Novel Congestion-Free Alternate Routing Path Scheme using Stackelberg Game Theory Model in Wireless Networks

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Abstract

Recently, wireless network technologies were designed for most of the applications. Congestion raised in the wireless network degrades the performance and reduces the throughput. Congestion-free network is quit essential in the transport layer to prevent performance degradation in a wireless network. Game theory is a branch of applied mathematics and applied sciences that used in wireless network, political science, biology, computer science, philosophy and economics. The great challenges of wireless network are their congestion by various factors. Effective congestion-free alternate path routing is pretty essential to increase network performance. Stackelberg game theory model is currently employed as an effective tool to design and formulate congestion issues in wireless networks. This work uses a Stackelberg game to design alternate path model to avoid congestion. In this game, leaders and followers are selected to select an alternate routing path. The correlated equilibrium is used in Stackelberg game for making better decision between non-cooperation and cooperation. Congestion was continuously monitored to increase the throughput in the network. Simulation results show that the proposed scheme could extensively improve the network performance by reducing congestion with the help of Stackelberg game and thereby enhance throughput.

Keywords: Congestion; correlated equilibrium; Stackelberg game theory; wireless networks

1. Introduction

Recent advances in technology [1] have led to a persistent need for novel congestion avoidance frameworks that suitable to tackle the technical challenges accompanying future wireless networks. Game theory approach [2,3] has emerged as a pivotal tool for the design of future wireless networks. This is mainly due to the need for incorporating decision-making rules and techniques into next-generation wireless nodes, to enable them to operate efficiently and meet the users' needs in terms of network services like congestion and load balancing [4]. The key challenge of game theory in a wireless network has many problem in finding accurate models and solutions. Existing congestion control schemes are not adequate to cope with issues such as wireless channels, transmission rate, queuing delay and signal to- noise ratio. Game theoretic approach provides a wide range of wireless applications such as wireless local area networks, multi-hop networks, cooperative networks and cognitive-radio networks.

An application of game theory in wireless networks pertains to modeling the issue of congestion in wireless network and power control [5] in cellular networks. In wireless network, researchers have been concerned with the problem of designing a mechanism to prevent congestion to increase throughput. In a non-cooperative game [6], a number of players are involved in a competitive situation in which, whenever a player makes a move, this move has an impact on the utility of the other players. Similarly, in a congestion control game, we have a competitive situation in which the transmit packet in a wireless network provide impact positively or negatively on the transmission rate. As a result, non-cooperative game was designed in solving a congestion control in the wireless network. Congestion control used game theory mechanism to design next-generation congestion-free wireless networks. Game theory has emerged in a novel application area including wireless and signal processing communities.

We proposed a novel scheme, reducing congestion-free alternate routing path for wireless Networks, which uses a Stackelberg game theory model (SGTM); its goal is to reduce the congestion using correlated equilibrium. Differently from the above existing methods, this work reveals the best reaction to select a congestion-free alternate path.

The remainder of the paper contains five sections. Section 2 summarizes existing work and highlights the importance of the proposed work. Section 3 describes our Stackelberg game theory model in wireless network to provide congestion-free network. Section 4 presents our simulation results and a relevant performance analysis. Finally, Sections 5 presents our conclusions and discusses future direction.

2 Related Works

The issue of congestion in wireless networks is very complex that includes measures taken for manipulating the traffic within the network in order to prevent congestion. Hierarchical Tree Alternative Path (HTAP) algorithm [7] created a dynamic alternative path by performing minor computations to mitigate congestion in wireless sensor networks. Saad, et al [8] proposed a coalition formation game with transferable utility for forming coalitions among the Road Side Users (RSU). In coalition formation, each RSU take an individual decision to join or leave a coalition, depending on its utility. This scheme improves the diversity of the information circulating in the network.

Pavlos, et al. [9] presented on the bird flocking behavior to coherently move packets to the sink to reduce congestion in wireless sensor networks. The synchronized group behavior of birds' flocks is mimicked in order to control the motion of packet flocks through a network of constrained sensor nodes. This scheme avoided congestion regions and dead node zones. Prajakta, et al., [10] presented a Congestion Avoidance and Route Allocation using Virtual Agent Negotiation to provide cooperative route-allocation decisions in the network. Anastasopoulos, et al., [11] proposed an adaptive coding and modulation (ACM) mechanism for TCP throughput maximization. It investigated the speed of convergence on various physical-layer metrics that provide stability of ACM scheme. Most theoretical research on routing games [12] in wireless networks has so far dealt with reciprocal congestion effects between routers.

Ng and Seah [13] presented Game theoretic approach for improving cooperation in wireless multi-hop networks. This scheme obtain clause for collusive packet forwarding, and truthful routing broadcasts for wireless multi-hop environment. Niyato, et al. [14] proposed a Markov chain dynamic model to obtain a stable coalitional structure. The authors also presented the well-defined merge and split mechanisms for a distributed environment to maximize the social welfare of all vehicular users. Saad, et al. ,(2010) [15] presented a hedonic coalition formation game among the secondary base stations (SBSs) that take an individual decision to join or leave a coalition while maximizing its utility resulting in improve the cooperative sensing in Cognitive networks.

Wang, et al. [16] proposed a sensing game called as evolutionarily stable strategy (ESS) of the secondary users. It provides dynamics converge to the ESS that gives the possibility of a decentralized implementation and maximize the throughput. Yang, et al. [17] presented a cooperative Nash bargaining power-control game to provide network efficiency and user fairness. A minimum signal-to-interference-plus-noise ratio requirement is employed to provide reliable transmission to secondary cognitive users. Pedro Lopez, et al., [18] presented a hybrid method that combination of genetic algorithm and the cross-entropy to optimizing the elements. It is used to predict congestion in the network. Paramasivan, et al., [19] a Dynamic Bayesian Signaling Game to reduce the malicious node's utilities in mobile ad hoc networks. It reveals the best actions of individual strategy to minimize the utilities of malicious nodes in

MANETs by analyzing strategy profiles of malicious nodes.

Ali Hameed and Arkadii Slinko [20] proposed weighted hierarchical games that are used for secure secret sharing. Shapley value is used as a solution of this game for making cooperation. Dieter, et al. [21] presented the refined best response correspondence of a game for reducing the payoff by all pure strategies. Previous schemes are not perform excel in terms of congestion and maximizing throughput. So, it is very much essential to derive congestion-free networks for various social welfare networks. In this work, we proposed a Stackelberg game theory approach to finds a buffer level threshold using correlated equilibrium and also provide maximum throughput by selection of leader and followers. The proposed scheme finds alternate paths for maximizing successful delivery of packets to destination.

3 Proposed Works

3.1 Wireless Routing-game formation

A wireless network is represented as directed graph G = (V,E) with vertex set V and edge set E with undirected. It has source and destination set that represents as $\{(S_1, D_1).....(S_i, D_i)\}$. Different players originate from different source vertices and pass information to different destination vertices. The path of a wireless network is represented as $p_i = S_i - D_i$. A graph G contains parallel edges, and a vertex that participate in multiple source–destination pairs. Each edge e of a wireless network has a congestion cost function c_e. The cost of each edge is determined by both nature (link quality) and players' actions. The cost c_e represents a quantity that increases with the network congestion when players utilize the edge too much. The congestion cost function is described as follows in terms of congestion parameters $c_e = (\alpha_i , \beta_i)$.

The utility for a player u_i. is devised as the sum of the cost over the selected paths, and depends on the flows. In the routing game, the strategy s_i for each player is choosing minimal overall cost that consider as optimal flow in the network. The path between source – destination flow is a non-negative vector indexed by the path set p_i. There are two constraints on the flows and paths. First, a player selects multiple paths for transmission. The summation of flows over different paths is equal to the player's source–destination rate. Second, in each vertex, the sum of the input flows and the flow generated by this vertex is equal to output flows.

In this, independent players interact in the network. The total network flows result from individual players' decisions. The graph G was formed when player i plays a strategy s_i while all other nodes maintain their strategies that represented as $s_{-i} = [s_1 \ldots s_{i-1}, s_{i+1} \ldots s_k]$. The best response for a player and the Nash equilibrium found to analyze the outcome of the game. The best response for player is the selection of the flow that optimizes its utility, ven that the other players maintain their strategies. The Nash equilibrium is the stable point at which no player can unilaterally improve its performance by changing its own strategy alone. Atrategy s_i^* is the best response for a player that is given by Equation (1)

$$s_i^* = u_i\left(G_{s_i^*}, s_{-i}\right) \geq u_i\left(G_{s_i}, s_{-i}\right), \forall s_i \quad (1)$$

We formed the wireless network as hierarchical level. The network is divided into l hierarchy levels based on the distance. In initial network stage, each node at a level l selects the nearest neighbor in level l +1. Each node at level l' transmits packets using the nodes' strategies at level l +1 with different probabilities over time.

3.2 Stackelberg Game Theory Model

In non-cooperative games, a hierarchy among the players exists whereby one or more players declare their strategies before the other players choose their strategies. In such a hierarchical decision-making scheme, the declaring players enforce their own strategies upon the other players who are called the leader. The players who react to the leader declared strategy are called followers. There are multiple leaders and multiple followers exist in a network. A leader and a follower with their strategy sets are denoted by s_1 and s_2, respectively. The leader announces any strategy to play $s_1 \in S_1$, the follower must respond with a leader's strategy $s_2 \in S_2$. The congestion of two players p1 and p2 are given below $\left(\alpha_i , \beta_i\right) \in \left\{\left(\alpha_{p1}, \beta_{p1}\right), \left(\alpha_{p2}, \beta_{p2}\right)\right\}$ for $\alpha_{p1} \geq \alpha_{p2}$ and $\beta_{p1} \geq \beta_{p2}$.

A Strategy s_i^* is the best response for a player in terms of congestion cost function that is given by Equation (2)

$$s_i^* = u_i\left(G_{s_i^*}, s_{-i}\right)c_e \ge u_i\left(G_{s_i}, s_{-i}\right) c_e, \forall s_i$$

A strategy might have many reactions of the leader. The reaction set $R_2(s_1)$ defined for each strategy $s_1 \in S_1$by

$$R_2(s_1) = \{ s_2 \in S_2 : u_2(s_1, s_2) \ge u_2(s_1, t), \forall \in s_2 \} \quad \text{Eq.(3)}$$

$R_2(s_1)$ is the optimal response or optimal reaction set of player2 to the rategy $s_1 \in S_1$ of player1. A Stackelberg strategy is defined by a reaction set to find an equilibrium point with hierarchical decision-making. Stackelberg game with player1 as the leader, aategy $s_1^* \in S_1$ is represented as Stackelberg equilibrium strategy for the leader.

$$\min_{s_2 \in R_2(s_1^*)} u_1(s_1^*, s_2) = \max_{s_1 \in S_1} \min_{s_2 \in R_2(s_1)} u_1(s_1, s_2) \triangleq u_1^* \quad \text{Eq.(4)}$$

The quantity u_1^* is the Stackelberg utility for the leader. Similarly, Stackelberg equilibrium strategy for player 2 is just swapped subscripts 1 and 2.

Stackelberg utility for the leader has a unique value that provides hierarchical decision making. In Eq.(4), the leader's Stackelberg strategy s_1^* ensures that the leader receive a utility that is more than u_1^*. The optimal response of the follower becomes unique for evy strategy of the leader, and u_1^* becomes the actual leader's utility when the follower's reaction set $R_2(s_1)$ is a singleton set for each $s_1 \in S_1$.

Leader's Stackelberg strategy represented as $s_1^* \in S_1$. The equilibrium wh s_1^* is an optimal strategy for the follower in any strategy $s_2^* \in R_2\left(s_1^*\right)$. Thus, the pair (s_1^*, s_1^*) is a Stackelberg solution for the game with player1 being the leader, and the utility pair $u_1\left(s_1^*, s_2^*\right)$, $u_2\left(s_1^*, s_2^*\right)$ is the corresponding Stackelberg equilibrium outcome.

Let u_1^* and u_1^{NE} denote the Stackelberg utility and the Nash equilibrium utility for player1 in two player finite game, respectively. If the reaction set $R_2(s_1)$ is a singleton set for all $s_1 \in S_1$ in the Stackelberg formulation for a leader.

$$u_1^* \ge u_1^{NE} \quad \text{Eq.(5)}$$

The leader improves its utility as per proposition (5). Whenever the follower has a single optimal response for every strategy of the leader, then the leader performs the Nash equilibrium. This proposition holds if $R_2(s_1)$ is a singleton set for all $s_1 \in S_1$ and not only at the Stackelberg strategy s_1^* of the leader. Table 1 shows the Stackelberg game for two players.

Table 1: Stackelberg game for player1 and player2

	U	D	M
U	(3,3)	(2,3)	(0,2)
D	(1,4)	(1,3)	(4,4)

(D,M) and (U,U) are Nash equilibrium with no hierarchy, but (D,M) is the better payoffs for both players that yields (4,4). If a player 1 be a leader. The leader chooses strategy U, and then the reaction set of the follower is $R_2(U) = \{U, D\}$. The Stackelberg utility for the leader is $u_1^* = 2$. In contrast, if the leader chooses D, then $u_1^* = 1$. Consequently, $s_1^* = U$ would be the leader's Stackelberg strategy, and the Stackelberg utility would be $u_1^* = 2$. It is depending on whether the follower chooses U or D, at the Stackelberg equilibrium. The leader achieves either 2 or 3. The game confess two Stackelberg equilibrium (U, U) and (U,D) with payoffs (3,3) and (2,3), respectively. This demonstrates the difference between the Stackelberg utility $u_1^* = 2$ and the actual utility at the Stackelberg equilibrium $u_1\left(s_1^*, s_2^*\right)$, which could be either equal to u_1^*, if the follower plays U, or better than u_1^* if the follower plays D. The Stackelberg equilibrium provides lower utilities for the leader and the follower in the best Nash equilibrium. We used the Stackelberg solution with a single leader and multiple followers. The leader's announced Stackelberg strategy to indicate the point where congestion raised and declared that the best strategy to take alternate path that provide congestion-free network. Figure 1 shows the congestion avoidance path with alternate path. The alternate paths P1 and P2 were found when congestion was occurring in a network.

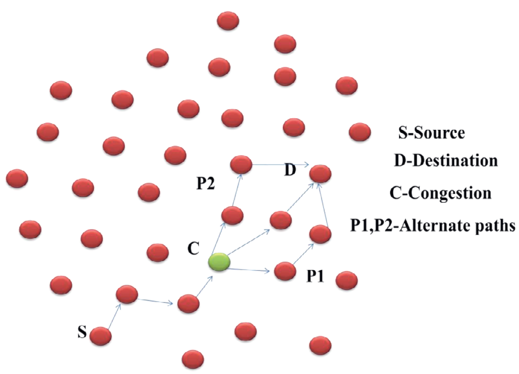

Figure 1: Congestion avoidance with alternate path

3.3 Correlated equilibrium

The correlated equilibrium was suitable for decision process in between non-cooperation and cooperation. A coordinator was helped to correlate their actions by sending signals to the players. The signal from a coordinator does not depend on the individual states that make co-ordination of actions between the players. The correlated equilibrium of players allows utilizing a joint action profile with a certain probability. It generates a better Nash equilibrium to set the threshold value. A non-cooperative strategic game is defined as Eq.(6)

$$G = \left(N, \left(S_i\right) c_e \; i \in N, \left(u_i\right) \; i \in N\right) \quad \text{Eq.(6)}$$

The correlated strategy p(s) is a probability distribution over the strategy profile $s \in S$. The correlated equilibrium denoted as a strategic game G, a correlated strategy $p(s) = p(s_i, s_{-i})$ is said to be a correlated equilibrium if, for all $i \in N, s_i, s_i^{'} \in s_i$ and $s_{-i} \in S_{-i}$ we have

$$\sum_{s_{-i} \in S_{-i}} p(s_i, s_{-i}) \left[u_i(s_i^{'}, s_{-i}) - u_i(s_i, s_{-i}) \le 0 \right] \quad \text{Eq.(7)}$$

By dividing the inequality Eq.(7) by $p(s_i) = \sum_{s_{-1} \in S_{-1}} p(s_i, s_{-i})$ and using Bayes' rule

$$\sum_{s_{-1} \in S_{-1}} P(s_{-1} | s_i) \left[u_i(s_i^{'}, s_{-i}) - u_i(s_i, s_{-i}) \right] \le 0, \forall s_i^{'} \in S_i \quad \text{Eq.(8)}$$

This implies that the expected payoff received by a player i choosing strategy s_i at the correlated equilibrium is greater than or equal to its expected payoff for choing any other strategy s_{-i}. A probability distribution at the correlated equilibrium must satisfy the following:

$$(0-1)_{p11} + (5-4)_{p12} \ge 0, \quad \text{Eq.(9)}$$

$$(0-1)_{p21} + (5-4)_{p22} \ge 0, \quad \text{Eq.(10)}$$

$$(0-1)_{p11} + (5-4)_{p21} \ge 0, \quad \text{Eq.(11)}$$

$$(0-1)_{p12} + (5-4)_{p22} \ge 0, \quad \text{Eq.(12)}$$

$$\sum_{i,j \in \{1,2\}} p_{i,j} = 1, \; 0 <= p_{i,j} \le 1, \forall i, j \in \{1,2\} \quad \text{Eq.(13)}$$

where $p_{i,j}$ is the probability of player 1 choosing strategy i and player 2 choosing strategy j, where $i, j \in \{1,2\}$ with strategy 1 being stay straight, Table 2 shows the Nash equilibrium in which strategy ST, and strategy 2 being swerve, i.e., strategy S. The first two inequalities represent the optimality of the distribution for player 1 by comparing the payoffs for the cases when player 1 chooses strategy ST of first inequality and S of second inequality.

Table 2: Pure-strategy Nash Equilibrium

	Straight(ST)	Swerve(S)
Straight(ST)	(0,0)	(0 or 1)
Swerve(S)	(1 or 0)	(0,0)

Table 3: Mixed strategy Nash Equilibrium

	Straight(ST)	Swerve(S)
Straight(ST)	1/4	1/4
Swerve(S)	1/4	1/4

Table 4: Correlated Nash Equilibrium

	Straight(ST)	Swerve(S)
Straight(ST)	0	1/2
Swerve(S)	1/2	0

Table 5: Correlated Nash Equilibrium

	Straight(ST)	Swerve(S)
Straight(ST)	0	1/3
Swerve(S)	1/3	1/3

Similarly, the third and fourth inequalities are written for player 2's case. The last two equations simply state that $p_{i,i}$ are probability values. This system of inequalities admits an infinite number of solutions, i.e., correlated equilibrium. Nonetheless, we find straight forward correlated equilibriums in Table 2, 3, 4 and 5. In Table 2, we show the two pure-strategy Nash equilibrium which are in the correlated equilibrium set. In Table 3, we show the correlated equilibrium which is the mixed-strategy Nash equilibrium of this game. This mixed strategy Nash equilibrium dictates that each player use each strategy with a probability of 1/2. The correlated equilibrium in Table 4 can be interpreted as a congested point. The correlated equilibrium in Table 4 yields a better expected utility than the mixed-strategy Nash equilibrium. Finally, the correlated equilibrium in Table 5 is the one that maximizes the expected sum of utilities, obtained by a linear maximization over the set of correlated equilibrium. The set of correlated equilibrium contain an infinite number of points. Therefore, it is useful in a congested application to define a metric or threshold. We used a correlated equilibrium to find the buffer level threshold. The expected sum of utilities defined by a correlated strategy $p(s)$ if it satisfies the following conditions:

$$p(s) = \underset{i \in s}{\operatorname{argmax}} \sum_{i \in N} E_p(u_i), \forall s_i, s_i^{'} \in S_i \text{ and } \forall\ i \in N \quad \text{Eq.(14)}$$

In contrast, the max-min criterion attempts to find the correlated equilibrium that guarantees a minimum expected utility: A correlated strategy $p(s)$ satisfying the max-min criterion is given by

$$p(s) = \underset{i \in s}{\operatorname{argmax}}\ \min E_p(u_i)\ \forall s_i, s_i^{'} \in S_i \text{ and } \forall\ i \in N \quad \text{Eq.(15)}$$

The correlated equilibrium in wireless networks provides a balance between the cooperative solution which requires a lot of overhead but can be highly efficient.

3.4 Alternate routing path

In buffer-based congestion, congestion is still possible to happen when a node receives packets with a higher rate than it can transmit. In a wireless network, all nodes are exactly the same. When the buffer of a node starts filling, this node has to take action. Each node is able to run congestion detection (CD) algorithm. When the buffer reaches a buffer-level **threshold** value or congestion cost value, the CD algorithm starts counting the rate with which packets are reaching the node. Since each packet is identified in its packets header, the CD algorithm is aware of all the nodes that transmit packets through this node, as well as their data rate.

$$\sum_{i=1}^{j} Rx_i \geq Tx_{max} \quad \text{Eq.(16)}$$

The CD algorithm is able to calculate the total receiving rate and compare it with its maximum transmission rate (Tx_{max}) using Eq. (16), When this ratio is large the node sends a backpressure message to the nodes that transmit packets through it to search for an alternative path. The Stackelberg game concept is used where a leader and follower is selected. A leader provides a best response strategy to alternate path from the congested point. Hence, it is a hierarchical network, an upstream node is informed to stop transmitting packets through a specific downstream node, it follows the leader node's strategy to transmit or reduce the transmit rate with the same level in comparison with the congested node. Subsequently, all upstream nodes that reside in a level lower than the congested node update their leader's strategy that this downstream node is congested and avoid transmitting any data through this node and follows the leader node's path. Similarly, when this downstream node becomes available again, it informs the upstream nodes accordingly. It offered the topology control for source based hierarchical tree, each node is able to inhibit the transmission of packets through itself and also it is able to join the first available shortest path, after path alternation.

3.5 Monitoring congestion situation

A node is congested in terms of occupied buffer space. The parameter needs to be tuned is not just the value of the threshold, but also the duration of the excess burst period. If the duration is set too low, then the alternative routing path mechanism is triggered often. Buffer monitoring begins when the buffer occupancy of each node reaches half of the total. At this instance the affected node counts the number of nodes from which it is receiving packets. Then, it assumes that each node is transmitting with the maximum data rate and calculates the time until the buffer occupancy will reach the maximum limit. When this time elapses it checks again the occupancy of the buffer. If it is receiving packets with a higher rate than it can transmit and it triggers the alternative routing path mechanism to avoid congestion. If the buffer occupancy is less than maximum it re-calculates the remaining buffer and adjusts accordingly the time, which obviously is greatly reduced. It employs lightweight congestion detection scheme that able to face both permanent congestion situations successfully.

4 Performance analysis

The proposed scheme has been implemented in network simulator (NS2). We evaluate the performance of proposed scheme and the other algorithms through extensive simulations. In the simulation, we evaluate the performance of proposed scheme in comparison with two other algorithms such as and HTAP and CADA [22]. 100 nodes were randomly deployed in a 500 m 500 m area of interest. The transmission range was 20 m. The Stackelberg Game Theory Model reduces the effectiveness of the congestion in the network. The simulation results were studied by varying the network size from 50 to 200. Table 6 shows the parameter setting for simulation of proposed scheme. With the objective of improving routing performance with related approaches, we have modeled a Stackelberg Game Theory Model in terms of avoidance of congestion and select alternate path for routing. While in previous works were not providing alternate path while congestion occur in the network.

Table 6: Parameter setting for simulation

Parameter	value
Number of nodes	50,100,150,200
Access links of each user	5 Mb/s
Delay	10ms
Bandwidth	1500 Mb/s
Packet size	576 Bytes
Congestion windows size	70
[α_i, β_i]	[1,0.9999]
Initial energy	10 j
Transmit energy	0.5j
Receiver energy	0.1j
Ideal energy	0.01j

4.1 Average delay

We evaluate the average delay for varying data rate. Simulation results in Figure 2 depict that, when congestion occur, the proposed SGTM scheme starts increasing remarkable data rate in the network. The proposed SGTM uses Stackelberg Game Theory Model to reduce the congestion by reducing data flow where the congestion occurs. On the other hand, the related schemes such as HTAP and CADA achieved an increased delay after 100 pkts/s since they have generated control packets lie ACK to reduce the congestion in the network. Also, there is a packets drop at this stage by overhead rose. We notice that the proposed SGTM presents less delay in the range of 4-5% because nodes exchange less control messages in comparison with related schemes. The proposed SGTM introduces less overhead. The performance of SGTM is also enhanced than the related schemes. This means that the Stackelberg Game Theory Model pioneered in this work to avoid the congestion in the network.

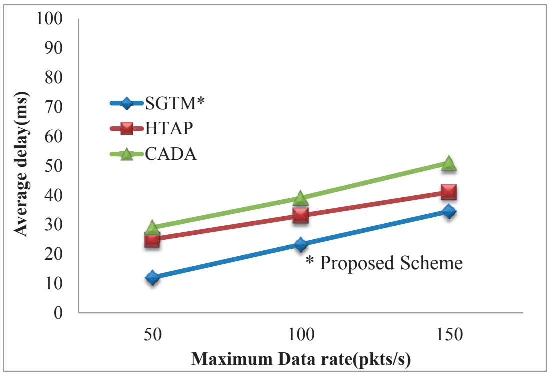

Figure 2: Average delay vs maximum data rate

4.2 Throughput

Figure 3 shows the throughput by varying the data rate in the network. It counts the actual number of packets that are received in destination. The proposed scheme SGTM scheme compared with related schemes HTAP and CADA in terms of throughput. It clearly shows that the proposed SGTM scheme are maintained higher throughput about 95% because the proposed scheme finds the alternate paths to forward the packets when congestion was occurring. A performance evaluation shows that the proposed SGTM scheme has better capability of finding alternate routes with help of Stackelberg Game. Figure 3 shows that the throughput performance of the proposed SGTM scheme is more efficient than the related HTAP and CADA schemes. The related schemes has less throughput compare with proposed scheme. This parameter is a clear sign of the ability of the Stackelberg Game model to transmit a maximum number of packets to the destination. Figure 3 indicates that the percentage of received packets is decreasing for HTAP and TARA, compared to SGTM. It show a strong indication that the Stackelberg Game model provide large number of data packets, even when the congestion in the network is high. On the other hand, the related schemes lowers the number of packets transmitted to the destination.

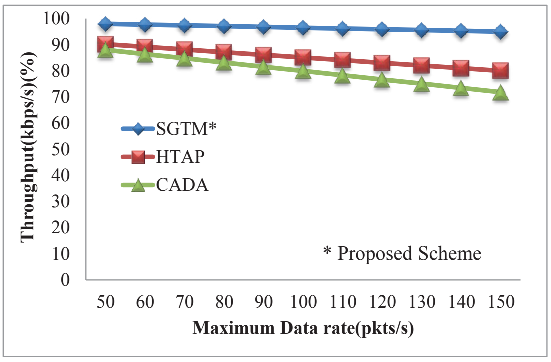

Figure 3: Throughput

4.3 Routing overhead

The routing overhead parameter is a sign of how the proposed scheme handles congestion and the overhead introduced by control packet exchanges and number of routing packets (RTP)**.** It is defined as number of routing packets transmitted for establishing alternate routing paths that caused minimum routing overhead. Figure 4 clearly shows that the routing overhead caused by SGTM has transmitted less routing packets than related schemes. SGTM has transmitted average of 200 routing packets for forwarding packets in the selected alternate routing path. The related schemes had required more routing packets and control message exchange for routing purpose that led more routing overhead**.**

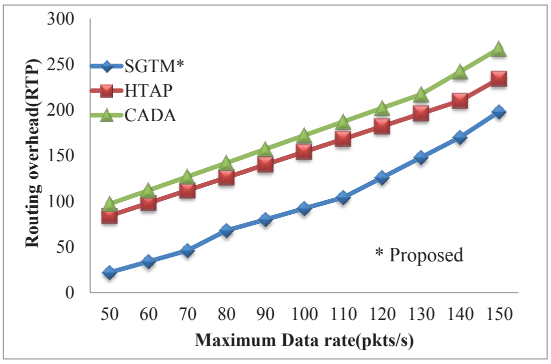

Figure 4: Routing overhead

4.4 Buffer level threshold

Figure 5 shows the received packets ratio of the proposed scheme and related schemes. In general, nodes in wireless network are used the buffer-based congestion technique. Congestion occurs when a node receives packets with a higher rate than it can transmit. The proposed scheme received maximum packets in destination because each node is able to play or run Stackelberg game approach that produce leader and follower. Also, the proposed scheme uses correlated equilibrium that used to set a threshold for buffer. When the buffer reaches a threshold value, nodes start with reducing data rate that produce maximum packet flow in among the nodes. The related schemes lower the received packets because it does not follow the any congestion cost mechanism.

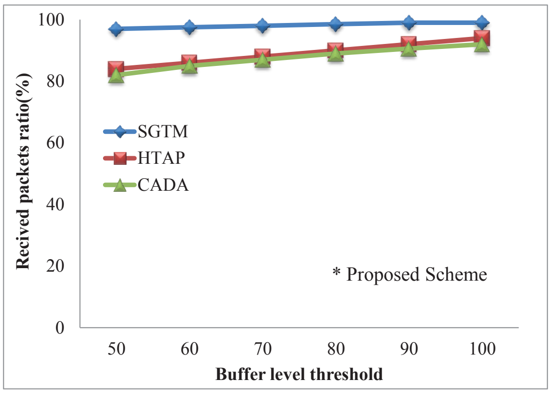

Figure 5: Buffer level threshold vs received packets ratio

4.5 Energy Consumption

Figure 8 shows the energy consumption of nodes for the proposed scheme and related schemes. It clearly noticed the energy efficiency of the proposed scheme. The energy consumption is the sum of used energy of all the nodes for routing including transmitting, receiving, idling and sleeping in the network. As it is expected, STGM consume less energy since minimum control packets are introduced in the network. The related schemes consume more energy at the point where congestion occurs. This fact is justified by the operation of the proposed STGM scheme control the congestion and reduces the overhead. The related schemes HTAP and CADA consume more energy since more nodes are involved for forwarding packets from the source to the destination. As we can see from Figure 4 this energy consumption is rather negligible in comparison with the achieved throughput.

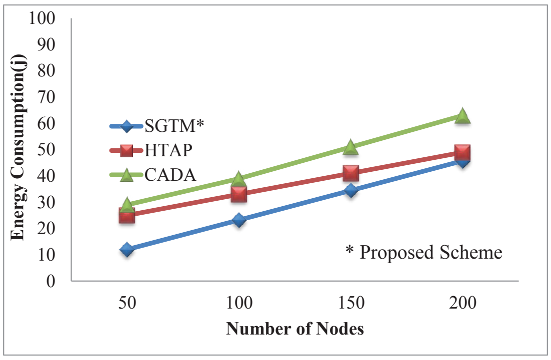

Figure 6: Energy Consumption vs number of nodes

As we conclude the performance evaluation section, we can state that the proposed STGM scheme provides an increased performance in terms of energy efficiency throughput and routing overhead in comparison with HTAP and CADA. Also, STGM outperforms in certain cases, which is Correlated equilibrium and finding alternate paths. The SGTM used game theory approach that was find leader and follower to reduce the congestion and increase the maximum packets to destination. As it is accepted, SGTM has proven crucial for the successful operation of it. Specifically, this enhancement improved the average delay, while the avoidance of congestion.

5 Conclusion

We have used a Stackelberg Game model to reveal the best correlated equilibrium of to minimize the congestion in network. A novel scheme of buffer level threshold or congestion cost is calculated for nodes. Buffer level threshold is used to set the maximum data rate for nodes that reveals the best throughput. Each player or nodes is allocated utilities that depend on its correlated equilibrium. The proposed SGTM scheme find alternate path where at the congestion point. Then, SGTM found the leader and follower nodes in which the followers are choose the leader's strategy for forwarding the packets. A packet can be forwarded through a congestion-free path when the leader chooses to alternate path, preventing a packet-dropping and congestion. This is a novel way to enhance congestion-free routing and motivate the follower choose leader's action. This game model also analyses the equilibrium strategy profiles for players based on its payoffs. It emphasizes reducing congestion by Buffer monitoring mechanism. It employs lightweight congestion detection scheme that able to face both permanent congestion situations successfully when it follows the correlated equilibrium strategy. Simulation results reveal that the correlated equilibrium strategies for players are better than pure or mixed strategies. To the best of our knowledge, this is the first work that uses the Stackelberg Game model for reducing congestion in wireless network.

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