Performance Analysis of Gateway Load Balancing in Ad Hoc Networks with Random Topologies

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ABSTRACT

In wireless multihop networks such as MANETs or Wireless Mesh Networks (WMN), an Internet gateway (IGW) is a node that provides Internet connectivity, linking the wireless network with the global Internet. Congestion around the IGW represents a potential bottleneck for all Internet traffic that has to pass through the IGW. To alleviate this problem, the common solution is to have multiple IGWs in the network. However in order to take advantage of the capacity provided by multiple gateways, the routing protocol utilized must efficiently load balance the traffic among available IGWs such that the network performance is optimized. In this context, it is questioned to which extent it is possible to enhance the performance by utilizing a load balancing metric instead for the traditional shortest path metric. Furthermore, what are the factors that may set an upper limit for the performance that can be achieved. The aim of our investigation is to seek the answers to these questions through extensive simulations of a large number of random topologies. While a number of other studies have reported potential benefits of load balancing with some specific network topologies, to the best of our knowledge none have conducted similar studies covering a larger number of random topologies.

Keywords

Ad hoc networks, load balancing, routing

1. INTRODUCTION

Internet connectivity in multihop wireless networks has been an active area of research in recent years. The motivation behind this effort is the ever increasing demand for ubiquitous Internet connectivity. By connecting a dynamic mobile wireless network with the global Internet, a range of new user application scenarios are feasible or envisioned, such as community networks [1, 2] and emergency services communication systems [3].

One vital entity in these kinds of networks is the Internet Gateway (IGW), acting as a bridge between the wireless network and the global Internet. Usually, much of the traffic in the network is passing through the IGW, either upstream or downstream, causing it to become the bottleneck node [4]. The common solution to mitigate this problem is to have multiple IGWs deployed in the network. First, the total bandwidth capacity towards the Internet is increased, both in terms of the wireless and wired bandwidth. Second, using several IGWs means that the Internet traffic may be distributed more evenly throughout the network, allowing for a higher frequency reuse and a higher total bandwidth if the IGWs are spread apart.

The traditional shortest path routing protocol will ensure that an ad hoc node that is an end-point of the Internet traffic will always be associated with the IGW (or one of the IGWs) that is nearest to the node. When a number of such nodes are spread randomly throughout the ad hoc network, there will normally be a certain level of load distribution on the different IGWs. However, by using additional load balancing functionality in the routing protocol it may be possible to balance the load between the IGWs in a more controlled, intelligent and efficient way. This paper explores to which extent it is possible to increase the network performance by distributing the traffic more intelligently between the IGWs.

In the literature, there exists a number of proposals suggesting various load balancing scheme targeted for multihop wireless networks like MANETs [5–8] and Wireless Mesh Networks (WMNs) [9–12]. Load balancing is commonly classified into two categories: *multipath load balancing* and *gateway load balancing*. In multipath load balancing, the traffic load between a source node and a destination/gateway is distributed among a set of alternative paths in order to maximize throughput performance and minimize the impact of route failure. However, [5, 6] report that multipath load balancing in single channel wireless networks only provides a negligible improvement in the performance due to route coupling among the alternative paths. Multipath load balancing is therefore not of interest in this paper. On the

other hand, in networks with multiple gateways, traffic may be distributed among these gateways in order to maximize throughput performance and to reduce the load imbalance. Such gateway load balancing is considered to improve the network performance more effectively than multipath load balancing [9]. In this paper, we therefore focus only on gateway load balancing, and we will refer to it simply as "load balancing" in the remainder of the paper.

While a number of other studies have reported potential benefits of load balancing with specific network topologies, to the best of our knowledge none have made a study under the condition that the topology is random. In this paper, we explore the potential benefits of load balancing by extensively simulating a large number of randomly generated network topologies with a varying degree of asymmetry both in terms of topology and traffic load. The results of this work thus provide a statistical estimate on the potential benefits of load balancing that we can expect on the average.

The rest of this paper is organized as follows. In Section 2, we present related works within the area of load balancing in multihop wireless networks. A general description and definition relevant to this study are given in Section 3. Simulation results and detailed analyses are presented in Section 4-6 for a number of topology scenarios. Finally, discussions and conclusions are given in Section 7.

2. RELATED WORKS

In the literature, there is a considerable number of works addressing the issue of load balancing in multihop wireless networks. These proposals are in general based on a variety of techniques for evaluating the network load, such as RTT [12], average queue length [11, 13, 14] and number of active flows [15, 16]. While some proposals focus their work on multipath load balancing, others try to solve the gateway load balancing issue. Since the focus of this paper is related to gateway load balancing, we review some of the previous works pursuing this strategy.

The authors in [10] propose a load balancing scheme for MESH networks. Load balancing is performed when the difference in the bandwidth utilization between to neighboring gateways exceeds a pre-configured threshold value. The load balancing is achieved by migrating a cluster of nodes consisting of a mobile router (MR) and its associated mobile nodes (MNs) from the congested IGW to a less congested neighboring IGW.

The work in [11] proposes a gateway load balancing scheme based on the average queue length monitored at each IGW. If the average queue length of an IGW is higher than a certain threshold, it indicates that there is congestion by the IGW. As an attempt to reduce the congestion, the IGW will then unicast a gateway congestion notify message to a set of active sources, so that these sources can forward their traffic to other less congested IGWs.

In common for most of the papers mentioned above is that they base their evaluations of the proposed load balancing schemes on only a few constructed topology scenarios. Random topolgies are not considered, and hence, the results obtained cannot be regarded as a statistical estimate of the expected throughput enhancement. Thus, the work in this paper aims at addressing this missing part.

3. DESCRIPTIONS AND DEFINITIONS
3.1 Network Topologies
In general, all network topologies in this study are randomly generated consisting of 50 nodes and 2 IGWs that are confined within an area of 1400 m by 800 m, as shown in Fig. 1. (The areas A, B and C will be explained later). The IGWs are symmetrically placed at fixed locations within the network area (see Fig. 1), and unless otherwise stated, the distance between the two gateways is 1000 m. On the other hand, the nodes are deployed at random locations and remain at these locations for the duration of the simulation, i.e. no mobility. Even though there is no node mobility in the simulated topologies, it is anticipated that our results also give insight into the performance of scenarios with random node mobility, assuming that each simulated topology might represent a snap-shot of a topology with mobile nodes.
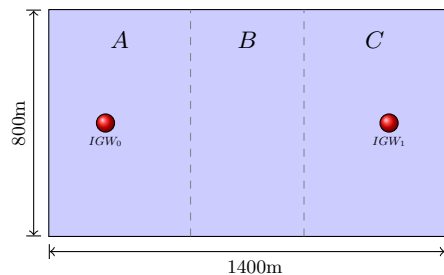

Figure 1: The network model.

3.2 Traffic Model
Two traffic models are utilized in this study. When utilizing the *distributed traffic* model, all nodes in the network send traffic of equal rate destined to the global Internet, i.e. towards one of the IGWs. Thus, this traffic model may be said to reflect the topology in the network. When utilizing the *random traffic* model, only a random subset of nodes in the network send traffic to the global Internet while the remaining nodes will act as relaying nodes. For both traffic models, CBR traffic is utilized with a fixed packet size of 512 Bytes. TCP traffic is not considered in this study. Since the scope of this study is limited to the efficiency of gateway load-balancing for upstream traffic, intranet traffic is not considered.

3.3 Routing Metric
In this study we compare the throughput performance of three different routing metrics described below:

1. With the *shortest path (SP) metric*, also known as shortest hop count metric, nodes search for the nearest IGW and select this as the default gateway in which traffic is sent to. In the case when a node has the same hop count to both gateways, i.e. $h_{IGW0} = h_{IGW1}$, where h_{IGW0} and h_{IGW1} are the hop distance to IGW_0 and IGW_1 respectively, then the default gateway is selected randomly for the traffic flow. Since the network topologies are static in this study, the selected default gateway will persist for the whole duration of the simulation.

2. With the *simple load balancing metric (SLB)*, nodes also select the nearest IGW as their default gateway. In the case when a node has the same hop count to both gateways i.e. $h_{IGW0} = h_{IGW1}$, then the least loaded IGW in terms of the number of traffic flows, is selected as the default gateway. This metric is a light load balancing metric, since only a limited number of nodes that satisfy the above condition are allowed to perform load balancing. Furthermore, this metric may be regarded as conservative in the sense that it does not allow a node to send traffic to alternative less congested gateways that are farther away, and hence would have consumed more resources due to the additional hop length.

3. In the *even load metric (EL)*, the total network load is attempted to be distributed as evenly as possible between the IGWs. In contrast to the SLB metric, a node can choose to forward its traffic to a more distant and less congested IGW in order to achieve load balancing. For example, if IGW_0 is more congested than IGW_1, some of the nodes in which $h_{IGW0} \leq h_{IGW1}$ may forward their traffic to the less congested IGW1 even though this implies a longer path. The nodes that are migrated to the less congested IGWs are selected in such a way that the total number of additional hops induced by the EL scheme is minimized.

As our study is only concerned with the potential benefits of load balancing, we are not concerned with the numerous ways these schemes can be implemented. By the same token, we neglect the overhead required to implement them. It seems clear, however, that an advantage of SLB is that it will be relatively easy to implement, while the selection of nodes to be migrated from one IGW to another in the EL scheme calls for more advanced mechanisms/protocols. Furthermore, the SLB metric might be implemented without the use of tunnelling, while the nodes that are subject to EL must tunnel their traffic to selected IGWs that are farther away. Otherwise, the EL scheme would be in conflict with the shortest path routing. Another disadvantage of EL is the additional cost in terms of increased average path length and the average number of transmissions per packet. The advantage of EL over SLB, however, is the ability to obtain a more well balanced load between the gateways. In summary, the trade-off of the EL metric when compared to the SLB metric, is the increased overhead of the EL in change for a more aggressive load balancing metric that is capable of distributing the load more evenly between the IGWs.

3.4 Asymmetry Index
The asymmetry index is a measure of the degree of imbalance in load distribution between the two gateways, and is defined as follows:

$$AI = \frac{abs(n_{IGW0} - n_{IGW1})}{n_{IGW0} + n_{IGW1}}$$

where n_{IGW0} and n_{IGW1} are the number of traffic flows sent to IGW_0 and IGW_1 respectively. When the load between the two gateways is perfectly balanced, then AI=0. In the worst case when all traffic is sent to one gateway, then AI=1. Furthermore, the AI may also represents the asymmetry in the topology, i.e. the asymmetry in node distribution relative to the gateways. This is however true only for the case when we utilize the distributed traffic model and the SP metric.

3.5 Simulation environment and parameters
All simulations are conducted in the ns-2 simulator, with the proactive OLSR [17] routing protocol. The duration of each simulation in this study is 300 s, and data sampling is only performed for the last 250 s. Table 1 summarizes the most important parameter settings of the simulations.

Table 1: Simulation parameters

Simulator	ns-2.33
Routing protocol	OLSR
Packet size	512 MByte
Interface queue size	50 packets
Data rate (wireless)	2 mbps
Data range	250 m
Carrier sensing range	550 m

4. UNIFORMLY DISTRIBUTED TOPOLOGIES
In the initial part of the study we perform simulations and analysis on network topologies that were generated by randomly deploying 50 nodes (not including the IGWs) within the whole simulation area shown in Fig. 2. We refer to these topologies as *uniformly distributed topologies* (UD) since the node deployments follow the uniform distribution. For all simulations in this part we utilize the *distributed traffic* model, i.e. all nodes send traffic of equal rate to either one of the gateways.

Fig. 2 presents the average throughput performance of the three routing metrics described in Section 3 for 100 random topologies. Surprisingly, it is observed that SP, SLB and EL have on the average almost the same performance. This occurs even though the average AI is 0.142 when utilizing SP. This is equivalent to, on the average, 7 flows or approximately 32 % in load difference between the two gateways. We believe that the coupling effect (i.e. interference and lack of spatial frequency reuse) [5, 6] may be one of the reason why SLB and EL do not improve the throughput compared to SP. Another reason might be that the degree of asymmetry, i.e. AI, is not large enough.

Fig. 3 shows the peak throughput enhancement of SLB and EL relative to SP for each topology, where each mark in the figure refers to the simulation result of one specific topology using one specific metric, SLB or EL. The throughput enhancement is plotted as a function of the AI of the SP metric, since this is a measure for the topological asymmetry in the network. From the results we can draw some conclusions.

First, the potential benefit of enhanced performance in a random setting is relatively limited. Of the 100 selected topologies, only two topologies gave a peak enhancement
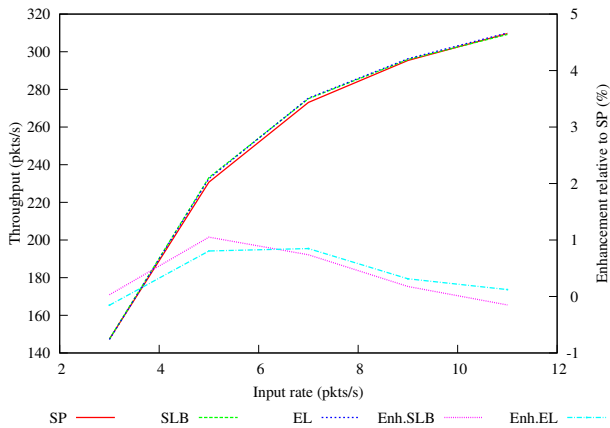
Figure 2: Average throughput performance for 100 uniformly distributed topologies.

Figure 3: Enhancement vs. AI of SP

exceeding 10 %. On the other hand, if we consider the average peak enhancement for all topologies, the results are even less encouraging, i.e. only around 1 % for SLB and EL respectively. These results are quite surprising, given the amount of research efforts focusing on harvesting the potential benefits of load balancing. As a consequence, in a mobile ad hoc network where the nodes are moving at random, the topology will be random at any point in time and the potential benefits of load balancing are likely to be even more limited over time.

Second, the scattering of the results in Fig. 3 indicates that the enhancement in throughput performance is strongly dependent on the layout of the specific topology. In fact, the specific topology layout determines the extent of a number of factors, such as partitioning, local hot spots, interference, hidden node [18], asymmetry etc., that directly affect the benefits of load balancing. If it would be possible for the ad hoc network to automatically detect that its topology is of a constellation where load balancing is beneficial, one could envision that the load balancing mechanism could be turned on only when such situations occur. This might even be feasible in a network of randomly moving nodes, if the level of mobility is limited.

Third, the linear regression lines for SLB and EL in Fig. 3 indicate that the enhancement in throughput increases with an increasing degree of asymmetry, which is as expected.

Although the majority of works on load balancing demonstrate the advantage of load balancing on some selected topologies where there are potentials for achieving some performance benefits, few works try to analyze what characterizes a topology where load balancing might be beneficial. In the next section, we will explore some of the parameters that might affect whether load balancing will be beneficial or not. Asymmetry is definitely one of these parameters. However, the scattering of results in Fig. 3 indicates that other parameters than the asymmetry seem to be of higher importance for the benefits of a specific topology. We realize that addressing all these parameter is too extensive to be covered in one paper alone, as it requires quite extensive exploration and analyses. Thus, continuing this kind of work
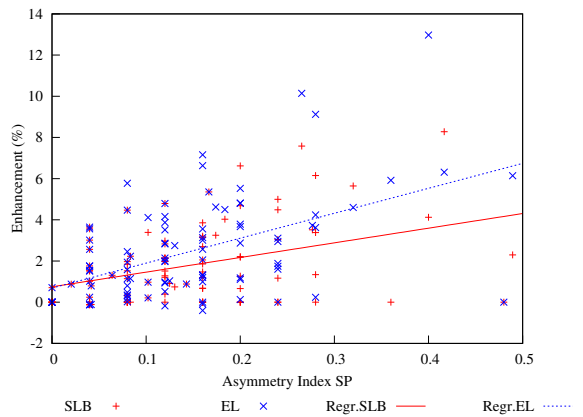
seems like a very interesting and promising topic for further research.

5. EXPLORING PARAMETERS THAT AFFECTS THE EFFECTS OF LOAD BALANCING

5.1 Using Asymmetric Random Topologies

Fig. 2 demonstrated that for the set of uniformly distributed random topologies, the average difference between using load balancing or not is hardly noticeable. Therefore, this set of topologies is not appropriate for analyzing the benefits of performing load balancing.

Instead, from now on we will use a new set of random topologies. We relax our requirement of randomness in order to obtain a set of topologies that is able to give a statistically significant difference between using load balancing or not. Using this new set of topologies, it is possible to statistically explore parameters that affect the potential for load balancing.

With the new topologies, the locations of the nodes are also generated at random, however with some conditions that ensure that the topologies are asymmetric. Indeed, the results presented in the previous section indicated that the chances of benefiting from load balancing increase with an increasing asymmetry of the topology.

For the *asymmetric random topologies* explored in this section we deploy the nodes asymmetrically such that, on the average, significantly more nodes are associated with IGW_0 than with IGW_1. This is achieved by dividing the simulation area into 3 sections denoted as A, B, and C as shown in Fig. 1, and then we randomly deploy 20, 20 and 10 nodes in section A, B and C respectively. This topology set consists of 30 random topologies.

Results for the asymmetric random topologies are shown in Fig. 4. Here, it is observed that the enhancements of load balancing are indeed noticeable with the set of asymmetric random topologies.
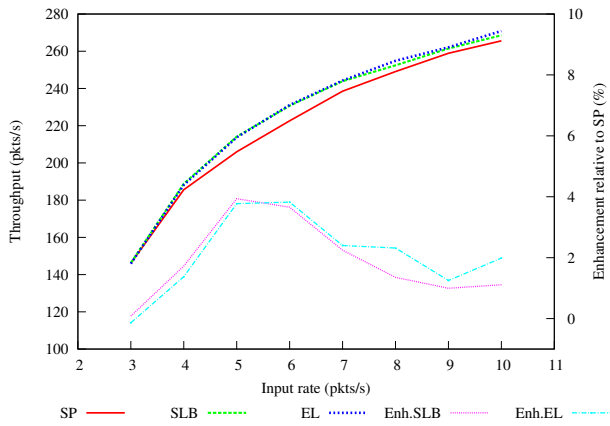
Figure 4: Average throughput performance for 30 asymmetric topologies (I)

Figure 5: The unfairness effect

5.2 Offered Load

Using the set of asymmetric random topology, it is possible to study how the offered load influences on the prospects of doing load balancing.

From Fig. 4 we observe that the enhancement in performance is significant only within a limited window along the offered load axis. At the lower limit of this window when the offered load is low, none of the gateways are congested and load balancing is unnecessary since there is no excessive load that needs to be migrated. This explains why the load balancing metrics have approximately the same performance as SP at low loads. In fact, utilizing an aggressive load balancing metric like EL will only result in poorer performance due to the increased average path length, and consequently increased packet loss.

On the other hand, when the offered load is high (i.e. in the upper limit of the window or above), nodes closest to the gateways will be able to successfully send more traffic while nodes farther away will suffer from higher packet loss. In this situation, load balancing will no longer be able to enhance the throughput, since it is only the nodes closest to the gateway that contributes to the throughput in any case. The migrated nodes, which all are usually several hops away from the gateway, will not make an impact on the throughput under these conditions.

Fig. 5, illustrates how the unfairness between nodes close and distant from the gateway increases with an increasing offered load. This kind of unfairness will become more and more dominating as the offered load increases. This explains why the SLB and EL metrics have approximately the same performance as the SP metric at high loads.

When the offered load is not too low and not too high (i.e. in the middle of the aforementioned window), IGW_0 experiences congestion while IGW_1 is still underutilized. In this case, load balancing might improve the performance by migrating parts of the excessive load from IGW_0 over to IGW_1.

However, it is observed from Fig. 4 that the window of offered load where load balancing is beneficial is quite small.
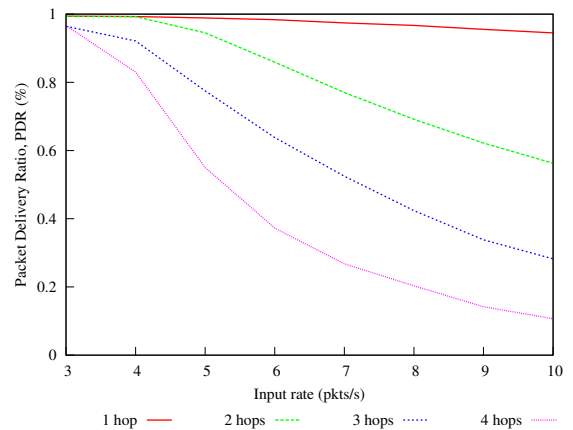
If the load is a little smaller than this, all traffic will make it through any gateway and there is no reason to balance the load. If the offered load is a little higher, on the other hand, only the nodes closest to any of the gateways will get their traffic through. The traffic of the more distant nodes, which will be the nodes most beneficial to migrate to other gateways, will be lost anyway.

This might explain why the average benefit of load balancing is so limited for random topologies. It is only when we deviate from full randomness (e.g. by artificially generating topologies that are systematically asymmetric) that any significant benefit of load balancing can be observed.

5.3 The Gateway Distance

Another parameter that might affect the potential benefits of load balancing is the positioning of the gateways. First, the gateways can be positioned asymmetrically, so that there are more nodes located closely to one of the two gateways. In fact, this effect has already been studied by employing the asymmetric topologies. Second, the distance between the gateways might play a role. We will explore the latter in the following.

In order to determine the impact of the gateway distance on the performance we carried out simulations on our asymmetric random topologies also with gateway distances of 600 m and 1400 m (i.e. in addition to the 1000 m gateway distance studied so far). Results are shown in Fig. 6. Here the throughput is in fact highest when the gateway distance is 1000 m (the three upper curves). Thus, by reducing the gateway distance to 600 m (the three middle curves) or increasing it to 1400 m (the tree lower curves) will both decrease the average performance. Hence, the results indicate that there is an optimal gateway distance.

The difference in throughput performance due to the gateway distance may be explained as follows:

The drawback with a short gateway distance like in the 600 m case is interference and the potential for reduced degree of spatial frequency reuse. For example if a node that is located somewhere in the area between the two gateways, sends traffic to either one of the gateways, it will at the same
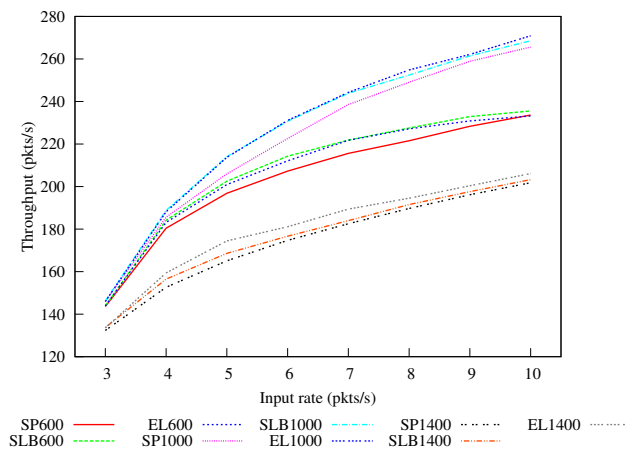
Figure 6: Comparing Throughput vs. Gateway distance

Figure 7: Comparing Sensing Range vs Throughput

time interfere the medium of the other gateway, preventing it from receiving traffic. This is because the sender node is likely to be within the sensing range of both gateways (default 550 m in ns-2). As a consequence, the throughput performance is lower compared with the results where the gateway distance is 1000 m.

On the other hand, when the gateway distance is 1400 m, we observe that there are two factors that cause the throughput performance to decrease. First, due to the increased gateway distance, the average path length to the gateways is increased, and consequently the probability for packet loss is also increased. Second, the probability for network partitioning is higher. We observed that 5 out of 30 topologies are partitioned, and in most of these cases, the throughput performance is generally low, due to high asymmetry and the eliminated possibility to perform gateway load balancing.

In Fig. 6, we also observe that the net throughput gain of performing load balancing is comparable between the different gateway distances. However, in the case where the gateway distance is 1400 m, we observe that the benefit of SLB is lower due to the reason that there are now fewer nodes that have equal hop length to both gateways. This is caused by the change in topology as a result of the gateway relocations.

Otherwise, the figure shows that our previous analysis on the benefits of load balancing for a gateway distance of 1000 m, applies well also to other gateway distances.

5.4 The Sensing Range

As we have seen, the frequency reuse around the gateways was poor when the gateway distance is 600 m, and this turned out to affect the throughput negatively. Indeed, the benefit of sending traffic in different directions (i.e. load balancing) depends on a certain level of spatial frequency reuse. If there is no frequency reuse, all transmissions compete for the same wireless channel, no matter which way the traffic is directed, and there is little use in performing load balancing. Hence, the degree of frequency reuse is another parameter that affects the potential benefits of load balancing.
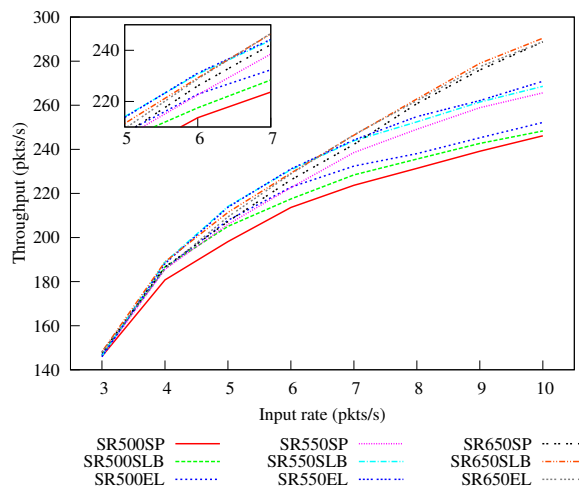
One way to explore the importance of the degree of frequency reuse is by tuning the sensing range. Intuitively, if the sensing range is high, we may expect that the level of frequency reuse is low, which in turn will reduce the effects of load balancing. On the other hand, if the sensing range is low, the degree of frequency reuse will increase, but unfortunately this will also increase the probability for packet collision. The big question is, with the presence of these two conflicting mechanisms, how will the effects of load balancing be affected when tuning the sensing range, and what impact will it make on the throughput?

All the results presented until now are taken from simulations where the sensing range is set to 550 m, which is the default value in ns-2. To find the answers to the above questions, we also carried out simulations with a sensing range of 500 m and of 650 m. The results presented in Fig. 7, reveal several interesting characteristics.

First, the dependency on the offered load is significant. At low loads, we observe that the results are hardly affected by the sensing range. However, with an increasing load the influence of the sensing range on the throughput is more evident, particularly when the load is high. As seen in the figure, the throughput increases with an increasing sensing range and load. In fact, this indicates that the effects of frequency reuse become less important compared to the effects of packet collisions, as the load is increased. Hence, at high loads, the throughput might be increased by increasing the sensing range in order to reduce the packet collision probability.

Second, the results also confirm the above assumptions, i.e. the effects of load balancing are indeed affected by the sensing range. As shown in Fig. 8 the average enhancement through load balancing is highest when the sensing range is 500 m, and then decreases with increasing sensing range because the degree of frequency reuse is also decreased.

Third, due to the two conflicting mechanisms between frequency reuse and packet collisions, the optimal sensing range is therefore a function of the offered load. As can be seen
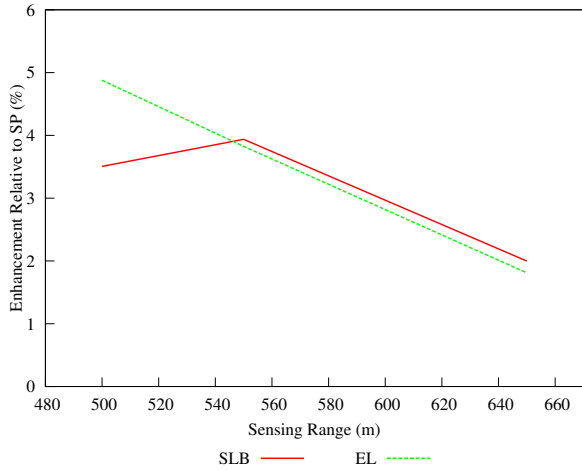
Figure 8: Peak enhancement vs. sensing range

Figure 9: Throughput vs. asymmetry

Figure 10: Enhancement vs. asymmetry

from Fig. 7, the effects of load balancing as well as the throughput is slightly higher for sensing range 550 m than 650 m when the input rate is around 5-6 pkts/s. However, above this load, the negative impact of packet collisions and packet loss are more dominating than the benefits of the frequency reuse, and we see there is an intersection that occurs between the load balancing curves for sensing range 550 m and 650 m at around 7 pkts/s. From this point on, we see that a sensing range of 650 m will give the highest throughput.

Finally, the low performance of the curves with a sensing range of 500 m indicates that the sensing range is not optimal regarding the trade-off between frequency reuse and packet collisions. This causes more packet collisions induced by a too high frequency reuse.

5.5 The level of asymmetry

We have analyzed a set of topologies with constraints that ensure an artificially high level of asymmetry compared to what is normally seen in a topology of uniformly distributed nodes. In this section, we will study the potentials for load balancing when the level of asymmetry is even higher.

Thus, in addition to the topology set in Section 5.1, we generated two even more asymmetric topology sets, utilizing the same procedure. Table 2 summarizes the node distribution of the three asymmetric topology sets (the topology set from Section 5.1 is denoted as set I in the table). For all simulations in this section we utilize the same distributed traffic model as in the previous section.

Table 2: Node Distribution Configurations

Topology Set	n_A	n_B	n_C
I	20	20	10
II	30	15	5
III	35	10	5

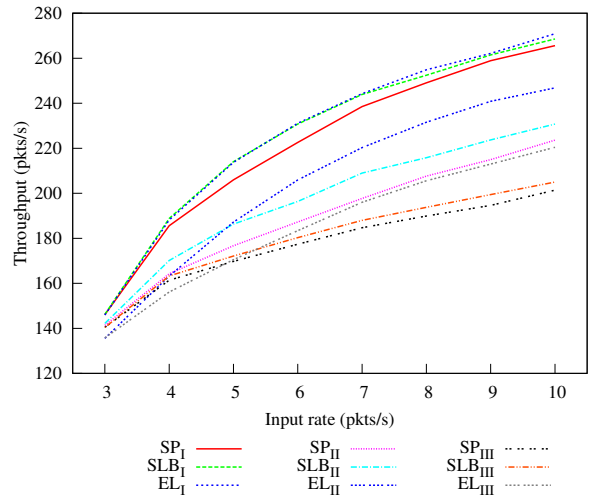From the results shown in Fig. 9, we see that the degree of asymmetry has a remarkable influence on the throughput. The more asymmetry there is in the topology, the lower is the throughput performanc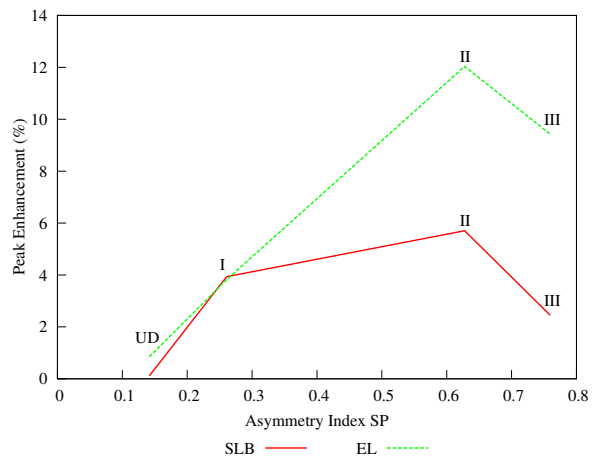e, as expected. On the other hand, it also shows that the potential for enhancing the throughput is greater when the asymmetry is higher. For comparison, Fig. 10 shows the average peak enhancement for both the uniformly distributed and the 3 asymmetric topology sets. The results clearly indicate that with increasing asymmetry, the benefits of load balancing are indeed greater. However, the results also indicate that above a certain level of asymmetry, the advantages of load balancing will decrease as in the case of the asymmetric topology set III. This is due to the fact that with a very high level of asymmetry, the chance for partitioning is also considerably higher.

Furthermore, we also see that at higher levels of asymmetry, there is a stronger need for a more aggressive load balancing approach, such as the EL metric. Thus, for the topology set II and III, EL appears to yield a higher enhancement compared to SLB. On the other hand, at lower asymmetry a conservative approach such as the SLB metric may be more appropriate. This is because both SLB and EL have approximately the same performance, but the cost in terms of network resources is less with SLB compared to EL.
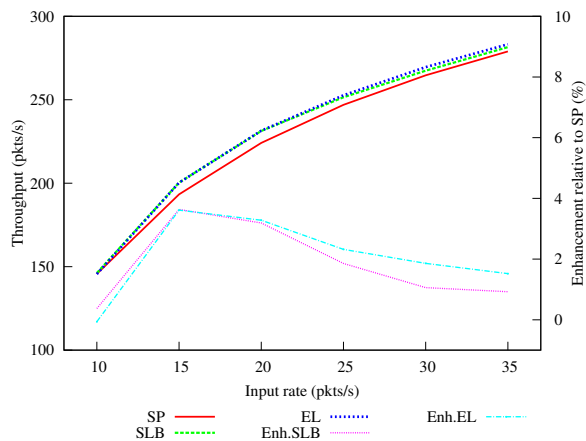
Figure 11: Throughput performance with randomly selected traffic sources. (Topology set I)

6. RANDOMLY SELECTED TRAFFIC SOURCES

All the results that we have obtained so far are based on simulations with the distributed traffic model, where all nodes send traffic of equal rate to either of the gateways. This means that the traffic patterns are given directly by the topology. Thus, so far the analyses have focused only on the randomness of the topology.

In this section, on the other hand, we will study the randomness of the traffic, by using the *random traffic* model. For the study in this section, we use the same topology set as in Section 5.1 (topology set I). For each topology in this set, the subset of source nodes is chosen by randomly selecting 6, 6, and 3 nodes from the regions A, B and C respectively. This means that only 30 % of the nodes in the network will originate traffic to either of the gateways and with equal rate. To faciliate comparison with previous results where the distributed traffic model is used, the total amount of network traffic is maintained approximately at the same level as in the previous simulations, by increasing the input rate from each sender node.

Fig. 11 shows the simulation results with random traffic which appear to be almost similar to the results in Fig. 4 with the distributed traffic model. Based on these results we may infer that the the simulation results are approximately the same no matter if we use the distributed or the random traffic models.

7. CONCLUSIONS

While a number of other studies have reported potential advantages of gateway load balancing in ad hoc networks with specific topologies, to the best of our knowledge none have made a study under the condition that the topology is random. This paper explores the potential benefits of load balancing when the network topologies are random.

We consider both an aggressive load balancing mechanism (i.e. the EL metric), and a moderate mechanism (i.e. the SLB metric) and compare their performance with no load balancing (i.e. the SP metric). With the aggressive mecha-

nism, the traffic load is equally distributed on the two different gateways, at the cost of additional overhead in terms of tunneling overhead and network resources. The moderate mechanism, on the other hand, reduces the additional implementation complexity.

Our results show that load balancing may increase the overall throughput. The enhancement is on the average low for uniformly distributed topologies, i.e. around 1 %. On the other hand, for the artificially asymmetric topologies, the average enhancement is higher, ranging from around 4-12 %. These results indicate that with random topologies load balancing has only a limited potential on the average, especially considering that the extra overhead of the load balancing mechanism (e.g. for gateway selection, tunneling overhead, additional complexity, etc) was not taken into account in our analysis.

The large scattering of the results around the average value indicates that the dependency on the topology is strong. In fact, we have observed that it is possible to enhance the performance up to 45 % for some specific topologies and at the most optimal traffic load. If it would be possible for the ad hoc network to automatically detect that the network is of a constellation (in terms of topology, traffic load etc.) where load balancing is beneficial, one could envision that the load balancing mechanism could be turned on only when such situations occur. This might even be feasible in a network of randomly moving nodes, if the level of mobility is limited. This represents a promising issue for further work.

The first step to address this issue would be to identify the parameters that affect the potentials for load balancing. In this paper we commenced this work by investigating some possible parameters, including the offered load, the level of asymmetry, the positioning of the gateways and the level of frequency reuse. It was observed that the level of asymmetry has a certain impact on the effect of load balancing. However, we experienced through this work that the parameters we explored cannot alone render the full picture of the mechanisms that might influence the potentials for load balancing. The specific layout of the topology plays nonetheless a crucial role.

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