# CONNECTIVITY AWARE ROUTING IN AD-HOC NETWORKS

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Ad-hoc networks that use the IEEE 802.11 MAC layer suffer from severe performance issues because nodes compete to access the wireless channel. In such a context, the network topology has a great influence on the overall network performance. In this paper, we present a connectivity aware QoS routing framework that takes routing decisions with regards to the local characteristics of the network topology. The advantages of the approach is to rely solely on observations made by each node locally and applies with existing MAC layers.

## 1. Introduction

Ad-hoc networks allow the spontaneous set up of communication systems when deploying an infrastructure is a non-trivial task or may take too much time. An ad-hoc network is composed of several mobile nodes sharing a wireless channel without centralized control or an established structure. Furthermore, all the nodes communicate only with the ones within their transmission range. As a consequence, nodes need routing capabilities to allow multi-hop communication and the topology is expected to change frequently.

This work is situated in the context of an ad-hoc network using the popular IEEE 802.11 MAC layer. In such a network, all nodes compete to access the same

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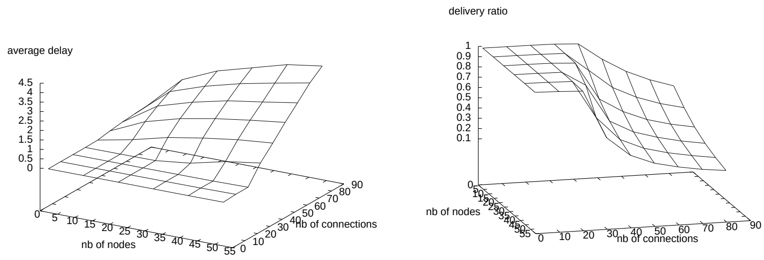
wireless channel. Network topology thus has a strong impact on performance. Indeed, the geographic positions of nodes greatly influence the ambient level of interference and the level of competition between nodes. We present in this paper a QoS routing framework that we use to investigate the benefit of using connectivity as the metric for routing.

The rest of the paper is structured as follows. Sec. 2 provides some simulation results that motivate this study. Sec. 3 describes the QoS routing framework that we use. Sec. 4 gives an overview of existing work on connectivity metrics and describes the ones we have chosen for this study. Sec. 5 presents the simulation results and Sec. 6 a discussion around this work. Sec. 7 concludes the paper.

## 2. Motivations

As a preliminary study, we ran simulations to determine the impact of the local level of connectivity on the local network performance. We analyzed the performance of an ad-hoc network composed of fixed nodes placed on a 100 square meter playground having a radio range of 250m. This means that for this simulations any node is at a one hop distance from any other node. They all compete for the same channel. A number of Constant Bit Rate (CBR) connections at the rate of 4 packets per second are established between pairs of nodes. The packet size is 512 bits and the routing protocol is AODV[1]. We used the network simulator ns2[2] with nodes having the 802.11 MAC layer at 2 Mbits with the RTS/CTS mechanism. In order to evaluate the overall performance, we measured, for data packets, the average delay and the packet delivery ratio, i.e the ratio between the number of received packets and the number of sent packets.

Fig. 1 shows average results for 30 instances of the experiment. Fig. 1(a) shows that the delay increases both with the number of nodes and the amount of traffic. Despite the fact that the amount of traffic seems to have a more severe impact on the delay than the number of nodes, the effect of the number of nodes is not negligible. Note that even if a node does not send traffic, it runs the routing protocol, which needs to periodically send packets toward its neighbors. The effect of higher connectivity is also visible for the packet delivery ratio (see Fig. 1(b)). For a constant amount of traffic, the performance decreases with an increase in the number of nodes involved in the scenario. Thus, when the connectivity is high, competition increases dramatically, meaning that the delay becomes higher due to contentions, which results in a poor use of network resources.




(a) Evolution of the delay (b) Evolution of the delivery ratio

Figure 1. Influence of the connectivity level on network performance.

## 3. The QoS Routing Framework

Since connectivity has a strong impact on network performance, our goal here is to use connectivity as a constraint for routing to improve network utilisation. To our knowledge, connectivity has never been the focus of a QoS routing study.

We decided to focus our work on the integration of QoS routing with the proactive link-state protocol OLSR [3]. In OLSR, all the nodes are aware of a subset of all links and use Multi-Point Relays (MPR) [4] to minimize the amount of control traffic. The heuristic for the MPR set selection can be changed to reserve link advertizement to those having certain properties. Munaretoo et al. [5] and Ge et al. [6] change the heuristic to make the OLSR route computation algorithm able to find routes having a good level of available bandwidth and delay. In our case, we simply use the Dijskstra algorithm [7], with links weighted according to our chosen connectivity metric. The metrics are combined using the additive operator. We plan to study multiplicative combination in future work.

In regular constraint based routing protocols, there is a need to propagate and to maintain QoS metric values. In our case, we rely on OLSR to maintain an image of the topology of the network. Thus, no additional network overhead is generated since no QoS information needs to be exchanged between nodes. Furthermore, we do not incur the measurement costs of classical metrics such as delay or bandwidth, which can be non-trivial [5,6].

## 4. Connectivity Metrics

This section presents an overview of connectivity metrics used in the literature and the ones we used for this study.

Several studies related to ad-hoc networks have dealt with connectivity metrics as a parameter to vary for simulation scenarios. There have been the $k$-

*connectivity* [8], the *number of shortest paths*[9], the *node density*[9], and the *directed connectivity*[9].

Lets use the following notation. The computation of the connectivity metric $v(a,b)$ attached to link $ab$ is usually done on the undirected graph of its $k$-hop neighborhood. A node $j$ is in the $k$-hop neighborhood of link $ab$ if there exists shortest paths from $j$ to $a$ and from $j$ to $b$ that have a length lower or equal than $k$ hops. Also, a link $cd$ is in the $k$-hop neighborhood of link $ab$ if $c$ or $d$ is in the $k$-hop neighborhood of link $ab$.

In this study, because they can be computed efficiently, and because they appear relevant, we choose to use the following metrics:

- *The $k$-hop node density*: It represents the number of nodes in the $k$-hop neighborhood.
- *The $k$-hop link density*: It represents the number of links in the $k$-hop neighborhood.
- *The clustering coefficient*[10]: It represents the probability that two neighbors of a node are connected. The clustering coefficient of a node $u$ is defined by $C(u) = \frac{2*E_u}{k_u*(k_u-1)}$. $E_u$ is the number of existing links between the neighbors of $u$ and $k_u$ is the number of neighbors of $u$.
- *The $k$-hop beta index*[10]: $\beta = \frac{E}{V}$ with $E$ the number of edges and $V$ the number of nodes in the $k$-hop neighborhood.

We have conducted experiments with $k$ equal to 1 and 2. Using a value of $k$ greater would not have made sense in this study because, for computational reasons, we did not perform our simulations on networks having a very large diameter.

## 5. Evaluation

To evaluate the connectivity aware QoS routing scheme described above, we ran graph oriented simulations to understand the metrics behavior and network oriented simulations to measure their benefit in term of performance.

### 5.1. *Metric performances*

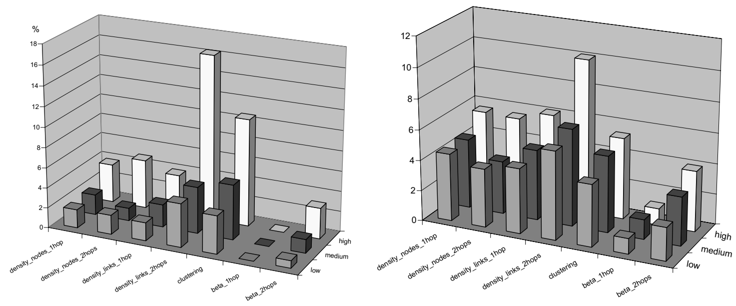
To evaluate the connectivity metrics we have implemented a stand alone simulator that measures several properties:

- *Path length inflation*: the difference in terms of number of hops between paths and minimum hop count paths. It should remain small since inflation in ad-hoc networks impacts performance.

- *Routing discrimination level*: the difference between the average metric value along paths found by the routing algorithm and along minimum hop count paths. This measures how well the new routing scheme performs in finding different routes than the minimum hop count.
- *Path stability*: the number of path changes that occur in a certain amount of time.

We consider a network composed of $200$ nodes having a radio range of 250m on a square playground 2000m large. We analyze the behavior of the metrics on three types of network graph, one with a low node degree variance, one with a medium node degree variance and one with a high variance. We have studied these three cases to artificially create three connectivity patterns.

This study aims to discover relevant metrics that imply a low frequency of routing changes, and that give a good level of discrimination without providing a high level of inflation.




(a) Average path length inflation

(b) Average routing discrimination level

Figure 2. Metric performances

Fig. 2(a) shows the average path length inflation. We can see that $beta\_1hop$ does not produce any inflation. The other metrics engender an inflation that increases with the node degree variance of the graph, which is normal. Only $density\_nodes\_2hops$ does not obey this law. We can also see that $density\_links\_2hops$ and $clustering$ introduce significant inflation compared to the other metrics.

Fig. 2(b) shows the average routing discrimination level. All the metric values have been normalized in order to be compared. We can see that they all have a quite high power of discrimination except for $beta\_1hop$. More generally, the discrimination increases with the node degree variance of the graph.

Fig. 3 shows the number of routing changes that occurred for each metric. We considered that nodes move according to the *random waypoint* mobility model with a maximum speed of 10m/s and a maximum pause time of 5s during 300 seconds. The routing tables are dumped every second. We observe that all the metrics involve more route changes than standard OLSR. We note in particular that $clustering$ engenders much a larger number of route changes than the others.

From the present results and studies we can conclude that $clustering$ and $density\_links\_2hops$ suffer from undesirable properties. The others seem to give better results.

| Metric | Number of route changes |
|---|---|
| hop count | 82.99 |
| density_nodes_1hop | 109.047 |
| density_nodes_2hops | 109.849 |
| density_links_1hop | 110.366 |
| density_links_2hops | 109.223 |
| clustering | 140.723 |
| beta_1hop | 128.592 |
| beta_2hops | 123.094 |

Figure 3. Route stability.

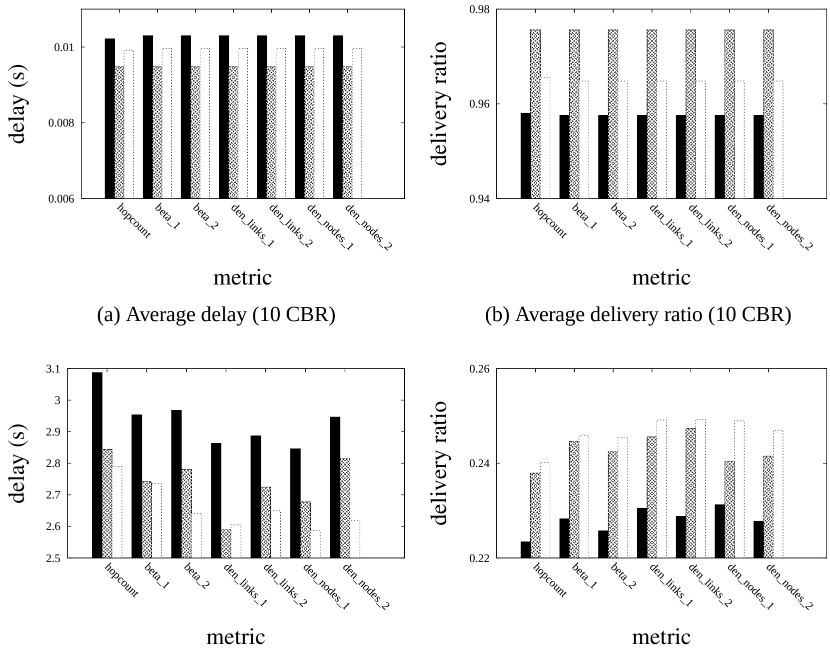
### 5.2. *Network simulations*

Fig. 4 shows simulation results for $30$ nodes obtained with the help of the *click router* [11] linked to the network simulator ns2 [2] for a network where nodes use the IEEE 802.11 MAC layer at the bitrate of 2 Mb/s. We measured the average delay and delivery ratio for data packets in networks having different connectivity patterns (low, medium, high as in Sec. 5.1) and we varied the number of CBR connections (same as in Sec. 2) chosen at random between nodes from 10 to 90.

We can see that when traffic is low, all the metrics perform the same. Whereas when traffic is high, the average delay is lower and the delivery ratio higher when conectivity metrics are used. Futhermore, we observe that one of the simplest connectivity metrics, $density\_links\_1hop$, clearly out-performs the others when traffic is high and especially when the connectivity level is high. For instance, when the connecitivy pattern is medium and when the number of CRR connections is 90, $density\_links\_1hop$ leads to a diminution of $8.77$% for the average delay and a gain of $3.65$% for the delivery ratio.

## 6. Discussion

We found that using connectivity as a metric for routing is only interesting when the amount of traffic is high and becomes even more relevant when the network connectivity is disparate. This may introduce the need for a hybrid system working as follows. One can extend the QoS framework to handle multiple constraints: the number of hops, the connectivity level, etc., and can imagine that nodes are




(a) Average delay (10 CBR) (b) Average delivery ratio (10 CBR)

(c) Average delay (90 CBR) (d) Average delivery ratio (90 CBR)

Figure 4. Average metric performances on 5 instances of the experiment (black bars are for low connectivity patterns, grey for medium and white for high ones).

observing the variance of the node degree to take the decision whether or not to integrate the connectivity level in the routing decision.

Such a routing scheme may introduce a lack of diversity in the routing decisions. This can be solved by adding some randomness in the choice of the routes. For instance, for a given destination, a node can choose a subset of possible next hops and distribute the traffic among them.

Regular QoS routing protocols suffer from two phenomena: the overhead induced by the additional exchanges of QoS information between nodes and the self-interference caused by the fact that the routing decisions have an impact on network resource availability, which can lead to flapping (as with bandwidth for instance). However the connectivity metrics used for the route computation in this work are calculated on the graph already maintained by OLSR, thus no real-time network performance information needs to be measured and no additionnal information has to be exchanged between nodes.

## 7. Conclusion and future work

This paper has highlighted some interesting properties of ad-hoc networks related to the network connectivity. It has presented a QoS routing scheme that benefits from the network topology, using connectivity metrics. We have shown that it improves the network utilization when the amount of traffic is high and even more when connectivity level is not constant through the network.

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