A Load-Aware Matching Game for Node Association in Wireless Ad-Hoc Networks

Upasana Dohare$^{(\boxtimes)}$ and D. K. Lobiyal

School of Computer and Systems Sciences, Jawaharlal Nehru University, New Delhi, India
upasanadohare@yahoo.com, dkl@mail.jnu.ac.in

Abstract. In this paper, a load aware matching game to achieve stable one-to-one matching of senders and receivers is proposed, when distance between sender and receiver, and busyness level of receivers are taken into account. We have formulated matching game for the network formation where the nodes are capable of load sharing, selfish behaviour of node that maximize their individual utility and agreeing to cooperate in pair. Sender keeps changing one hop receiver that assist in load balancing of the network. Busyness level of receiver is introduced into matching game to initiate competition between the proposing senders. Distance is introduced to instigate competition between the receivers. The proposed matching game theoretic models compared with the state of art load balancing model for ad hoc networks in the terms of lifetime of the network and standard deviation of the load. Simulation results have shown that the proposed LAMG performs better as compared with GLBR in the terms of network lifetime and standard deviation of the load.

Keywords: Ad hoc networks · Game theory · Matching game · Load balancing
Lifetime

1 Introduction

Ad hoc networks knows as wireless multi-hop networks formed by a set of mobile nodes in self-organizing manner without need of pre-established infrastructure, in which some pair of nodes may not be able to communicate directly with each other, and have to use multi-hop transmission to forward the packets for each other. In ad-hoc network, nodes can move anywhere any time and can formed arbitrary topology. In common crisis, whole the network belongs to the same authority where nodes forwards the packets unconditionally for each other to complete their common goals. The ad-hoc networks are also deployed in civilian applications where nodes belongs to different authority and may not intent to achieve common goal. The self-organizing ad-hoc networks would be control solely by the operation of end users [1]. The energy efficiency of the network can be increased by allowing packets to be delivered over several short links rather than one long link [2]. The speedup of connection setup, energy efficient, load balancing, and the ease of removal of services are the design objectives of the networks.

Previous works have evaluated the performance of ad hoc Networks analytically without forming a strong theoretical framework. The interaction among nodes in the

network may be modelled using game theory. Pair wise cooperation in forwarding of the packets in wireless networks has generally considered selfless behavior for all nodes in the network that will improve a network wide utility [3]. However, it is interesting to study how to autonomous selfish nodes are functioning for their own self-interest to maximize their individual utilities than work together to improve network wide utility. The nodes of the network are agreeing for cooperation only if they are instructed to improve the utilities of both parties [4]. Matching game theory is an appropriate tool to study such situations where individual nodes with differing interests that may be agreeing to cooperate in pair for mutual profit [5]. Matching the equal number of men and women from a group men having different preferences for women in another group of women has been modelled by matching game for stable and optimal pairs in [5].

In this paper, we differ in process of formation of network from these aforementioned previous works, which assume optimum load balancing in a given static network topologies. In particular we consider the network formation where the nodes are (i) capable of load sharing, (ii) selfish behavior of node that maximize their individual utility and (iii) agreeing to cooperate in pair. The basis of matching game [5] has been used for one-to-one matching. A load aware matching game (LAMG) to achieve stable one-to-one matching of senders and receivers is proposed, when distance between sender and receiver, and busyness level of receivers are taken into account. Sender keeps changing one hop receiver that assist in load balancing of the network. Busyness level of receiver is introduced into matching game to initiate competition between the proposing senders. Distance is introduced to instigate competition between the receivers. The proposed matching game theoretic models compared with the state of art load balancing model for ad hoc networks in the terms lifetime of the network and standard deviation of load.

The rest of the paper is organized as follows. In Sect. 2, work related to the proposed work is presented. We explained the problem description is Sect. 3. In Sect. 4, we proposed the solution using matching game for node associations, stability analysis of the game and an incentive method. In Sect. 5, some analytical result and simulation results have been presented. In Sect. 6, we conclude the paper.

2   Related Work

Matching games have recently been applied to study the performance of wireless networks in [6–10]. Authors in [6] studies one-to-one and one-to-many matchings for transmitters and receivers according to the rates in ad hoc networks and observed that rates of whole networks are improved with additional nodes along with possibility of energy transfer considering the selfish behavior of the nodes. Author in [7] haves analyzed the problem of resources allocation with one-to-one and many-to-one matchings and concluded that stable matchings for throughput maximization are not always feasible. They have also shown that if nodes preference and resources are strict, then there is uniqueness in the stable matching. A stable matching between primary and secondary users in cognitive radio network for spectrum allocation has been identified in [8], a distributed algorithm has been proposed to solve the matching problem, and that enables both the users to self-organize into a stable and optimal matching. In [9],

cooperative spectrum sharing in the cognitive radio network between primary and secondary users using matching theory is presented. The transmission rate and power consumption have optimized for the primary and secondary users as their utilities. Authors in [10] investigate a matching game for caching problem of video downloading between small base station and service provider's servers in a small cell network and provides a pairwise stable matching.

Load balancing has been proposed as way of reducing delay, jitter, and energy consumption in ad hoc network by means of manageable load in the network and non-distortable nodes [12–14]. A cooperative load balancing approach for ad hoc networks has presented in [12], in which nodes ranks their channel access providers based on the availability of the resources, and select the best one to improve performance of the network in terms of throughput, energy consumption and delay. In [13], a game theoretic load balancing routing (GLBR) with cooperative stimulation has been presented to minimize the average end-to-end delay and packet loss. To balancing the traffic over the networks, utility function in the term of delay is used. Authors in [14] also considers minimization of delay and jitter by balancing the load in ad hoc network using quantum inspired game theory.

3   Problem Description

Consider an ad hoc network with a set of sender nodes S and a set of receiver nodes R. All the nodes having same transmitting range at a time constraint t. Each sender can transmit to any receiver. We consider current load at each node, whether it is a sender or a receiver, arises at price and outcomes in an increase in the node's utility. We define normalized load ϕ_{sr} of a node as the ratio of current data rate p_{r_t} at time t to the bandwidth b_r assigned for transmission, and it is given by

$$\phi_{sr} = \frac{p_{r_t}}{b_r} \tag{1}$$

Different values of ϕ_{sr} are taken at different time intervals and the values vary between 0 and 1. A node has maximum possible load when $\phi_{sr} = 1$. It is desirable to associate a sender node with a less busy or free receiving node. the packets of each active node forwarded by their neighbour. For load balancing among the nodes, each active sender node is served by a neighboring node, which offers the fastest service. In other words, by carefully examine individual neighbour nodes, we can identify the node where additional load can be forwarded, and where it cannot be. The load balancing problem in ad hoc networks is defined as an optimization problem in which source nodes are assigned to forwarding nodes ($\mu : S \rightarrow R$), which will maximize the overall sum of utility of the networks.

$$\text{Maximize} \quad \sum_{s \epsilon S} \sum_{r \epsilon R} \phi_{sr} \tag{2}$$

$$\text{Subject to } \forall_s, r : \phi_{sr} \leq 1 \tag{3}$$

Since the nature of the combinatorial assignment problem mentioned in (2) and (3) is non-linear. Therefore, we propose a new approach to solve the problem using matching in the next section.

4   Proposed Solution: Node Association as a Matching Game

In a matching game, two sets of players evaluates each other using well-defined preference relation [15]. We formulate our load balancing problem in ad hoc networks as one to one matching game in which we map a set of senders S to a set of receivers R, and each sender will be associated at most one receivers. We assume that multihop packet forwarding is used to send data packets to a destination node. A node have maximum load limit b_r bits per second. Depending on the load at receiving node, each sender node $s \in S$ builds a preference relation $\succ_s$ over their receiving nodes $r \in R$ and not being matched $\varnothing$. In general, set S is able to form $S \times R$ matrix in which each elements ϕ_{sr} of the matrix will be the busyness level (load) of r measured by s. Moreover each neighbour node r of a sender node has a preference $\succ_r$ over the subset of S that propose to their most preferred neighbour node s but sender might accept or reject the request for forwarding their data. Nodes of set R prefer s if it is destination for them or the geometrically nearest node s. Based on these assumptions, we define a matching μ between sender and receiver nodes.

Definition 1. A function μ is defined from $S \times R$ to $S \times R$ known as a matching if:

$|\mu(s)| = 1$ for each elements of S and $\mu(s) \in R \bigcup \varnothing$

$|\mu(r)| \leq b_r$ for all r and $\mu(r) \subseteq S \bigcup \varnothing$, and

$s \in \mu(r)$ iff $\mu(s) = r$

Consequently the tuple $(R, S, \succ_r, \succ_s, Q)$, defines the node association load balancing matching problem using $\succ_R = \{\succ_r\}_{r \in R}$ as a preference set of the R and, $\succ_S = \{\succ_s\}_{s \in S}$ as a preference set of the $S \cdot Q$ is a set of quota on the nodes of set R and defined as $Q = \{b_r | \forall r \in R\}$ [11].

4.1   Context-Based Preferences

To describe two side matching μ, we defines the preferences of sender and receiver in the next section.

a. *User's Preferences*

Each node s wishes to forward data packets to maximize its own individual utility. In our assumption, sender nodes ranks the forwarding nodes based on normalized load, therefore, we uses the normalized load ϕ_{sr} as utility function. Let z is the number of elements in R. The $1 \times z$ utility vector of sender node s can be determined. Each member of S ranks the member of R and make a preference list by using g as a load function, and it is defined by

$$L = g(\phi_{sr_z}) = \frac{1}{z} \sum_{r=1}^{z} \phi_{sr_z} = \frac{1}{z} \sum_{r=1}^{z} \frac{P_{z_t}}{b_z} \tag{4}$$

Where L is the average possible load over z nodes, which are directly connected with s. A neighbour node will be acceptable for a sender node if $r \succ_s \varnothing$ if and only if $L < 1$. A neighbour node $u \succ_s v$ if and only if $L_u < L_v$ and $L_u, L_v < L$. Hence a preference matrix $P_{S \times R}$ can be originated whose s-th row will be the preference vector of user s and is represent by ρ_s.

b. ***Preference of neighbour nodes***

In neighbour node side game we define a scheme, which gives priority to sender nodes, based on urgency of information. Sender nodes sends their preference vector to each neighbour node and neighbour nodes wishes to associate with a sender node. Therefore each neighbour node form a 1×S vector, we call them chance vector $(Ch_{1 \times S})$ for their sender nodes coming in their transmission range. Whose elements are chosen from the given equation with respect to r,

$$D_s = d_s.T_{s-delay}$$
$$s = 1, 2 \ldots \ldots .S \tag{5}$$

where, D_s is mobility distance factor, d_s and $T_{s-delay}$ is distance and delay between the link r to s. If a link between two neighboring nodes exists then $d_s = 1$, otherwise it equal to 0, d_s equals 1 means node is accepting the proposal and 0 means the node is discarding the proposal.

Next, we describe the receiver node side matching approach and clarifying assignment procedure. By using (1) the utility function for receiving nodes is defined as follows:

$$U_{sr}(\beta_s, \delta, \phi_{sr}) = \begin{cases} \psi_{sr}(\beta_s, \phi_{sr}) & if, \quad \delta = 0 \\ g(\phi_{sr}) & if, \quad \delta = 1 \end{cases} \tag{6}$$

where U_{sr} is known as the utility of the sender node s given by the receiving node r. As above defined utility is the function of priority coefficients β_s, likeness factor $\delta \epsilon \{0, 1\}$, and ϕ_{sr}. Hence sender node $s_1 \succ_r s_2$ if and only if, utility of $s_1 (U_{s_1 r}) >$ utility of $s_2 (U_{s_2 r})$. Clearly, every sender node increases their utility, for that it communicates with an appropriate neighbour node. We take $\delta = 1$, when two or more sender nodes are on same priority otherwise, the neighbour node assigns $\delta = 0$ to the utility of those sender nodes. Now the function $\psi_{sr}(\beta_s, \phi_{sr})$ is defined as

$$\psi_{sr}(\beta_s, \phi_{sr}) = V_r(\beta_s, \phi_{sr}) + g(\phi_{sr}) \tag{7}$$

$$= \frac{1}{Z} \sum_{r=1}^{Z} \left[\frac{\beta_s \eta_1}{\eta_2 + \beta_s \phi_{sr}} + \phi_{sr} \right] \tag{8}$$

In Eq. (7), function $V_r(\beta_s, \phi_{sr})$ represents the promotional amount to the sender node. Promotional amount is dependent on priority $\beta_s \cdot \eta_1$ and η_2 are the control parameters and used to decide the shape of utility function. Once the sender nodes proposal are sent to an arbitrary receiving node, the following three groups of priorities can be divided as follows.

1st priority: When a sender node and their neighbour node both have their first and only remaining preference. Then this type of sender nodes have been accepted by neighbor node in the first iteration.

2nd priority: In second type of priority we have taken those user nodes for whom neighbour node r is not on first choice but it is the only neighbour node remaining in the preference list.

3rd priority: Those user nodes will come in third priority which user node was rejected by a neighbour node but the user node still have other choices in their preference list.

Matching Algorithm:-

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Inputs – R, S, Q, A_s

Initialize – first we will compute the preference
matrix P with the help of equation (4) and prepare a
provisional rejected vector as W.

While W is nonempty repeat given steps

Step 1:  if a user node s ∈ W then short their
preference vector ρ_s (s^th row of P_{S × R}) in descending
order and match with preference of next ordered
neighbour node.

Step 2: neighbour node ranks the sender nodes by
their utility, selects first Q(r) node from them, and
discards the rest.

Step 3:  let A_cc be an acceptance matrix, update A_cc
and W for ∀s ∈ W

If Ch(s) = 0 ,

Then remove s from W and put them in unmatched set if
user node list U.

Output:

Stable matching μ
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4.2   Stability

In this section we derive some results in the form of theorems and prove them for ad hoc networks.

a. *Existence of stability*

Theorem 1. If sender nodes and neighbour nodes submit their preference lists then our given matching algorithm will produces a non-empty output, which will be stable also.

Proof. We know a matching is a set of ordered pair and there should be at least two nodes required to form a network. With these two nodes, our algorithm gives non-empty output (a matching pair of those nodes). For N number of nodes in networks, each neighbour node r match with q_r choice with its final updated preferences of sender nodes. Since any sender node s whom some neighbour node r initially ranked higher than one of its final assignment, higher in his ranking than r. Hence the final obligation gives s a position that the sender node ranked higher than the neighbour node r. So the final output will stable with respect to any such s and r.

Definitions: - S-Optimal and R-Optimal matching
A stable matching is called S-optimal if every user node like it at least as much every other stable matching.
    A stable matching is called R-optimal if every neighbour node like it at least as much every other stable matching.

b. *Common and Conflicting behaviour of network's nodes*

    Now we discuss another salient feature of two sided matching, which is common and conflicting behavior of players (nodes) of different sides. When we give our attention to the stable outcome, the conflicting feature will reversely behave. It is natural that there would be competition with one another in sender nodes for desirable neighbour nodes, while neighbour nodes compete with one another for desired sender nodes. However players (nodes) of opposite sides of the game have a common interest in matching with one another but players of the same side of the game interests in conflicting with some angle.
    For the given preference vector ρ_s (s^{th} row of $P_{S \times R}$) and chance vector ($Ch_{1 \times S}$) a sender node s and a neighbour node r will be achievable for each other if r forwards s's data for some stable match.

Theorem 2. In the set O(sta) of stable matches, there is a S-optimal stable match s* with the property that every sender node assigned with its most preferred achievable neighbour node and a R-optimal stable match r* with the property that every neighbour node will assigned with less than or equal to q_r most preferred achievable sender nodes.

Proof. let for the first part of the theorem s* and s_1^* are two matches for sender nodes, where s* is most preferable output and s_1^* is lesser preferable match than s*. We have already discussed above that sender nodes compete for better neighbour node therefore,

the S-optimal stable match occur with s* because it is better one and hence the result "there is a S-optimal stable match s* with the property that every sender node assigned with his most preferred achievable neighbour node" proved. Similarly we can prove the second part of the theorem.

As our algorithm progresses, results comes out with neighbour nodes dominating but output remains stable.

4.3   Incentive

Now we consider the incentive part of our game when we concentrate on networks mechanism. A node should assigns data packet to its neighbour node to forward or receive the data packet that node should give preferences over its neighbour node's potentials assignments. The acceptance of any such mechanism makes a new game among the nodes, which decides what preferences given to the nodes.

The algorithm proposed for matching process for the networks nodes offered some nodes an incentive to public an order different from their true preferences. In ad hoc networks this problem has occurred because of mobility of the networks nodes and frequent change of networks topology. There should be an incentive for the sender node that is not for providing its first choice neighbour node, but the algorithm gives an opportunity to solve this problem.

"For all players there is no such stable matching technique exists that makes it a dominant strategy to public their true preferences."

If there exist most of the players of the networks public their true preferences then the published preference and true preference coincide, and then there is no problem arises. It could be probable that because of incentives of distortion of preference information the state of collision occur. If distortion exists in the preferences, it means information needed about outer player's preferences to know how too gainfully and securely coincides one's true preference.

"If the networks nodes are highly rational and up-to-date then their submitted preference ordering will coincide with a Nash equilibrium."

It would finish the possibilities for further gainful manipulations. However, according to theorem first, our algorithm give stable results for any preference order and for true preference order both.

5   Results and Discussion

In this section, analytical result in the form of theorem considering the dynamic network topology is presented. We evaluated the performance of the proposed load aware matching game for ad hoc networks by conducting simulation. The simulation results have been compared with the similar type of work carried out in GLBR [13]. Comparison Table 1 presents a qualitative comparison of previously discussed GLBR and the proposed LAMG load balancing protocols using game theory for Ad-hoc networks in terms of game type, assumptions, mobility model, energy balancing, topology type and simulators. GLBR used game theory for cooperation stimulation where as the prosed

LAMG used matching game theory that is non-cooperative game theory for node association based on data rate/load and distance between the sender and receiver. The both the load balancing protocols considered energy consumption balancing, Random Waypoint mobility, and random topology.

Table 1. Comparison between GLBR and LAMG

Load balancing protocols	Game type	Assumptions			Mobility model	Energy balancing	Topology	Network simulator used
		Link capacity	Delay	Distance				
GLBR	Cooperative game	Yes	Yes	No	Random Waypoint	Yes	Random and dynamic	OPNET
LAMG	Non-cooperative game	Yes	Yes	Yes	Random Waypoint	Yes	Random and dynamic	Own simulation script written in MATLAB

5.1 Analytical Results

In ad hoc networks, nodes topology gets change frequently, therefore, some nodes comes to the closer to a node and some goes away. This effects nodes preferences.

Theorem 3. when the topology of the network is not strict or fixed then there may not exist two stable outcome.

Proof. consider a six nodes in the networks in which there are three $\left(S = s_1, s_2, s_3\right)$ sender nodes and three $R = \left(r_1, r_2, r_3\right)$ receiving nodes, each forwards a data packet at a time clock. Preferences are given as-

For neighbour/receiving nodes

$$r_1 = s_1 >_r s_2 >_r s_3$$
$$r_2 = s_1 >_s s_3 >_s s_2$$
$$r_3 = s_1 >_s s_2 >_s s_3$$

For sender nodes

$$s_1 = r_1 >_r r_2 >_r r_3$$
$$s_2 = r_1 >_r r_3 >_r r_2$$
$$s_3 = r_2 >_r r_3 >_r r_1$$

For the given preferences there are exactly two stable outputs are possible, let them name X and Y where

$$X = \begin{cases} X_s = \big((s_1, r_1), (s_2, r_3), (s_3, r_2)\big) \\ X_r = \big((r_1, s_1), (r_2, s_3), (r_3, s_2)\big) \end{cases}$$
$$Y = \begin{cases} Y_s = \big((s_1, r_2), (s_2, r_1), (s_3, r_3)\big) \\ Y_r = \big((r_1, s_2), (r_2, s_1), (r_3, s_3)\big) \end{cases}$$

Neighbour node r_1 does not have difference in between its obligation at X and at Y, while neighbour node r_2 and sender node s_2 prefer Y more than X, and neighbour node r_3 and sender node s_1 and s_3 prefer X more than Y. So each of stable output is preferable by the different set of sender nodes and neighbour nodes. Hence the theorem.

5.2   Simulation

a. *Simulation Environment*

In this section, a simulation has been carried out to evaluate the performance of the proposed load aware matching game for ad hoc networks. A square network area of 500 × 500 m^2 is considered. The number of nodes that are randomly deployed for the simulation is 20–100. The transmission range of nodes is taken to be 100 m. The data packets size of 512 bits is taken. The packets are generated using Poisson point process. The data rate of the traffic is 10 packets per seconds. The maximum bandwidth of 10 Kbps is taken. The Random Waypoint mobility has been used for movement of the nodes with 2 m/s. The energy model that has been used in [16] is employed in this simulation. The total energy e_t consumed for transmitting, and receiving, 1-bits of data is given by

$$\left. \begin{array}{l} e_t = e_{tx} + e_{rx} \\ e_{tx} = e_{el} + e_{am}d^\eta \\ e_{rx} = e_{el} \end{array} \right\}, \tag{9}$$

where e_{tx}, and e_{rx} denote the energy consumed by a node for transmitting, receiving 1-bit of data between two nodes separated by a distance d respectively. The energy consumed for electrical circuit is $e_{el} = 50$ (nJ/bit), and energy consumed per bit to run the transmitting amplifier is $e_{am} = 100 \left(\text{pJ}/\left(\text{bit}/\text{m}^2\right)\right)$. The initial energy for simulation is taken from 5 mJ to 25 mJ. The path loss $\eta = 2$, and d $= 200$ m have been considered. The values of the priority coefficient β_s, the contorting parameters η_1 and η_2 of utility function are equal to 1. Links between two nodes are established if they belong in each other's transmission ranges. We have verified and endorsed the proposed matching algorithm by simulations using our programs implemented in MATLAB.

b. *Evaluation Metrics*

The following matrices have been used to evaluate the proposed LAMG comprehensively.

- *Network lifetime:* The lifetime is defined as time taken in the simulation until first node depleted its energy completely.

- **Standard deviation of load:** It is defined as standard deviation of load ϕ_{sr} where $\overline{\phi_{sr}}$ is the mean of normalize load of N nodes, is given by

$$SD = \sqrt{\frac{\sum_{i=1}^{N} \left(\phi_{sri} - \overline{\phi_{sr}} \right)}{N}} \qquad (10)$$

c. **Simulation Results**

Figure 1 shows the result obtained for the simulation with 100 nodes and with the different initial energy of the nodes. The lifetime versus the number of nodes has been shown for the proposed LAMG and state of the art technique GBLR. It is noticed that as the number of nodes increases from 20 to 100 nodes, the lifetime increases for LAMG, that is 10 to 40 for initial energy 5 mJ and 20 to 75 for initial energy 15 mJ. This is because there will be more number of sender/user are available and, found the best match of receiver nodes with preferable choices. It is also noticed that when the initial energy of the nodes increases from 5 mJ to 25 mJ, the lifetime of the network also enhanced for both the approaches but the lifetime for LAMG is better than GLBR. When the number of nodes and initial energy increase, the lifetime for LAMG is better than that of GLBR, this is because in LAMG the looks for best match that is less loaded receiving nodes and nearest sender nodes from the receiver. Less load node reduces the quick depletion of energy node the node and shorter sender node same the energy of receiver in transmission.
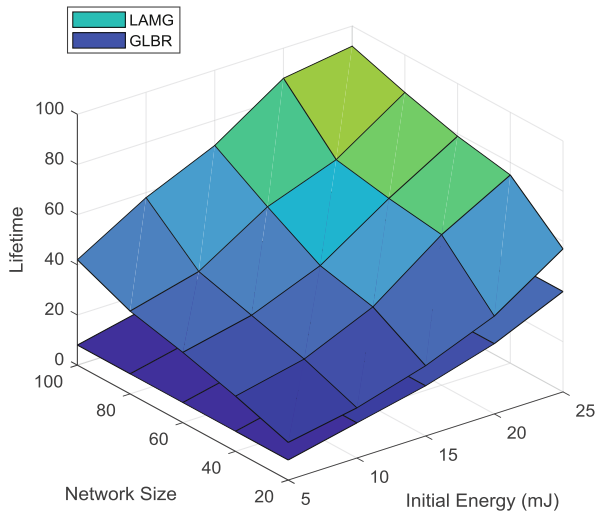

Fig. 1. Lifetime versus the number of nodes and initial energy

Figure 2 shows the results obtained in the simulation for standard deviation of load for different number of nodes. It is observed that as the nodes increases the standard deviation of load increases for both the game techniques. This is because there will be

more number of node. The increase in standard deviation is more for GLBR. It is also observed that when the simulation time increases, the standard deviation for both the techniques decreases but the rate of decrement is more for LAMG. It is clear that the LAMG fairly balance the load among the nodes as compared to the GBLR. This is due the fact that LAMG selects the best receiver node based on the current load.
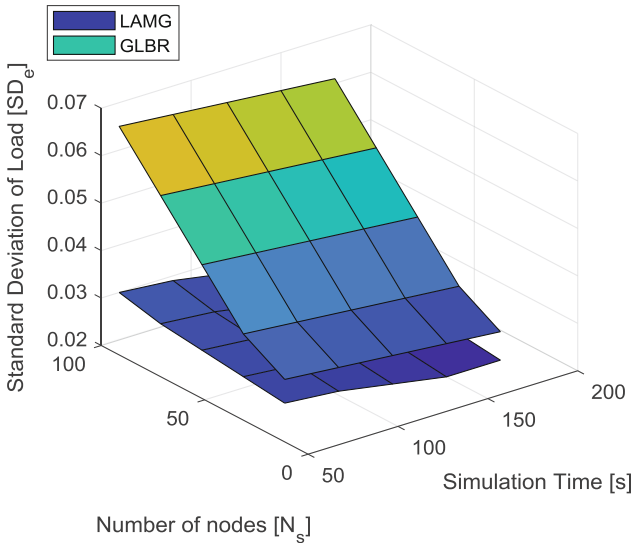

Fig. 2. Standard deviation comparison with number of nodes and simulation time

6 Conclusion

In this paper, we have presented a new approach for node association based on current load in ad hoc network. We have formulated load aware matching game to achieve stable one-to-one matching of senders and receivers is proposed, when distance between sender and receiver, and busyness level of receivers are taken as utility. In the proposed utility, the priorities for matching the players at both the sides has been introduced. Based on the priorities, the sender nodes ranked the forwarding nodes. Similarly, the receiving nodes ranked the sender nodes based on distances. It was show that being aware each others preferences, better association among the node can be made, which increases the lifetime of an individual node as well as the lifetime of the whole networks. Simulation results have shown that the proposed LAMG performs better as compared with GLBR in the terms of network lifetime and standard deviation of the load.

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