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OLSR Control Overhead and Power Consumption Reduction using Game Theory

Teerapat Sanguankotchakorn
Telecommunications Field of Study, School of Engineering and Technology
Asian Institute of Technology, Thailand
Tel: +66-2-524-5757 E-mail: teerapat@ait.ac.th

Supattra Wiriyapunt
Telecommunications Field of Study, School of Engineering and Technology
Asian Institute of Technology, Thailand
Tel: +66-2-524-5757 E-mail: keawpu123@gmail.com

Thanapol Saengsrichun
IP & Wireless Broadband Engineering
True Universal Convergence Company Limited, Thailand
Tel: +66-2-647-4418 E-mail: thanapol_san@truecorp.co.th

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Abstract

Recently, MANET has been gaining the popularity because of its ease of implementation. One of the major elements in MANET is routing protocol, which consists of two main protocols: proactive and reactive routing protocols.

In this work, we focus on proactive protocol called OLSR (Optimize Link State Routing Protocol), where the routes are always maintained by interchanging control overhead, namely HELLO and TC (Topology Control) messages. However, the resource is very wasteful and this causes the performance degradation. We propose the method to reduce the control overhead while maintaining the throughput of OLSR and also reducing the power consumption by using the well-known mathematic tool, which is widely used in interactive decision systems called game theory. Our proposed method is called Game Theoretical OLSR (gOLSR). We also investigate the effect of gOLSR on power consumption of nodes based on two type of Medium Access Control (MAC) protocol; IEEE 802.11 MAC and Sensor Medium Access Control (SMAC) protocol used in mobile sensor network.

OLSR is modified in such a way that every node in the system has to play the game when HELLO and TC interval are expired. Each node will choose its strategy to *"Update"* or *"Not Update"* the HELLO and TC messages in each round of game. The performance in terms of control overhead and throughput of the proposed algorithm is evaluated by using parameters namely Normalized Routing Overhead (NRO), Average Throughput and Normalized Overhead Reduction Index (NORI). However, the performance in terms of power consumption is evaluated by metrics called Average Power Consumption of nodes in two states (transmission and reception).

According to the simulation results, it is apparent that the proposed algorithm provides large NRO reduction while the Average Throughput is reduced a little bit. The power consumption of the network in all states is also reduced. That is, the proposed algorithm can reduce the certain amount of Control Overhead as well as the Power Consumption while the Average Throughput is reduced a little bit. Therefore, Game Theoretical OLSR (gOLSR) is able to support energy-efficient MANET in various node mobility and node density environments.

Keywords: Game Theory, HELLO and TC messages, MANET, OLSR, MAC Protocol

1. Introduction

Nowadays, an infrastructure-less network called MANET is becoming popular and playing an important role in communication because of its ease of deployment in anywhere anytime. In MANET, the routing protocol is one of the key technical issues. The routing protocol can be simply divided into two types: reactive and proactive. The reactive routing protocols, for example AODV and DSR [1], find the route only when a node has data packets to send and does not maintain the route via the exchange of route information. On the other hand, the proactive routing protocols, namely OLSR [2], always maintain the routes and keep updating the routing table by exchanging the routing information periodically. Hence, the source nodes can immediately send data packets whenever they want to send.

There are various researches on MANET and routing protocols [2-28]. The OLSR is firstly introduced and discussed in [2]. In [3][4], the tuning of OLSR parameters is studied under various scenarios, where it is found that the HELLO interval has more effect on OLSR performance than TC interval [4]. In addition, the increment of nodes' speed causes the increment of the normalized routing overhead (NRO). Many techniques have been introduced to improve the performance of OLSR [1-6]. One technique that has been drawing the attention of researchers is by applying Game theory [7-9] in OLSR operation. Game theory is a mathematical tool, which is the strategic interactions analysis among multiple decision makers [10]. In the literature, the works in [7] and [9] provide the tutorial and explain the method of applying the Game theory (non-cooperative game) in area of wireless networks. Recently, various works of applying Game theory in OLSR or MANETS have been proposed [6], [11], [24-27].

Another challenge in MANET is the power consumption [5],[10],[13-22]. This is very significant issue for MANET, since the mobile nodes in such networks are battery-powered. Power failure in mobile node does not only affect the node itself, but also affect the ability to forward data packets. Many researches being relevant to the power consumption in MANET have been proposed [10-22]. However, it is clear that the power consumption of OLSR in MANETs adopting Game theory has not been thoroughly investigated.

In this work, we consider a proactive protocol called OLSR, which is widely used in MANETs. Every node has to send HELLO and TC messages in the pre-defined intervals for maintaining the routing information. However, when the nodes have low mobility, the routing information does not change rapidly. To send the HELLO and TC messages every 2 and 5 seconds by default [2], respectively may waste the bandwidth and power of nodes. Therefore, game theory is proposed as a tool to find the appropriate time intervals for sending both control messages. Our proposed algorithm here is called Game Theoretical OLSR (gOLSR). The game is described as a set of players and their possibilities to play the game according to the rules. We perform the simulation using NS2 and evaluate the proposed scheme in terms of control overhead and throughput by the metrics namely Normalized Routing Overhead (NRO), Average Throughput and Normalized Overhead Reduction Index (NORI). In addition, we also investigate the effectiveness of our proposed gOLSR in reducing power consumption of the nodes in MANET. We illustrate the results based on two types of MAC protocols, namely SMAC (Sensor Medium Access Control) protocol [17] and IEEE802.11 [23].

According to our simulation results, it is obvious that the control overhead of OLSR can be reduced while the throughput of the system is maintained. In addition, the power consumption can be reduced as well.

This work is structured as follows: Section 2 describes the related works. Section 3 describes the game model and our proposed Game Theoretical OLSR (gOLSR). The detailed mathematic analysis is also shown. Section 4 illustrates the simulation scenarios, parameters, power consumption model and performance evaluation metrics used in this work. Section 5 shows all simulation results and discussion while section 6 concludes the work.

2. Related Works

Some recently published works related to OLSR, Game theory and power consumption in MANETs, which are relevant to our work, are described here.

There are various researches on MANET and especially OLSR routing protocols [2-28]. In [6], they propose the algorithm to decrease the control overhead in OLSR using game theory while the throughput is maintained. The use of forwarding dilemma game to control routing overhead of AODV in congesting multi-hop MANET is studied in [8]. In [11], a new model of routing based on non-cooperative game in computer networks is proposed. In [24], they study the effect of both mobility and channel fluctuations on network topology and provide a cooperation model in MANETs. Then, they propose an integration of a coalition game model for cooperation in MANETs with OLSR and found that although the cooperation model incurs an average overhead exceeding 100% of that incurred by OLSR in high-density scenarios, it shows better reliability in delivering traffic especially among selfish nodes in low and average density scenarios. In [25], they present a correct strategy based on cooperation rate (CR) of game theory to enforce cooperation and communication between nodes in MANET using OLSR routing protocol. The CR is calculated based on various types of OLSR messages (HELLO, TC, etc.) sent among nodes, and also based on different network processing (forwarding and routing). It is found that the quality of service and security is improved. In [26], they propose a game-theoretic framework based on the iterated prisoner's dilemma (IPD) to model the repeated dynamic interactions of multiple source nodes when communicating with multiple destinations in ad-hoc wireless networks.

The problem of non-cooperative and cooperative mobile nodes in MANETs has been addressed in many works [12][27]. In [12], cooperation incentive strategies in mobile ad-hoc networks are investigated to determine the trustworthiness of a node in reputation based and price-based systems. In [27], a collaborative watchdog based on contact dissemination of the detected selfish nodes is proposed. In addition, an analytical model to evaluate the detection time and the price of this collaborative plan of attack is also proposed.

Another challenge in MANET is the power consumption [5],[10],[13-22]. In [18], the power consumption aspect of the MANET routing protocols is discussed. A performance comparison of Dynamic Source Routing (DSR) and Ad hoc On-Demand Distance Vector (AODV) routing protocols with respect to average energy consumption and routing energy consumption are explained thoroughly. In [19], a novel energy consumption model using Residual Energy Based Mobile Agent selection scheme (REMA) is proposed. Using this scheme, the energy of the nodes can be retained to the maximum time to increase the battery life. In [20], the energy consumption of MANET is investigated by varying node mobility and node density while an efficient power aware routing (EPAR) to increase the network lifetime of MANET by identifying the capacity of a node not just by its residual battery power, but also by the expected energy spent in reliably forwarding data packets over a specific link is discussed in [21]. It is found that EPAR can reduce for more than 20% the total energy consumption and decreases the mean delay, especially for high load networks, while achieving a good packet delivery ratio. In [22], a mathematical modeling for end-to-end delay and energy consumption of MANETs considering the impact of different layers in the protocol stack in addition to that of different network parameters is proposed. It can be concluded that mathematical modeling of MANETs considering variation in all parameters is not feasible.

3. Game Model and Proposed Game Theoretical OLSR (gOLSR)

3.1 Game Model

The game used here, which is modified from Forwarding Dilemma Game (FDG) in [5], is defined as follows:

$$G = \left\langle N, (S_i)_{i\in N}, (U_i)_{i\in N} \right\rangle \quad (1)$$

where N is the set of nodes or players (all nodes have the same transmission range), S_i is the strategy set for node i (i=1, 2,.., N) ($S_i = \{Update, Not\ Update\}$), and U_i is the utility function for node i. Each node will receive the utility function depending on its own and the other nodes' strategies. The utility function of node i can be expressed as follows:

$$U_i(s) = \begin{cases} G_m; & if\ S_i = Not\ Update\ and\ \exists S_j = Update, where\ i \neq j \\ G_m - f(c_i); & if\ S_i = Update \\ 0; & if\ S_i = Not\ Update\ \forall i \in N \end{cases} \quad (2)$$

where G_m is the gain received by nodes, which do not perform *Update* while some nodes perform *Update* and $f(c_i)$ is the cost function paid by node i, which performs *Update*. We assume that the cost function is constant for every node $(f(c_i) = C; C \text{ is a constant})$ then the utility matrix for any player can be illustrated in Table 3.1.

Table 3.1 Utility Matrix for any one Player.

		$N-1$ Players	
		At least one $Update$	$Not\ Update$
1 Player	$Update$	$G_m - C$	$G_m - C$
	$Not\ Update$	G_m	0

If the probability that one player chooses $Update$ is p, then the probability to choose $Not\ Update$ is $1-p$. Hence, if all $N-1$ players choose $Not\ Update$, the probability of this event is equal to $(1-p)^{N-1}$, assuming that all events are independent to each other. The probability that at least one player choose $Update$ is equal to $1-(1-p)^{N-1}$. From Table 3.1 and the above analysis, the mixed strategy Nash Equilibrium can be constructed as follows:

$$\begin{aligned}&\left((1-(1-p)^{N-1})(G_m - C)\right) + \left((1-p)^{N-1}(G_m - C)\right) \\ &= \left(1-(1-p)^{N-1}\right)G_m\end{aligned} \quad (3)$$

Then, the probability to choose $Update$ can be calculated as:

$$p = 1 - (C/G_m)^{1/(N-1)} \quad (4)$$

From (4), it is obvious that the mixed strategy Nash Equilibrium is valid when the probability to choose $Update$ is equal to $1-(C/G_m)^{1/(N-1)}$.

3.2 Proposed Game Theoretical OLSR (gOLSR)

As shown in (4), the probability to choose $Update$ depends on N, C and G_m. Since N and C are constant, the probability to choose $Update$ is depending on only gain G_m. The gain achieved due to updating increases with both speed v, and movement probability p_m of nodes where the random waypoint model [1][2] is used. Therefore, the gain can be expressed as follows:

$$G_m = a \cdot v \cdot p_m \quad (5)$$

where a is a constant, v denotes the speed, and p_m denotes the movement probability. The speed of any node is randomly chosen following the uniform distribution within the following range:

$$v = [v_{\min}, v_{\max}] \quad (6)$$

where $v_{\min}$ and $v_{\max}$ denote the minimum and maximum speed, respectively.

In this work, we consider non-cooperative game, where each node makes decision independently to each other. This model also contains pause time. Once this time expires, the next location will be randomly chosen. The pause time can be interpreted as the movement probability, since the short pause time means the high probability of movement. Therefore, the movement probability of node, p_m, can be expressed as follows:

$$p_m = 1 - \left(\sum_{\forall i} t_i \Big/ T \right) \quad (7)$$

where t_i and T denote pause time of node i and the total time, respectively.

The game is played at every 2 seconds (default HELLO interval [2]) in each node. Therefore, in each round of game, every node has to calculate probability to $Update$ and use this value as a decision threshold (D_t). The decision maker (D_m) is a number generated randomly between 0 and 1. Each node will compare these two values and choose its strategy to make the probability to $Update$ based on the mixed strategy of Nash Equilibrium as follows:

$$\begin{array}{llll} if & D_m \le D_t & then\ select & Update \\ if & D_m > D_t & then\ select & Not\ Update \end{array} \quad (8)$$

If node chooses $Not\ Update$ for HELLO message as its strategy, the next round of the game will be started within (or exactly) the specified duration depending on the simulation scenario. In addition, since in normal operation, every node in OLSR has to broadcast the HELLO messages to identify itself at least within TC interval, therefore, it is assumed that the node will immediately choose the strategy $Update$ if the strategy $Not\ Update$ is chosen in the previous consecutive 2 games.

4. Simulation Scenarios and Parameters

4.1 Simulation Scenarios and Parameters

The simulation scenarios and parameters are shown in Table 1 and 2, respectively.

Table 1. Simulation Scenarios of Modified OLSR.

Scenario	HELLO interval	TC interval	Max NU
1	2/1	5/1	2
2	2/random(0,1]	5/ random(0,1]	2

Note: The form *x*/*y* implies that the interval is initially set to be *x* seconds, but if $Not\ Update$ was chosen as its strategy, the interval is set to be *y* seconds. NU denotes the number of rounds that the node chooses $Not\ Update$ as its strategy. Max NU means the node has to choose $Update$ as its strategy immediately if NU=2.

Table 2. Simulation Parameters of OLSR and gOLSR

Parameter	Value/Type
Software tool	NS 2
Area of Simulated	800 m^2
Number of Nodes/S-D pairs	10/2,15/3,20/5, (20/10), 25/5, 30/6, 35/6, 40/8, 45/8
Transmission Range of Node	250 m
Node Speed	[0,30] m/s, Uniform Distribution
Node Mobility	Random Waypoint Model
Average Pause Time	10 seconds
Packet Type/Packet Size	CBR/512 Bytes
Data Rate	1.3 Kbytes/second
Initial Energy of a Node	1,000 Joules
Simulation Time	500 seconds
No. of Simulations/Scenario	10

4.2 Power Consumption Model

The typical values of power consumption measured using a Lucent Sliver Wavelan PC Card for a wireless interface [15] are illustrated in Table 3. These power consumption values are adopted in the simulation in this work.

Table 3. Power Consumption of Nodes in each state.

State	Power Consumption (W)
Transmit	$P_{tx} = 1.3$
Receive	$P_{rx} = 0.9$
Idle	$P_{idle} = 0.74$
Sleep	$P_{sleep} = 0.047$

4.3 Performance Evaluation Metrics

The following parameters are used as performance evaluation metrics in this work.

• **Normalized Routing Overhead (NRO):** is the ratio between the total control overhead and the total throughput.

• **Average Throughput (THR):** is the throughput per a source-destination pair observed during a period of time.

• **Normalized Overhead Reduction Index (NORI):** is defined as

$$NORI = \frac{NRO_{dec}}{THR_{dec}} \tag{9}$$

where NRO_{dec} and THR_{dec} are the decreasing rates of Normalized Routing Overhead (NRO) and Average Throughput, respectively. NRO_{dec} and THR_{dec} can be calculated using the following formulas:

$$NRO_{dec} = \frac{NRO_o - NRO_g}{NRO_o}, \quad THR_{dec} = \frac{THR_o - THR_g}{THR_o} \tag{10}$$

where NRO_o and NRO_g denote the NRO of the typical OLSR and the proposed gOLSR, respectively. THR_o and THR_g denote the Average Throughput of the typical OLSR and the proposed gOLSR, respectively.

•**Average Power Consumption of Nodes in two states (Transmission and Reception):** the total amount of energy consumed by all nodes in Transmission and Reception states in the network within the given time period. The power consumption in both states of nodes (transmission and reception) of any given size of packets can be calculated using (11) as follows:

$$Power = \frac{Energy \times Bandwidth}{Packet\ size} \tag{11}$$

5. Results and Discussions

5.1 Scenario I

In this scenario, the HELLO and TC interval are initially set to be 2 and 5 seconds, respectively. If the node selects $Not\ Update$ as its strategy in any round of game, then the HELLO and TC interval will be set to be 1 second in the next update time.

From Fig. 1 to Fig. 3, it is apparent that the proposed algorithm gOLSR can reduce the Normalized Routing Overhead. Unfortunately, the Average Throughput is also reduced. We, then, compare the gain using NORI (the ratio between NRO reduction rate to the Average Throughput reduction rate). It is found that the proposed algorithm provides more gain

(NORI>1) when the speed is smaller than 15 m/s. In addition, NORI has higher values at low speed. That is, the proposed algorithm is appropriate for the scenario where speed is lower than 15 m/s.

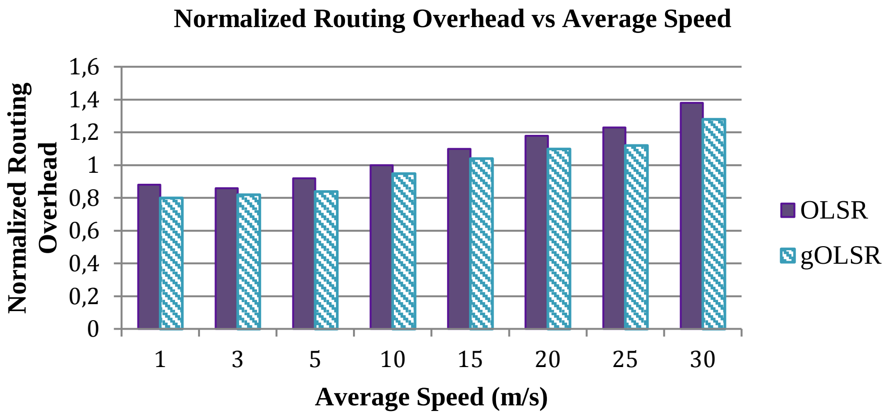

Figure 1. Normalized Routing Overhead (NRO) of OLSR and proposed gOLSR vs Average Speed

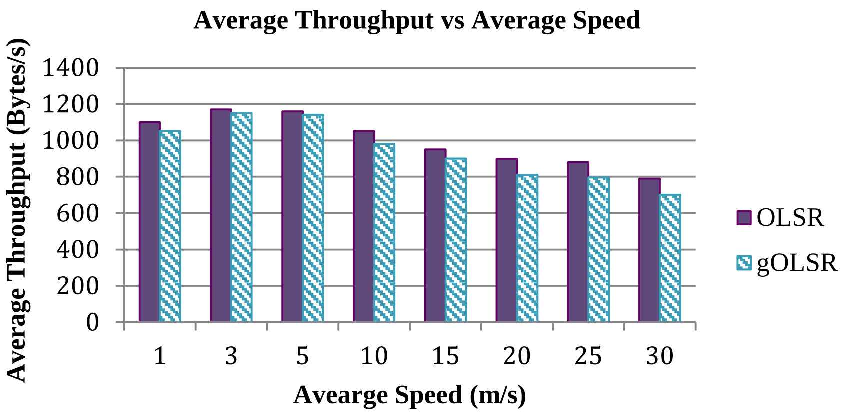

Figure 2. Average Throughput of OLSR and proposed gOLSR vs Speed

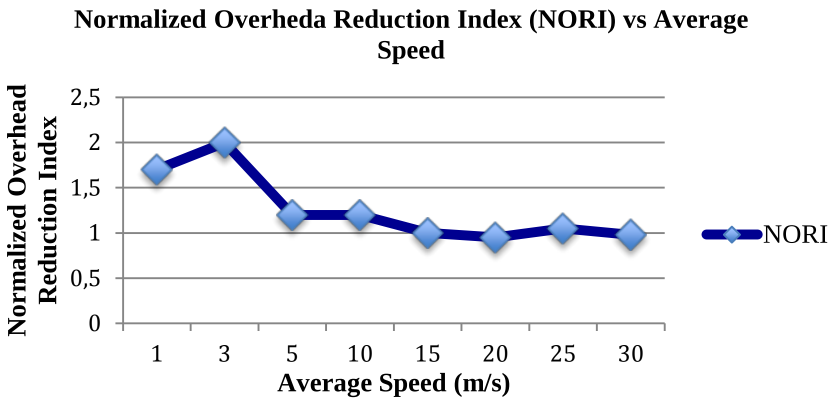

Figure 3. Normalize Overhead Reduction Index (NORI) vs Average Speed

The simulation results of average power consumption of nodes in transmission and reception states versus average speed are shown with 95% confidence interval.

From Fig. 4 and 5, we found that our proposed gOLSR can obviously reduce the power consumption of nodes comparing to OLSR in both transmission and reception states when MAC defined in IEEE802.11 is adopted. While in case of SMAC, the power consumption of nodes, regardless of routing protocols, are identical and lower than the case of MAC for both transmission and reception state. That is, gOLSR provides no effect on reducing the power consumption of nodes when SMAC is adopted.

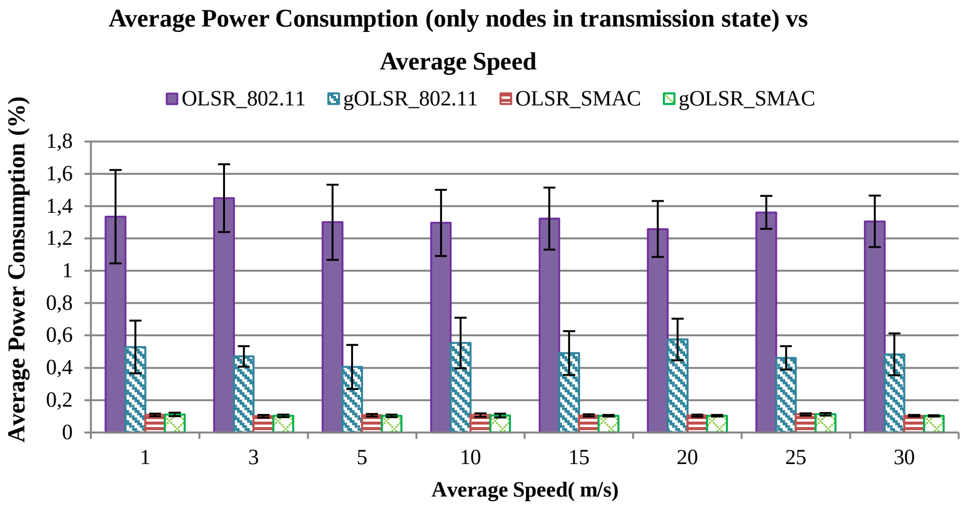

Figure 4. Average Power Consumption (only nodes in transmission state) vs Average Speed

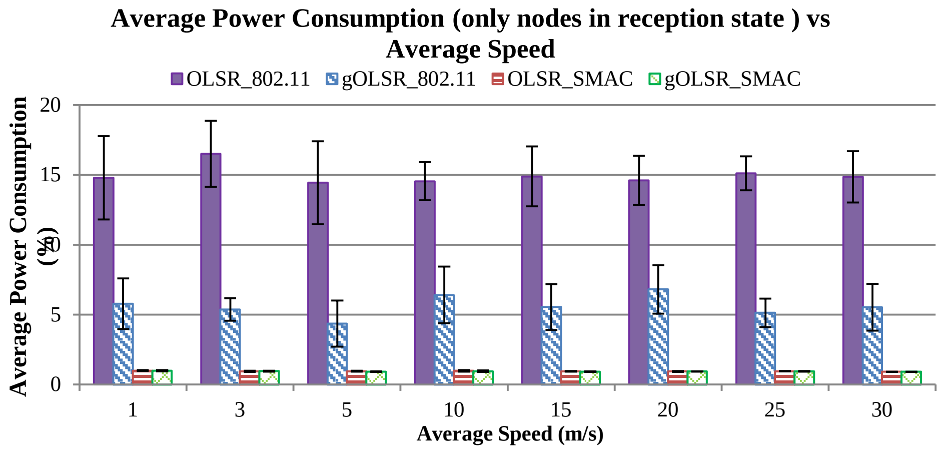

Figure 5. Average Power Consumption (only nodes in reception state) vs Average Speed

Note: OLSR_802.11 and gOLSR_802.11 denote the OLSR and our proposed gOLSR using MAC protocol defined in IEEE 802.11, respectively. Similarly, OLSR_SMAC and gOLSR_SMAC denote the OLSR and gOLSR using SMAC protocol, respectively.

As depicted in Fig. 6 and 7, general speaking, the power consumption increases when the number of nodes increases due to the huge amount of traffic flooded within the network. By comparing the power consumption between OLSR and gOLSR based on IEEE802.11 MAC protocol, it is apparent that gOLSR provides lower power consumption than OLSR. However, gOLSR and OLSR have approximately the same power consumption based on SMAC protocol.

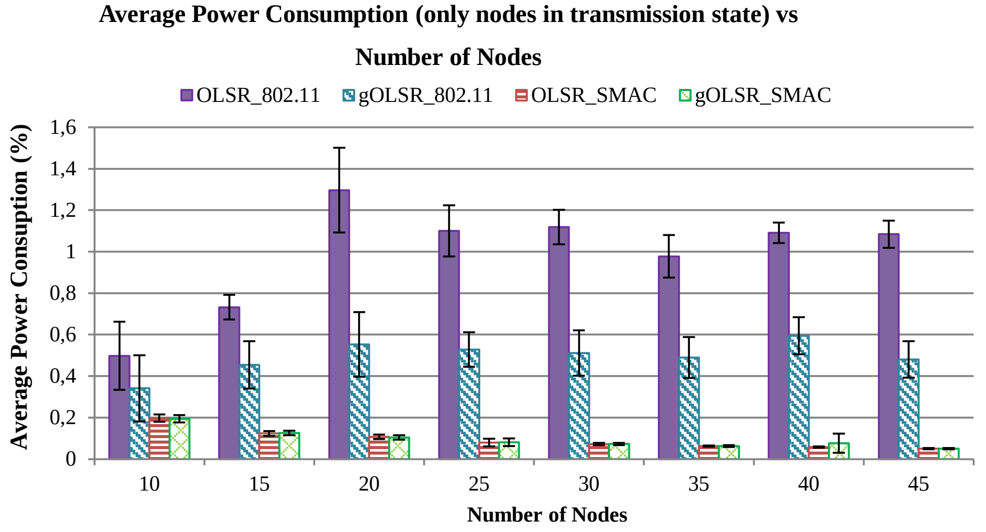

Figure 6. Average Power Consumption (only nodes in transmission state) vs Number of Nodes

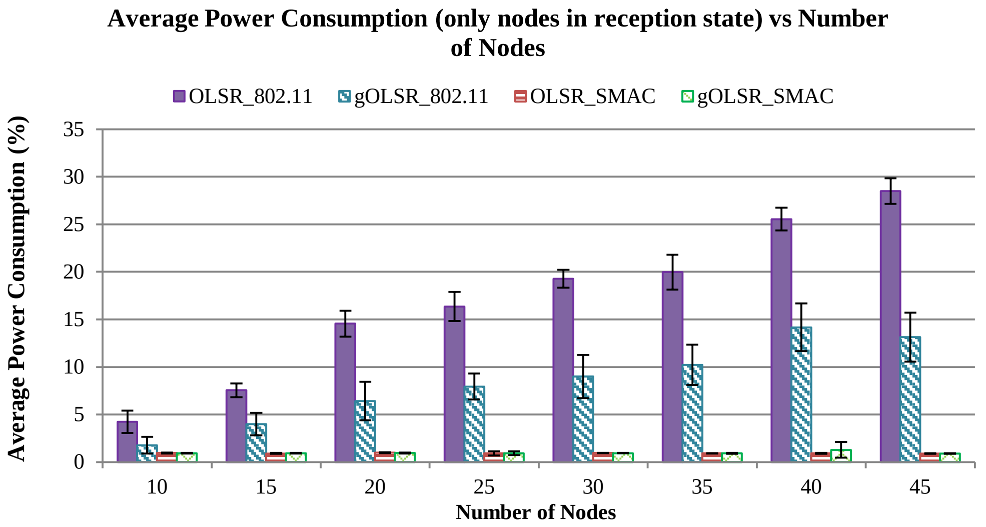

Figure 7. Average Power Consumption (only nodes in reception state) vs Number of Nodes

5.2 Scenario II

In this scenario, the HELLO and TC interval are initially set to 2 and 5 seconds, respectively. If the node selects $Not\ Update$ as its strategy at any round of game, then both the next HELLO and TC interval will be chosen randomly between 0 to 1 second.

Figure 8 shows the Normalized Routing Overhead (NRO) of OLSR and gOLSR vs Average Speed and Figure 9 shows the Average Throughput of OLS and gOLSR vs Average Speed.

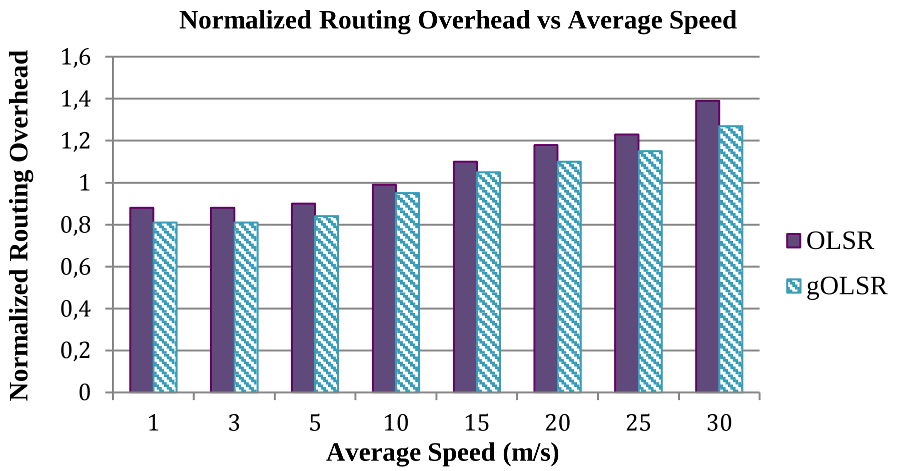

Figure 8. Normalized Routing Overhead (NRO) of OLSR and gOLSR vs Average Speed

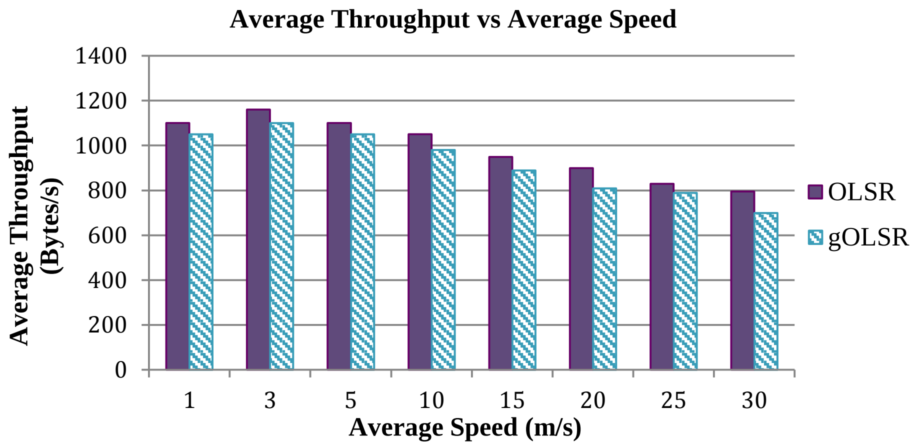

Figure 9. Average Throughput of OLS and gOLSR vs Average Speed

Figure 10 shows that for NORI, this scenario provides the similar results to scenario 1. Even though the maximum NORI in this scenario is lower, but the NORI is averagely better than that of scenario 1. The NORI drops lower than 1 at speed approximately 30 m/s. Hence, this scenario is more suitable to higher speed than scenario 1.

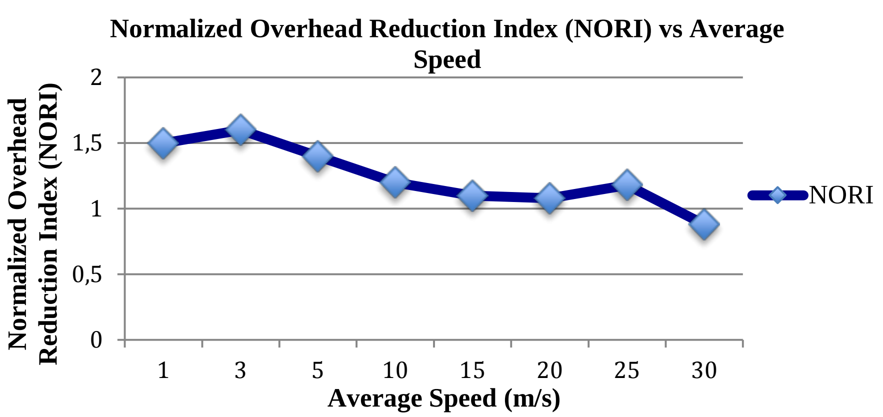

Figure 10. Normalize Overhead Reduction Index (NORI) vs Average Speed

5.2.4 Power Consumption

In this part, the simulation results of power consumption versus average speed of only nodes in transmission and reception states are shown with 95% confidence interval.

From Fig. 11 and 12, it is obvious that this scenario provides the same trend of results as Fig. 4 and 5. That is, the average power consumption of both OLSR and gOLSR with the underlying MAC protocols is quite stable regardless of the average speed. For standard IEEE 802.11, gOLSR consumes obviously less power than OLSR. However, in case of SMAC, gOLSR has the same power consumption as OLSR.

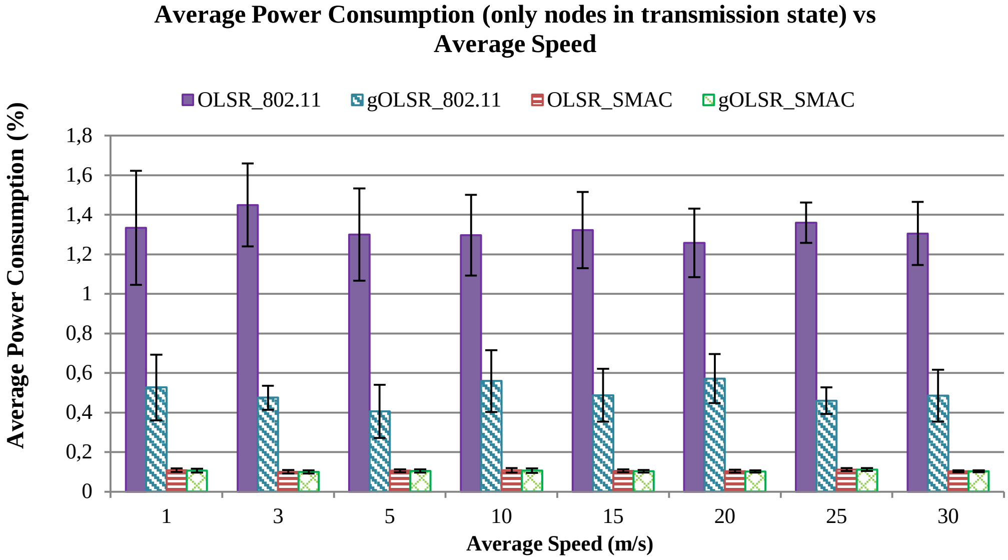

Figure 11. Average Power Consumption (only nodes in transmission state) vs Average Speed

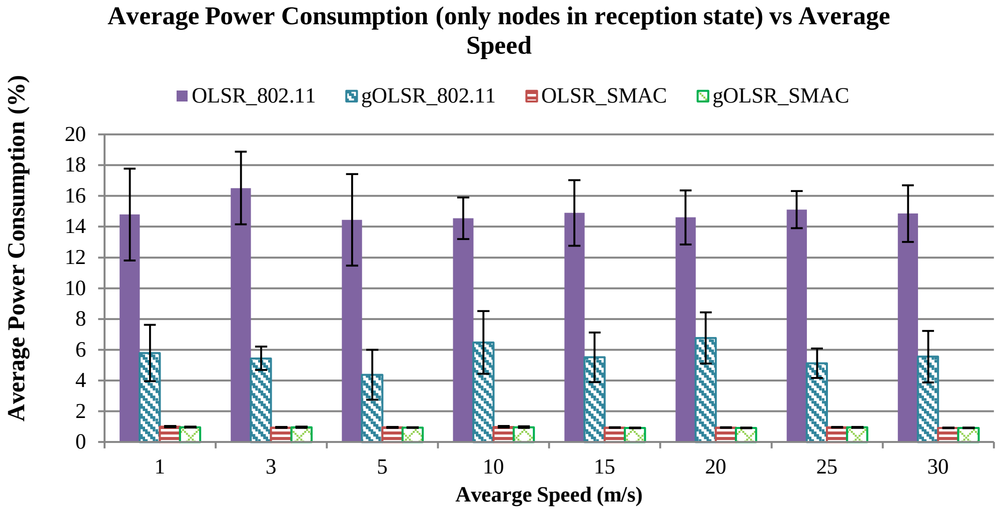

Figure 12. Average Power Consumption (only nodes in reception state) vs Average Speed

As depicted in Fig. 14 and 15, it is apparent that the results in these cases follow the same trend as the results in scenario 1 (Fig. 6 and 7). The reason can be explained similarly.

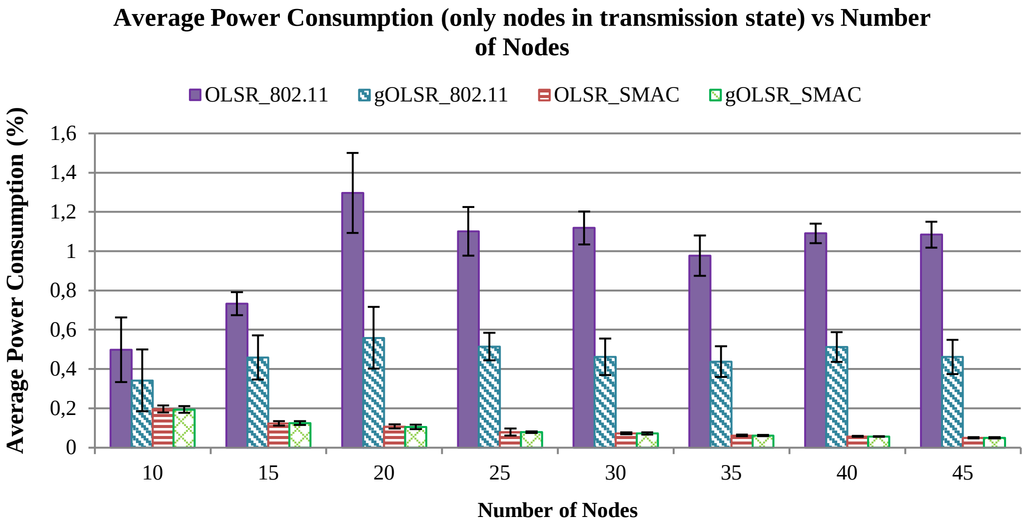

Figure 13. Average Power Consumption (only nodes in transmission state) vs Number of Nodes

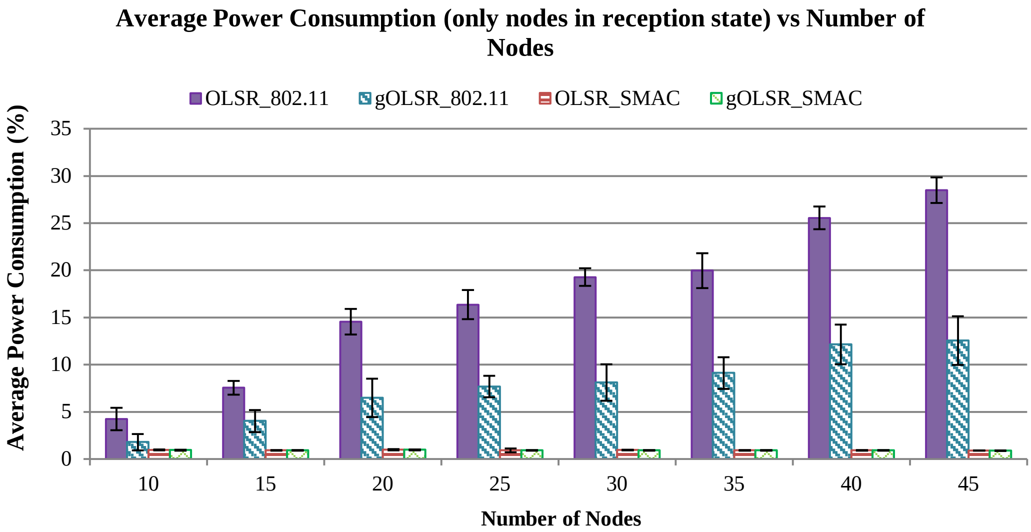

Figure 14. Average Power Consumption (only nodes in reception state) vs Number of Nodes

6. Conclusion

In this work, we proposed and implemented the algorithm to reduce the control overhead of OLSR in MANET by using game theory. The proposed algorithm called Game Theoretical OLSR (gOLSR), is implemented and the existence of mixed Nash Equilibrium point is shown. The Normalized Routing Overhead (NRO) and Average Throughput are the main performance metrics. In all scenarios, based on the simulation results, both NRO and Average Throughput of the proposed gOLSR decrease comparing to the typical OLSR at all speeds. Consequently, we propose the Normalized Overhead Reduction Index (NORI) to measure the NRO's decreasing rate comparing to the Average Throughput's decreasing rate. From NORI, it is obvious that our proposed gOLSR can decrease the large amount of control overheads while the throughput is reduced a little bit. (NORI $\geq$ 1).

Hence, we can conclude that the game theory is applicable to reduce NRO of the system comparing to the typical OLSR while the Average Throughput is also decreased at the lower rate than NRO. Therefore, our proposed gOLSR is appropriate for the scenario that has the large control overhead, for example, in the disaster areas where we have to transmit the large amount of control overheads.

In this research, we also investigate the efficiency of reducing the power consumption of nodes by using our proposed gOLSR comparing to OLSR based on two underlying MAC protocols, namely IEEE802.11 and SMAC.

We simulate and compare the results of power consumption in transmission and reception states on various combinations of routing layer of OLSR and gOLSR with the underlying standard IEEE 802.11 and SMAC. We found that our proposed gOLSR with underlying IEEE802.11 MAC has lower power consumption than OLSR in all node mobility and node density scenarios, since HELLO and TC messages of gOLSR can be reduced according to the outcomes of game theory. That is, they are not necessarily transmitted periodically. This leads to the reduction of power consumption of nodes in all states and can also prolong lifetime of network. While both gOLSR and OLSR have approximately the same power consumption with underlying SMAC.

The future work can be to apply the game theory in heterogeneous network, which is more realistic. In addition, to investigate the proposed algorithm with the other MAC protocols is also topic of interest.

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