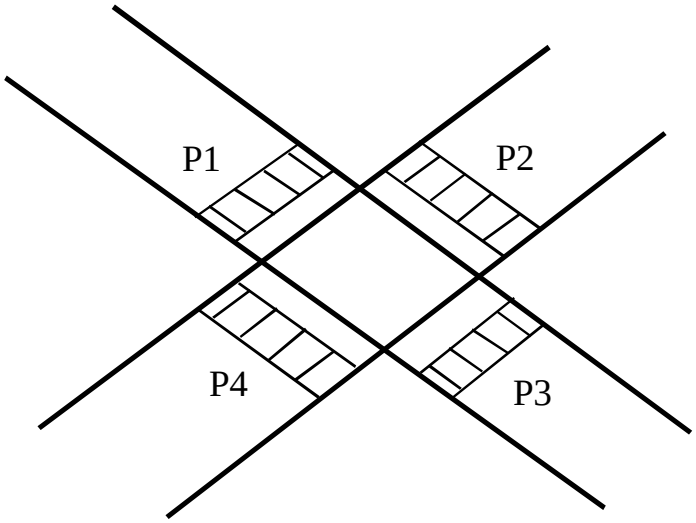

Figure 1: Traffic light intersection system in a city

A similar system in implemented in the SDN using the concept of game theory. P1, P2, P3 and P4 i.e. intersections traffic lights act as players of the game. The controller in the network have global view of the traffic in the network. It decides the strategy of traffic diversion in such a way that the chances of failure of the route is minimum and no route request event is again generated for the same flow. The major difference and advantage of implementing the system in SDN is that the packet arrived has known destination, whereas the destination of a vehicle is not known in advance to the traffic light system. The availability of destination for a packet allows controller even to take more appropriate decision. The players work in coalition to provide an optimal route to the packet. Players works against the traffic congestion, which is considered as another team of players that targets to generated random traffic to jam the system. The payoff is in the form of smooth traffic flow in the system and less chances of route failure, once the controller decides the strategy based on the game theory. This will reduce the forwarding towards the controller in the network. The objective is to design a new routing protocol that take advantage of coalition games in a centralized paradigm.

In game theory, a game consists of n players, each player selects a strategy s_i from the strategy set S. It can be modeled as
P= $\{p_1, p_2, p_3 \ldots p_n\}$- set of players in the game
A= $\{a_1, a_2, a_3 \ldots a_n\}$- set of actions that player can perform
S= $\{s_1, s_2, s_3, \ldots s_n\}$- set of strategy set
U=payoff function i.e. payout a player receives from arriving at a particular outcome based on the strategy chosen by it. The players in the game will strive to maximize their payoff in the game. Cooperative game theory assumes that players can communicate, form coalition and compete with external entity. It only describes the structure, strategy and payoff of coalition. Under cooperative game, player coordinate their strategy and share payoff. The branch of cooperative game that describe the formation of cooperative group of players is called coalition games. Coalition games involves set of players, denoted by N = {1,2,3…n} who want to create coalition to gain some profit or benefit in the system. Coalition value V, quantifies the worth of coalition in the game. The games are defined by pair (N, V) and for every V a different game may be defined.

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In SDN, to build the global view of the network, the controller requires the updated information from different switches regarding the traffic flow at their ports. This information can be taken regularly or randomly whenever new flow request arrives. To avoid the rush of packet generation whenever there is a request of new packet flow from the switch, regularly updating of information is preferred and implemented. A request for new path for a packet may arise when there is unavailability of the flow rule at the switch or there is already a traffic on the port for the flow. To reduce the number of counts towards the controller the switches are pre-loaded with flow rules to forward the packets. A controller is communicated only when there is congestion or failure of path at the switch. A game theory model is built to formalize this process of route selection at the controller. In this model, players are the switches; strategies are the routes and payoff is in the form of less congested network and reduced control plane events. The controller act as third party mediator, thus an optimized payoff function can be designed to achieve the equilibrium. In this model, topology T= (S, L) with L= {L1, L2, L3…. Ln,} and S= {S1, S2, S3…. Sn} is assumed. On receiving a path request message from the switch, the controller retrieves the information regarding the source, destination and the congested link from the message. The steps of the proposed routing protocol are listed as follows:

1) *Step 1:* Controller generates a set of strategy that includes all possible routes for packet forwarding, from the requesting switch to the destination, i.e. {ST1, ST2, …. STn}.
2) *Step 2:* These Strategies are communicated to the switches and works as proactive rules.
3) *Step 3:* On receiving a flow request from the switch, the controller need to generate other set of strategies excluding the congested link.
4) *Step 4:* The real-time traffic status for each link is monitored, those strategies are excluded that contains traffic at any of its link.
5) *Step 5:* The payoff is calculated for available strategies as per equation 1.
6) *Step 6:* The strategy with highest payoff is selected for implementation.

The amount of traffic decides the payoff for each strategy. A new route should be decided in such a way that a path with minimum traffic on its links is selected. The coalition of switches between the route is formed. The switches are directed by controller to forward the traffic of this new source and destination to the particular port. In case the two strategies have the same value for the above mention factor, then the strategy with less number of hops is selected. In equation 1, the traffic of route is evaluated to use in the payoff.

$$\text{Traf.Flow}(\text{Route}_i) = \sum_{i=1}^{n} (\text{Flow}(\text{path}_i) \quad (1)$$

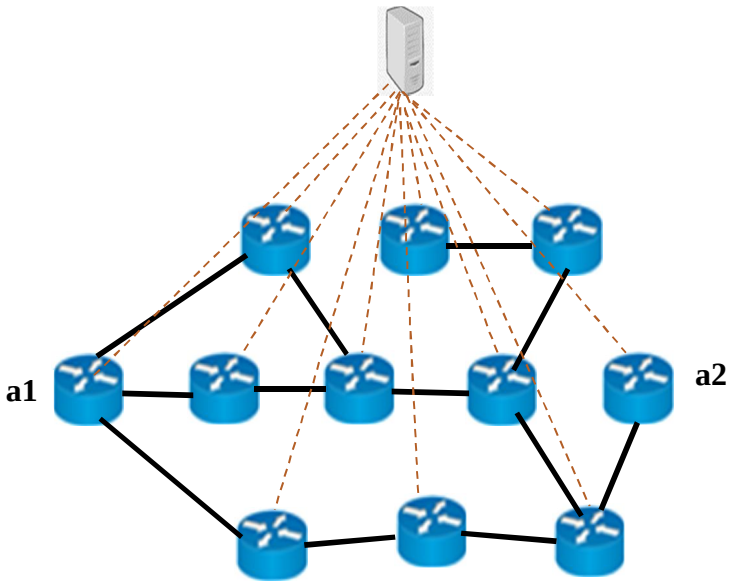

Figure 2: Architecture showing Controller-switch connection

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Algorithm1: Hybrid Routing with Game Theory (HRGT)

Input: A SDN with real time traffic
Output: A traffic flow system for the network
During initialization of the network
Step 1: For every source and destination in the network
Calculate Source-destination path
Step 2: These paths are communicated to switch in the form of rules
i.e. proactive rules are communicated
During real time traffic in the network
Step 3: For every flow request message
Generate new set of routes that exclude the congested path
Step 4: Monitor real-time traffic for every link in the new routes
Step 5: Find the strategy with minimum traffic
Step 6: Select the strategy with minimum traffic and reply the switch.

IV. EXPERIMENT RESULTS

For the purpose of evaluating the proposed system model, a network is created using Mininet [20] with a Ryu [21] controller. Mininet is famous emulator that allow us to deploy a network in a virtual machine. It is installed on a system Core i5, 8 GB Ram and 1TB hard drive. The simulations provided an easy way to find the performance of any system even hardware test beds are other options that are used to check the performance of any new proposals but due to high cost they are hardly ever used.

1) *Result1:* The comparison is made with a reactive method i.e. the main mode of communication in the OpenFlow networks. The reactive method calculates the path only when there is any request from the switch. For every new flow, the switch contacts the controller. the number of messages generated in the network with low, moderate and high traffic is studied and the results are generated. In case of low traffic in the network, the proactive rules that are installed in HRGT provides low controller overhead as compared to the reactive method. In moderate traffic flow, due to failure of few routes the number of messages are increased in HRGT, in high traffic the route failure occurs frequently but still the number of messages are less than the reactive method. Figure 3 depicts the comparison of HRGT with reactive mode of operation.

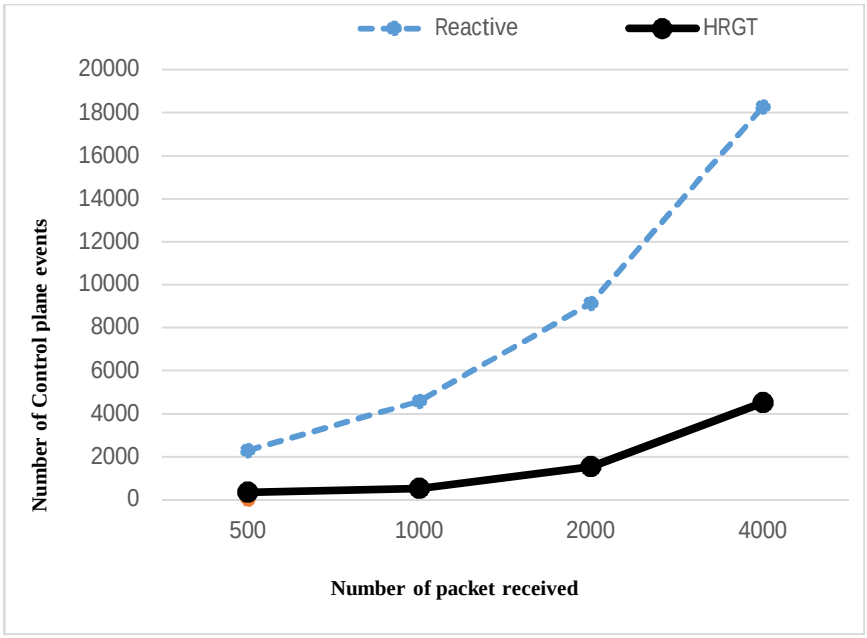

Figure 3: Number of packet received vs. number of control plane events generated

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2) *Result 2:* ERSDN is another protocol that is variant of source routing in SDN. It intends to increase the scalability of controller by reducing the number of events towards the control plane. The ERSDN informs all the switches in the path of the route regarding the flow rules update in case of rerouting. The concept of ERSDN is also implemented in HRGT and the switches that lie in the path of new route are also informed during flow rule updating. ERSDN did not provide any new method for rerouting and therefore HRGT provide better performance to it. The results in Figure 4 shows the output.

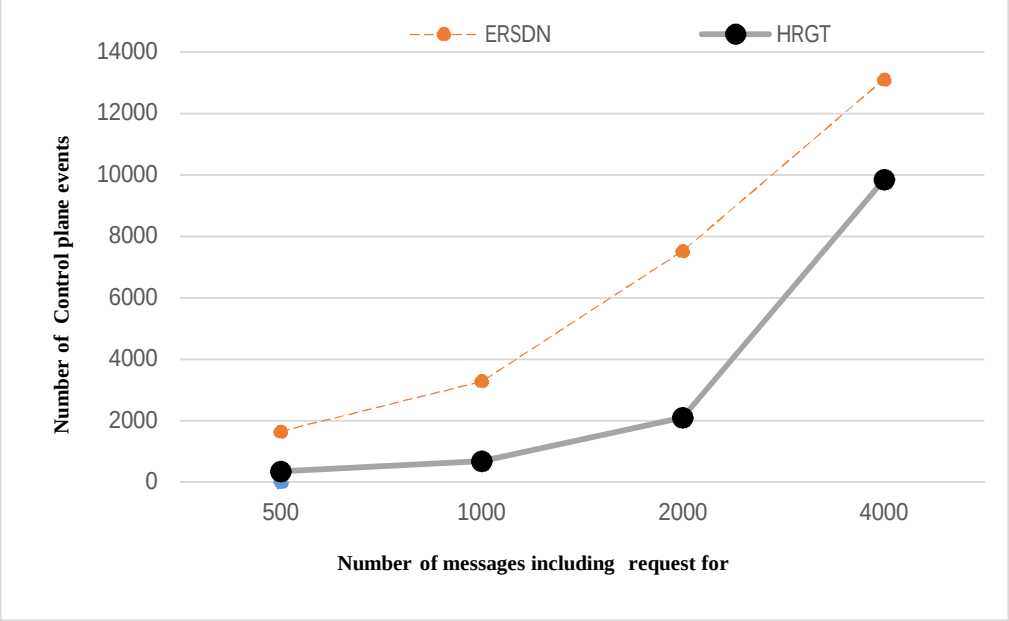

Figure 4: Comparing the performance of HRGT vs. ERSDN

Conclusion: Scalability is one of the major concerns of researchers in the community of SDN. Efforts are being made to increase the scalability of control plane by using different techniques. Reducing the events towards control plane reduces the load of the controller and it can handle other requests efficiently. Inducing the concept of reducing control plane events in routing provide and efficient solution to scalability in SDN. Game theory has proven its efficiency in different fields and it is applied in the proposal to achieve the target. The results show that it provides a better solution to reduce the events as compared to the basic approach of reactive method and ERSDN. In future the propose method can be combined with other to achieve more throughput.

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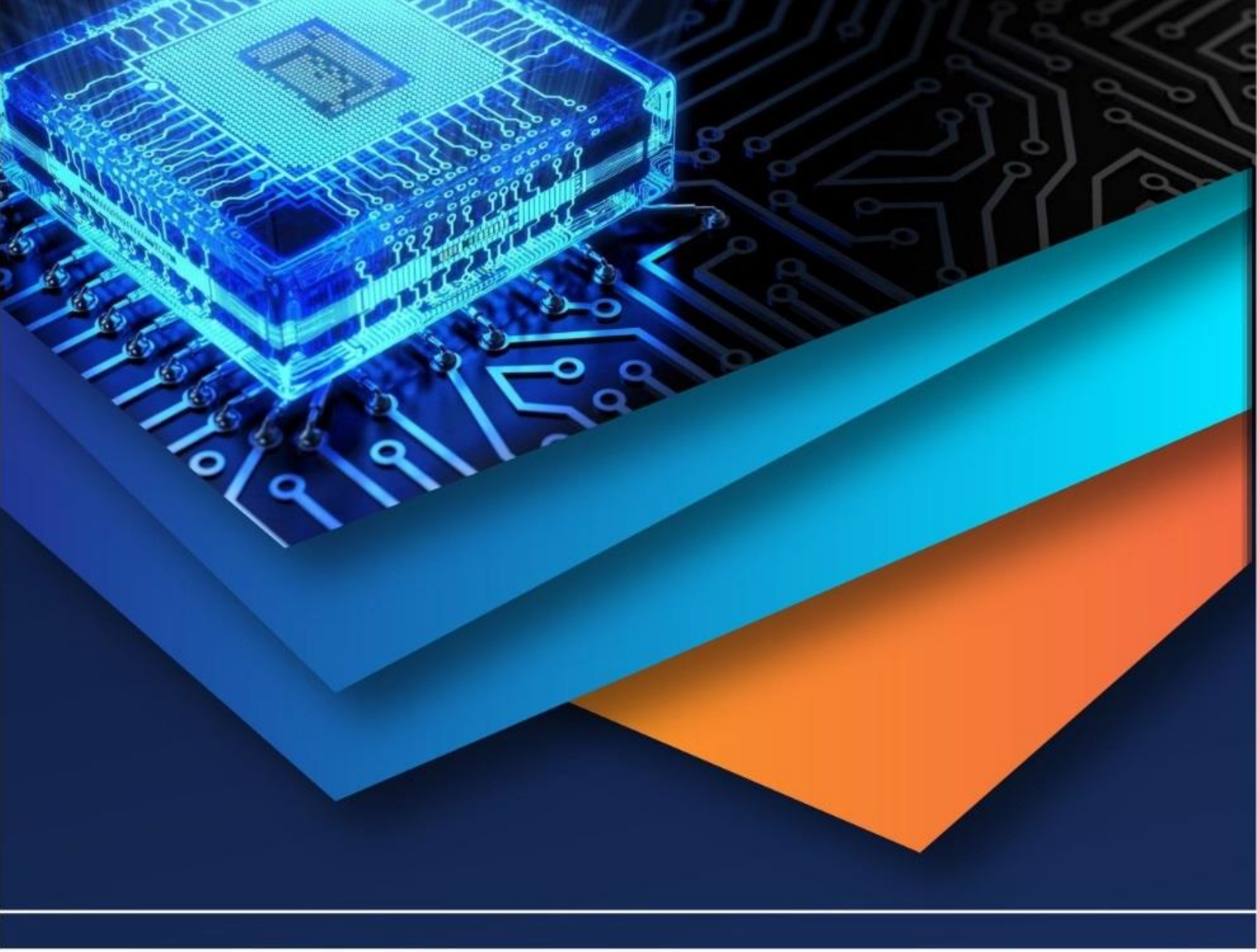

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