BISON
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Biology-Inspired techniques for
Self Organization in dynamic Networks

Demonstrator 2: Routing in Mobile Ad-Hoc Networks

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Abstract

In this document we describe the demonstrator which was developed to validate the solutions developed for routing in mobile ad hoc networks (MANETs) and report results obtained with it. The purpose of the demonstrator as stated in the project's technical annex is to test the effectiveness of the solutions developed for routing MANETs considering a city-like environment containing basic elements of real-world scenarios such as buildings/obstacles, street-constrained movements, and realistic traffic patterns. With the support of the QualNet simulator, we have set up a simulation environment with such characteristics, using the map of Lugano (Switzerland) as a template. We have run extensive simulation experiments in order to test the performance of AntHocNet, the biologically-inspired routing algorithm we developed, in this realistic environment. The performance of AntHocNet has been assessed versus that of AODV and OLSR. To provide a sound validation of the algorithms, we have considered many different scenarios varying a wide range of aspects such as the number of nodes, the amount and type of data traffic, the communication model (e.g., client-server and peer-to-peer), the response to sudden disruptive events (e.g., appearance of hot-spots and clusters of new nodes), etc.. We show that over the wide range of experiments reported, AntHocNet shows better performance than AODV and OLSR. Specifically, it delivers more data, with less delay and delay jitter. Moreover, in the majority of tests, AntHocNet uses less overhead than the competitor algorithms to provide this better service.

Contents

1 Introduction

This document reports on the activities carried out for Task 4.4, concerning the implementation of a demonstrator to validate the solutions developed for routing in mobile ad hoc networks (MANETs). More specifically, the purpose of the demonstrator, as stated in project's technical annex, consists in testing the effectiveness of the developed solutions for routing in MANETs at a level which goes beyond simulation or simplified proofs-of-a-concept, and moves the solutions closer to the real-world. In the technical annex we envisaged a city-like testing scenario in which two sets of mobile agents are engaged in communication activities. One set of agents consists of generic mobile users (e.g., walking people) moving across the city and communicating to each other according to random patterns. The other set of agents consists of users which are moving in relatively fast vehicles and are engaged in some specific task such as freight distribution (e.g., goods delivery company). At this aim they need to keep communicating with a central fixed node playing the role of a depot and control center. In the design and implementation of the demonstrator we followed these specifications as they were given in the technical annex.

As extensively discussed in Deliverables D5, D6 and D7, as well as in a number of journal and conference papers [7, 10, 8, 9, 6], we have developed a novel algorithm for routing in MANETs, called *AntHocNet*. The algorithm uses ant-like agents and diffusion processes as biologically-inspired building blocks. In the demonstrator's scenario we have run extensive experiments in order to validate AntHocNet's design choices under realistic settings. In particular, we have payed special attention to its properties in terms of adaptivity, scalability and robustness when facing challenges that can find their counterpart in a real world deployment. Moreover, we have also investigated the relative role of the different components of the algorithm.

The results presented here complement the large number of results about AntHocNet's performance reported in the mentioned Deliverables D5, D6, and D7, as well as in the more recent Deliverable D03.2 and in the cited journal and conference papers. While previous results concern scenarios characterized by open space node areas and nodes randomly moving in these open spaces, the demonstrator scenario involves obstacles (the city buildings) and structured mobility patterns (nodes are forced to move along the streets according to common walking and driving speeds). Moreover, while in all the previous scenarios all nodes are mobile, in the demonstrator we also studied the situation in which, together with the mobile nodes, also a mesh of stationary wireless nodes is placed across the town. So, according to the original spirit of Task 4.4, we set up a scenario that includes several components (obstacles, constrained movements, structured communications, a supporting mesh) which are expected to characterize possible real-world scenarios in which MANETs could be actually put to work. On the other hand, our scenario has no pretense to mirror real-world conditions exactly, especially for what concerns accurate modeling of the 3D signal propagation across the buildings. Using the underlying propagation model provided in the QualNet simulator [17] (see also Deliverables D11 and D12-13), we have made a rough but reasonable approximation of the signal propagation in the presence of obstacles, which allows us to study the effect of the presence of obstacles on the overall performance at a general level. A more detailed approximation of the signal propagation would have required an effort somehow out of the scope of this demonstrator.

Following the same experimental guidelines adopted in all the previous experiments, we assessed AntHocNet's performance versus other state-of-art algorithms, namely AODV [16] and OLSR [5], which are respectively a reactive and a proactive algorithm (while AntHocNet's design follows a hybrid approach). However, since the performance of OLSR was a lot worse that that of AODV and AntHocNet over all test scenarios, we report here only results for the latter two.

The rest of this document is organized as follows. We first provide a description of the adopted city-like scenario, and then we report and discuss all the experimental data.

2 Urban scenario

We considered Lugano (Switzerland) as reference city. Lugano is a relatively small old town presenting a quite irregular street topology common to most European cities. We focused on an area of 1561x997 meters, which covers most of downtown Lugano. The street structure is shown in Figure 1. We used an image composed of 976x623 pixels, such that each pixel in the image corresponds to 2.56m^2, which is therefore the used spatial resolution. As shown in

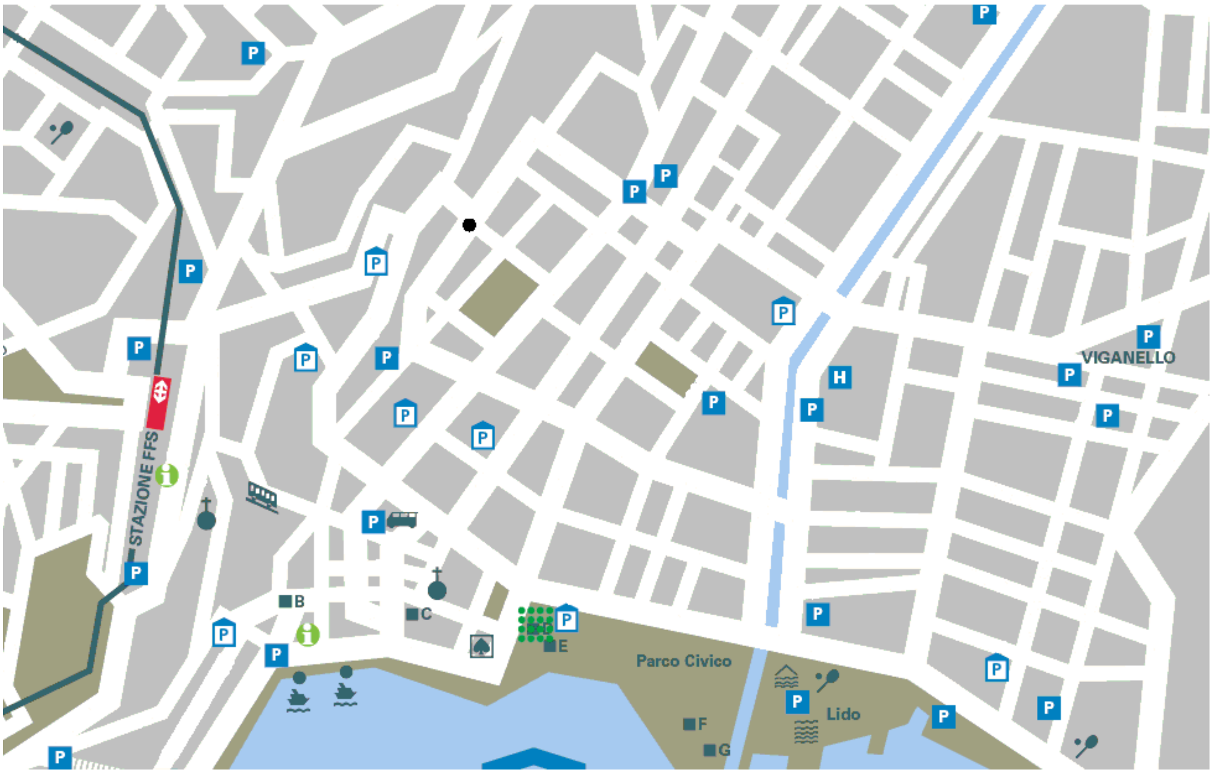


Figure 1: The map of Lugano that has been used to define the cityscape.

the figure, the cityscape is basically composed of streets (the white lanes) and buildings (the gray polygons). Streets define the open spaces where agents are free to move. Buildings are inaccessible to the agents and basically play the role of obstacles that put constraints on agent movements and shield signal propagation. Other elements are the lake, in the lower bottom of the image, and urban infrastructures such as parking lots and the train station. However, these latter do not play any role and are left in the image for the sole purpose of better showing town organization. The image of the 2D cityscape is stored as a binary matrix, where a value 0 or 1 is assigned to each pixel, indicating whether it is part of a street or not. That is, whether it belongs to an open space where both the nodes and the radio signals can freely propagate through or not.

2.1 The mobile agents

There are three groups of actors in the urban environment. The most numerous group represents pedestrians and slowly moving vehicles. They move freely along the streets according to a random waypoint mobility model [12] with 30 seconds as max pause time and speed ranging from 1 to 4 m/s (3.6 to 14.4 Km/h). Each next pausing location is selected randomly from the points in open space, without any constraint on the distance. The path followed to reach the next pausing location is calculated as the shortest path through the town from the current location. We will refer to the nodes in this group as *background nodes*. The other group of agents represents commercial vehicles used, for instance, for some freight distribution task across the town. Hereafter we refer to them as *truck nodes*. They all start from a common location, the depot, and then move following the streets according to a plan that selects intermediate points (e.g., customer locations) which are reached following the shortest path from the current location as in the case of the background nodes. During their journey the vehicles incur in temporary stops of random duration between 0 and 30 seconds (e.g., waiting at a traffic lights). Their speed ranges from 3 to 12 m/s (10.8 to 43.2 km/h). Each hypothetical customer site is constrained to be at least more than 300 meters along the x-axis and more than 500 meters along the y-axis from the current location (these values correspond to 1/3 of the cityscape width and height respectively). The third group of agents is made of non-mobile nodes which mainly act as relay nodes. We refer to them as *fixed nodes*. Their number is selected in the different scenarios as a (usually small) percentage of all nodes. They constitute a basic form of a mesh network which in principle can provide more robustness to the whole system. They are included in the scenario since one of the most promising directions for the actual deployment of MANETs in urban environments precisely includes the use of meshes playing the role of a supporting infrastructures [1].

In most of the experiments the trucks only communicate with the depot (e.g., to exchange traffic and delivery information/orders), establishing in this way a situation typical of the client-server model, with the depot playing the server role. In a few scenarios we also considered a peer-to-peer model, with the trucks exchanging information to each other in bidirectional way. The background nodes only communicate to each other according to a unidirectional model (e.g., exchange of multimedia or text data). We refer to the traffic generated by the background nodes as *background traffic*.

2.2 Radio communications and signal propagation models

For what concerns radio communications settings, we rely on the QualNet standard implementation of the IEEE 802.11b with 2 Mbits/s bandwidth at the MAC layer. For radio signal propagation in free line-of-sight communications along the streets we rely on QualNet's two-ray ground reflection model, which considers both the direct and the ground reflection path [18]. This empirical model provides a good approximation for open/obstacle-free spaces. On the other hand we are in presence of a structured environment with a number of obstacles. The effects of the buildings on the actual radio propagation depend in principle on a number of factors such as the height of the buildings, the height of the receiver and transmitter radio, the radio frequency, physical characteristics and shape of the buildings, street width, distance between the buildings, etc. In spite of the fact that a number of good models for outdoor radio propagation have been proposed in the literature (e.g., like those proposed in the EURO-COST 231 activity [4] and all their subsequent improvements), a "faithful" simulation of the specific site we are considering would require an enormous effort in terms of computations, data gathering, and modeling, and would still provide an incomplete model of reality. Therefore, we opted for a crude approximation of the effect of buildings which is similar to a number of basic empirical models commonly used for indoor propagation and outdoor propagation in wide spaces with isolated obstacles (e.g., [13, 15, 14, 11]). Following these models, we do not explicitly take signal reflection or interference from buildings into account. Rather, we consider the shielding effect of the buildings along the hypothetical line-of-sight between sender and receiver in order to define a correction to the two-ray signal attenuation calculated by QualNet. In operational terms, what we do is to count how many pixels along the line-of-sight belong to a building. Since each pixel corresponds to a square of 1.6m^2, we can count the cumulative width w_{cum} of obstacles attenuating the signal present along the line-of-sight. If the cumulative width exceeds a predefined value w_{max}, then the communication does not happen. On the other hand, if $w = \frac{w_{cum}}{w_{max}} < 1$, then the signal attenuation at the receiver as calculated by QualNet is further amplified by a multiplicative factor $\sigma \propto w, \ \sigma \geq 1$. In this way, the intensity of the signal sensed at the receiver is attenuated proportionally to the total amount of obstacles along the straight line-of-sight. Since in the real-world signals can actually turn around corners by diffraction and reflection on the nearby buildings, we tuned the values of all the involved parameters in order to approximately reproduce this behavior.

2.3 Online graphical visualization

To get a better understanding of the characteristics of the scenario and of algorithms' behavior, an online graphical visualization of node movements, used paths and performance evolution has been implemented.

The graphical visualization is split in two parts. On the left side, we show the movements of all the nodes as well as routing and forwarding information for the duration of the simulation experiment. Nodes are represented by small squares, of different color according to the group (mobile users, commercial vehicles, fixed nodes) they belong to. Mobile users are represented as orange squares, while truck nodes are black. Fixed nodes are slightly larger and are filled in red. The special depot node is represented in dark red. To show which paths are actually used, we highlight the paths followed by the data packets of an assigned traffic session involving truck nodes. After the reception of each data packet of the session, we report on the graph the entire multihop path followed by the packet using blue segments to join the nodes involved in the multihop path. In Figure 2, which shows a snapshot of this part of the graphical visualization. The bold-faced multi-segment line in the middle of the picture represents the path followed by a data packet sent from the depot (which is in all tests located in front of the area marked by “stazione FFS”, which is Lugano’s railway station) to a truck node located in the area close to the two parking lots indicated in the upper middle part of the picture. Also another multi-segment line between these two end points is shown in the figure, located below the other one and less marked than the first one. This represents a possible alternative path which is known and available to the algorithm. In fact, AntHocNet discovers, uses, and maintains multiple paths, when possible. Each discovered path has associated indicators of its quality (in terms of signal-to-noise ratio and number of hops) in the form of the pheromone variables held at each node. Lower estimated quality implicitly means lower probability of being selected for path forwarding. We dynamically show not only the different paths AntHocNet is maintaining moment by moment, but also the evolution of their estimated relative quality, which might change over time due to the proactive path maintenance activities. In the visualization we use different colors for different classes of quality/probability. Orange is used to indicate lower probability paths, magenta indicates an intermediate selection probability, and red is reserved for the best paths. A blue path indicates the path that has just been used to route the last data packet arrived at the monitored destination.

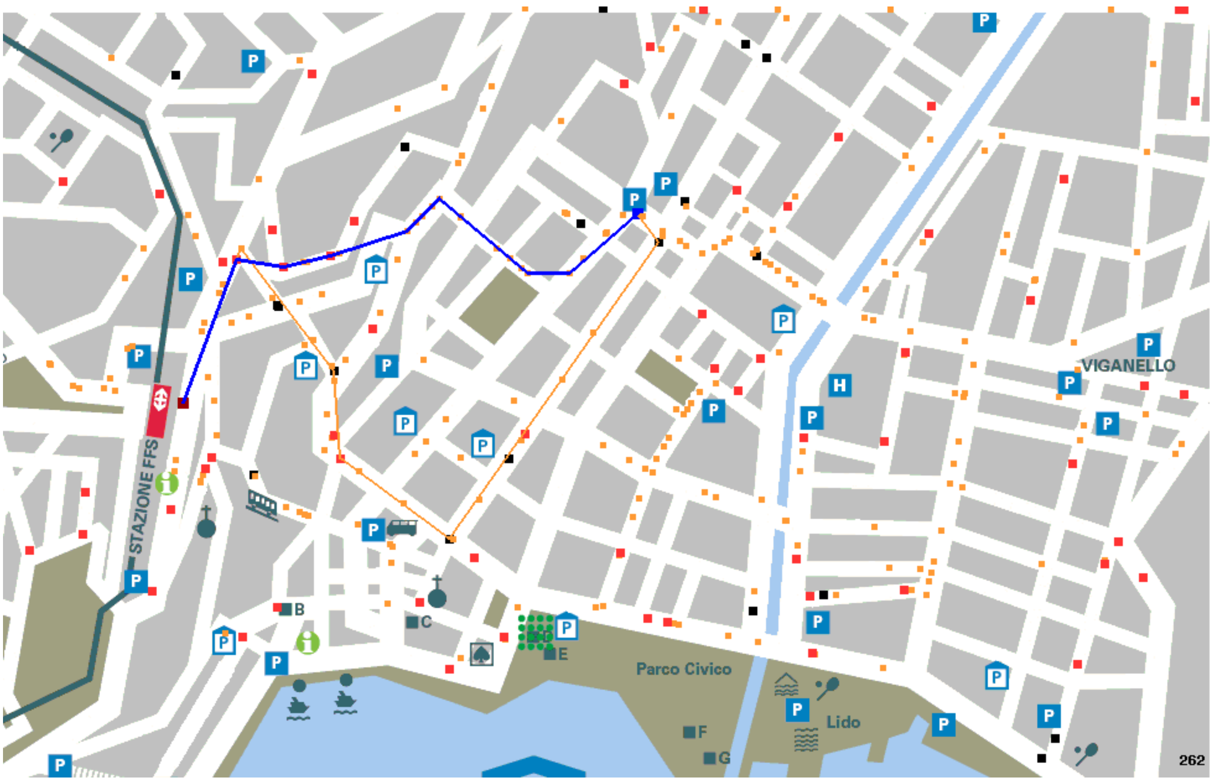


Figure 2: Snapshot of the cityscape part of the visual interface.

On the right side of the visual interface (not shown here), we plot the “instantaneous” (averaged over the last 10 seconds) value of standard performance indicators: end-to-end delay, data throughput and delay jitter. Plotted data refer to both AntHocNet and AODV. Clearly, AODV’s performance data are stored running AODV precisely on the same scenario. In this way, the user can appreciate the evolution of the global performance of the two algorithms while observing node movements, and, accordingly, the evolution of the network topology. In Figure 3 we show a full snapshot of the visual interface with both the cityscape and the running plots.

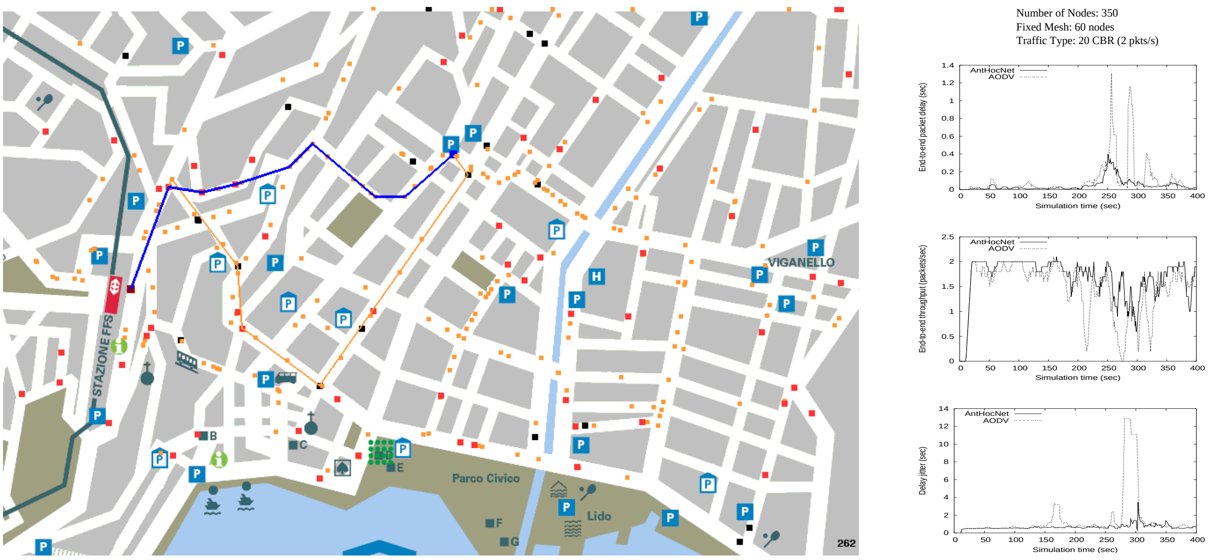


Figure 3: Full snapshot of the visual interface.

3 Experimental results

We ran extensive tests to provide a sound validation of the approach followed in BISON to design a biologically-inspired routing algorithm that would exhibit good adaptivity, scalability, and robustness. In all scenarios we considered the data traffic to/from the truck nodes as the main traffic and the traffic exchanged among the other nodes as background traffic. Fixed nodes act only as relay nodes and do not usually play the role of end points. We studied the response of the algorithms versus the variation of a number of aspects such as the total number of nodes, the fraction of fixed nodes, the number of running sessions, the data generation rate, the statistical characteristics of traffic generation, etc.. We also considered different models of communication such as client-server and peer-to-peer, and disruptive events like the sudden appearance of hot-spots or of a large number of new nodes. For all the experiments we report the performance in terms of average end-to-end delay, delivery ratio, average delay jitter, and used resources in terms of packet overhead (these metrics have been also extensively discussed in Deliverable D04). For the case of sudden events, we report only the instantaneous end-to-end delay variation averaged over the last 10 seconds.

The traffic loads have been selected according to the rule of thumb that the scenarios which are worth to discuss are those in which at least one of the algorithms is able to deliver more than 50-60% of the input traffic (while keeping acceptable average end-to-end delays). In all the experiments we used the characteristics of mobility of the nodes as explained in Section 2.1. In fact, on the one hand, the selected characteristics are enough general and realistic, and on the other hand, we needed to restrict somehow the universe of possible scenarios to investigate.

Extensive tests changing the mobility characteristics of the nodes were carried out in the mentioned previous work that considered obstacle-free node areas. Also the characteristics and the parameters regulating the behavior of the wireless nodes at the layers below the application layer were kept fixed. This means also that we did not operate any per scenario tuning of the parameters neither for AntHocNet nor for AODV (or OLSR). The same set of "reasonable" parameters were used across all scenarios. Indirectly, this was also a way to test robustness and behavior consistency of the algorithms. Also the simulation time has been set to the same value (400 seconds) for all the experiments. The 400 seconds represented a good tradeoff between the need of maximizing accuracy of per run results and the requirement of keeping cpu running times low to have the possibility to execute a large number of tests.

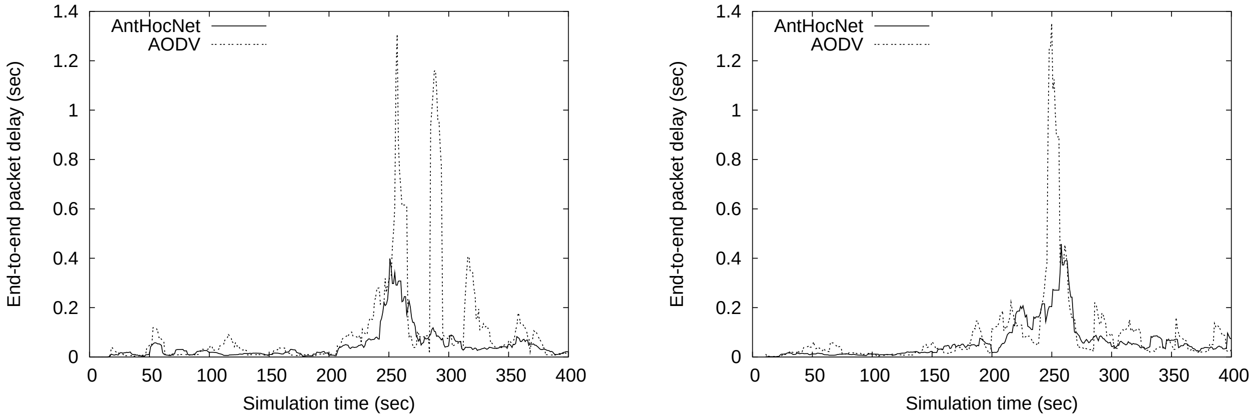
In most of the experiments the traffic generated is of CBR type. This is a quite common choice in the MANET community. CBR is totally deterministic and controllable, and relies on UDP at the transport layer. Apart from CBR, we also used a generic traffic generator (provided in QualNet under the name TRAFFIC-GEN) that generates packets according to negative exponential distributions for both inter-arrival times and packet sizes. Also TRAFFIC-GEN relies on UDP. TCP is known not to function well in the highly dynamic MANET environments [2], nor to deal properly with multipath routing [3]. Since these TCP-related issues are out of the scope of the BISON project, we have not explicitly addressed them, and we have therefore chosen not to use TCP at all in our experiments.

If not stated otherwise, the payload of all data packets is 64 bytes and the number of truck nodes is 20. These 20 vehicles keep communicating with the depot since the start of the simulation implementing a client-server model with the depot playing the role of server. Again, if not stated otherwise, they are receiving CBR data from the depot at a rate of 2 packets/s. The number of fixed nodes is usually set to be 20% of the number of total nodes, except for the scenarios explicitly involving the number of fixed nodes. In all the experiments not involving scaling of the number of nodes, the total number of nodes is set to 350, which determines a node density which can in general support satisfactory delivery ratios in the considered cityscape. We always run 10 different tests for each data point (using different node movements, randomly generated based on the earlier described characteristics), except in the case of the sudden events (subsections 3.1 and 3.2), where results for a typical run are shown.

In the following we discuss each scenario in a separate subsection.

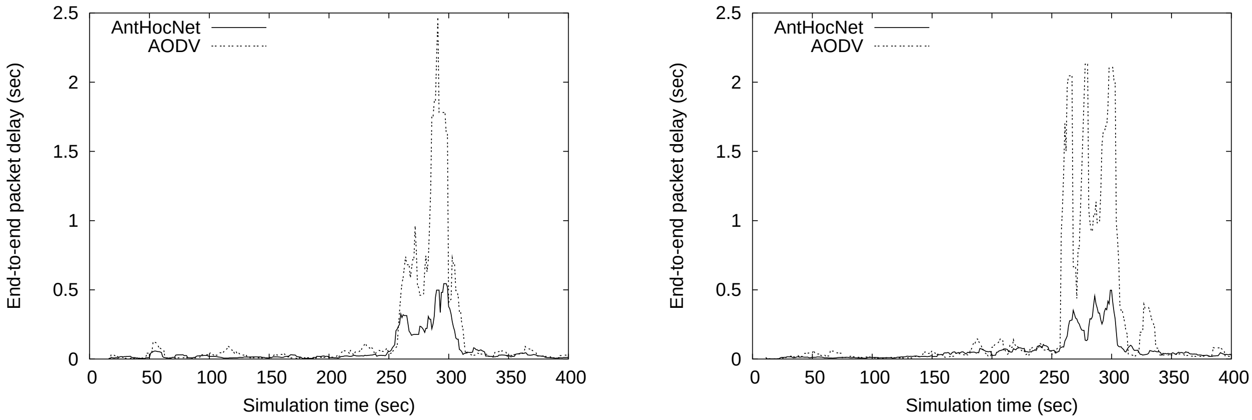
3.1 Sudden introduction of new nodes

In this scenario and in the following one, we want to study the short-time response of the algorithms after the occurrence of a major "disruptive event". Here the disruptive event is represented by the sudden introduction at the same location in the network of 50 new nodes (e.g., arrival of a ferry boat, end of a movie projection, etc.). These nodes enter the network after about 210s from the beginning of the simulation and for 50 seconds 20 of them keep sending CBR data at a rate of 4 packets/s. This traffic spike is superimposed to the background traffic of 20 CBR sessions (2 packets/s) and to the 20 CBR communications between depot and trucks. Figure 4 shows the typical time response of the algorithms in terms of end-to-end delay. The two plots refer to two different pairs of nodes involved in communications. A similar behavior can be observed also for throughput and jitter and/or for other pairs of communicating nodes.



(a) (b)

Figure 4: Two samples of typical instantaneous end-to-end delay for two pairs of communicating nodes in the case of the sudden appearance of 50 new nodes. Each point in the plot is the average of the observed end-to-end delays over the last 10 seconds.



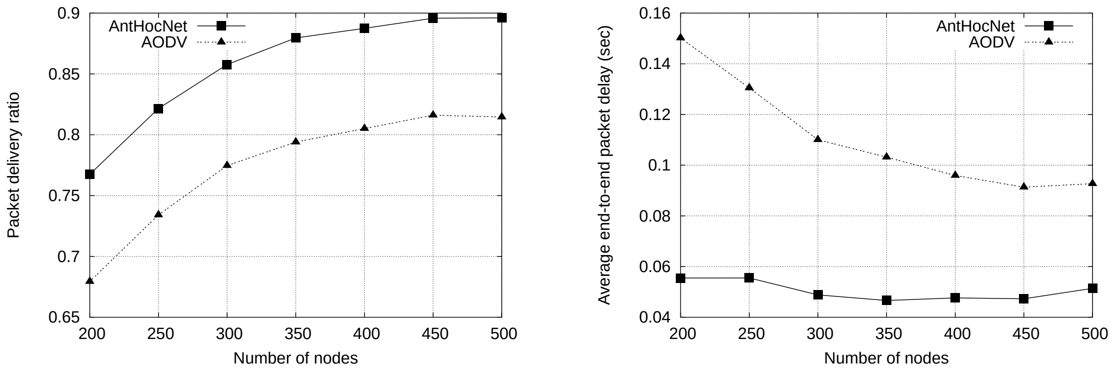
(a) (b)

Figure 5: Two samples of typical instantaneous end-to-end delay for two pairs of communicating nodes in the case of the sudden establishment of 20 new data sessions (8 packets/s) towards a hot-spot. Each point in the plot is the average of the observed end-to-end delays over the last 10 seconds.

The better short-term behavior of AntHocNet is evident. Not only does AntHocNet not "explode" during the sudden transitory, but it also shows a more stable behavior for the whole duration of the simulation.

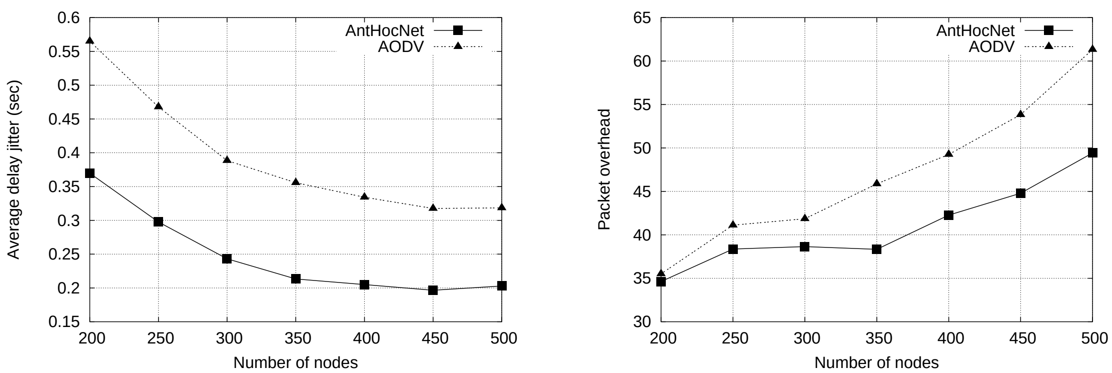
3.2 Sudden appearance of a hot-spot

This scenario has the same purpose as the previous one. However, in this case the sudden event consists in the appearance of a hot-spot: one of the fixed nodes at time 210s starts attracting



(a) (b)

Figure 6: (a) Delivery ratio and (b) average end-to-end delay for scaling the number of nodes while keeping the data traffic constant.



(a) (b)

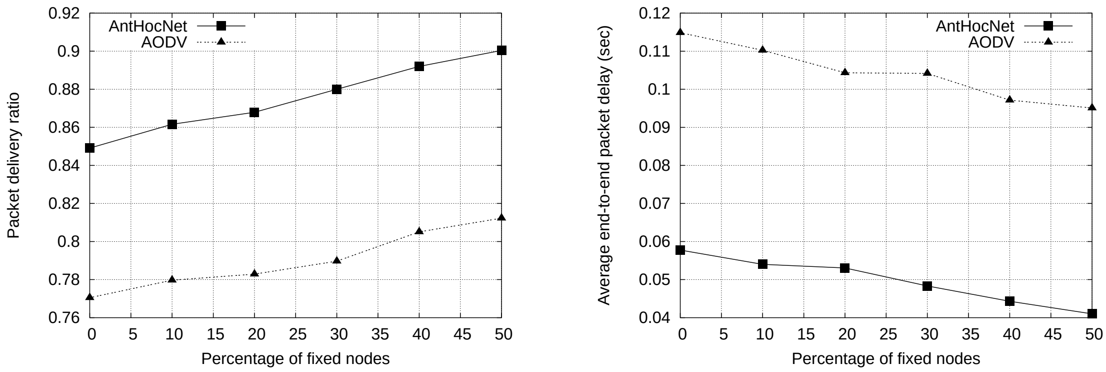
Figure 7: (a) Average delay jitter and (b) packet overhead for scaling the number of nodes while keeping constant the data traffic.

heavy traffic (e.g., it becomes an Internet access point). For 50 seconds 20 different background nodes send to this fixed node CBR data at a rate of 8 packets/s. This traffic adds to the traffic between the depot and the vehicles and to the background traffic of 20 CBR sessions.

The experimental results for two sample pairs of communicating nodes are reported in Figure 5. As in the previous case, AntHocNet shows superior local adaptivity and an overall behavior which is much more robust and stable than that of AODV.

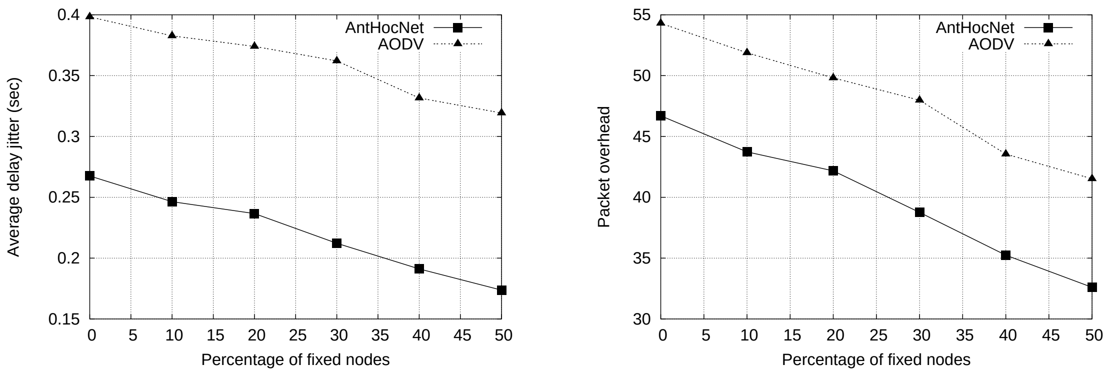
3.3 Scaling the total number of nodes

While the previous two set of experiments were aimed at observing the behavior of the algorithms at a short time scale, in this and in the following scenarios we focus on the cumulative performance over the whole duration of the simulation. In this scenario we keep the background and vehicle traffic fixed (20 CBR sessions each), while we increase the total number



(a) (b)

Figure 8: (a) Delivery ratio and (b) average end-to-end delay for scaling the fraction of fixed nodes while keeping the data traffic constant.



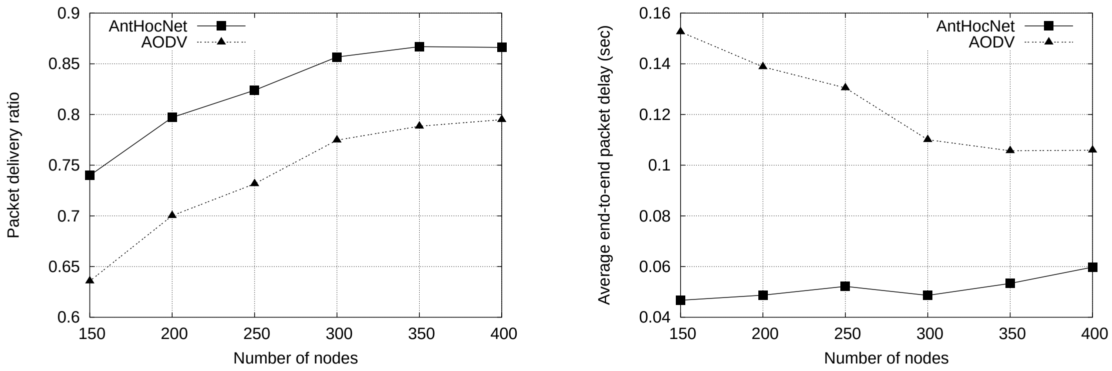
(a) (b)

Figure 9: (a) Average delay jitter and (b) packet overhead for scaling the fraction of fixed nodes while keeping the data traffic constant.

of nodes. In this way more connectivity is offered to the nodes. The results are plotted in Figures 6 and 7. Both algorithms profit from the increase in connectivity. However, AntHoc-Net constantly shows a clearly superior performance while using significantly lower packet overhead than of AODV.

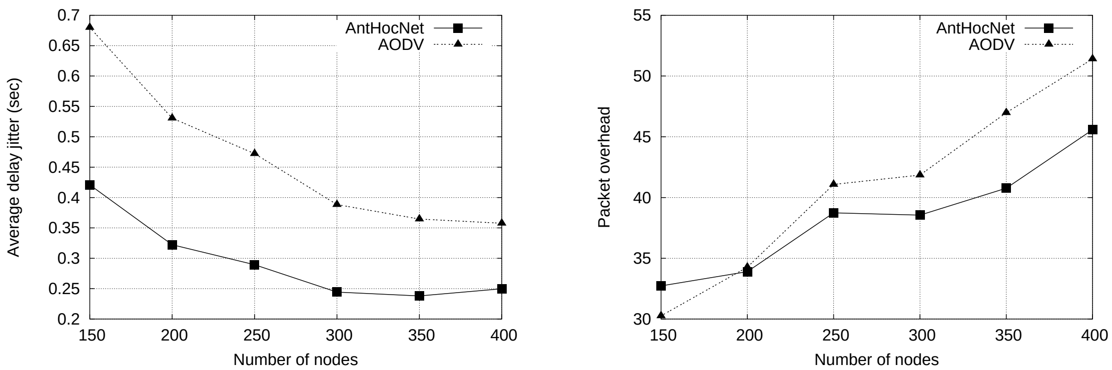
3.4 Scaling the fraction of fixed nodes

In this set of experiments we keep the total number of nodes and the total offered traffic fixed, and we increase the percentage of fixed nodes (over a total of 350 nodes). In this way the network environment becomes more stable and we can study the ability of the algorithms to exploit this increase in stability. Moreover, since with the increase in fixed nodes the network becomes an instance of a simple mesh network, in this way we can study the effectiveness of these algorithms, designed for pure MANETs, when working within a mesh network. Figures 8 and 9 show the experimental results. The general trend confirms the results of the previous



(a) (b)

Figure 10: (a) Delivery ratio and (b) average end-to-end delay for scaling both the number of nodes and the offered load.



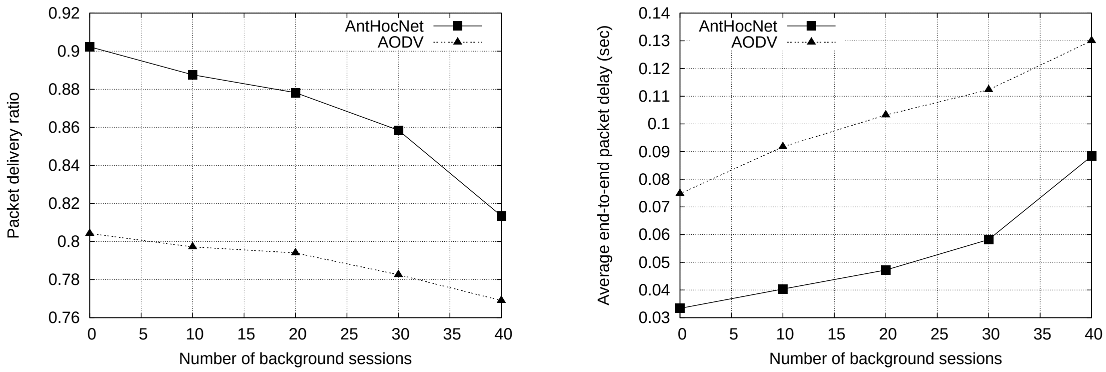
(a) (b)

Figure 11: (a) Average delay jitter and (b) packet overhead for scaling both the number of nodes and the offered load.

scenario. Both the algorithms can improve their performance, taking advantage of the increase of fixed nodes. However, AntHocNet delivers much higher throughput with significantly less end-to-end delay and delay jitter. Also in terms of routing overhead the difference between the two algorithms is constant and clearly in favor of AntHocNet.

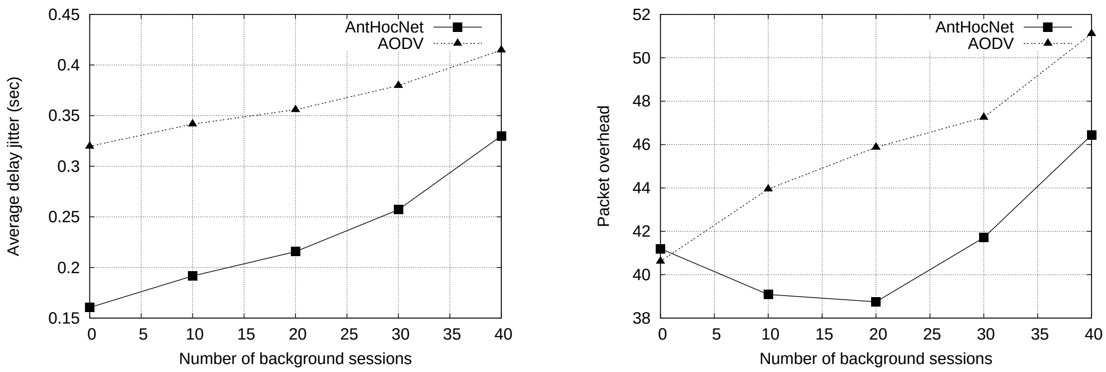
3.5 Scaling both nodes and offered traffic

While in the previous experiments we tested the ability of the algorithms to exploit increasingly favorable conditions in terms of connectivity and stability, in this set of experiments we add also a potentially negative component. In this scenario concurrently to the total number of nodes, we also increase the number of background sessions to observe the evolution of the combined effect of increasing connectivity while increasing also the amount of traffic exploiting this increased connectivity. In addition to the usual 20 CBR sessions for the trucks, we start with 5 CBR sessions for 150 nodes. Then we add 5 CBR sessions for each 50 new added nodes, to



(a) (b)

Figure 12: (a) Delivery ratio and (b) average end-to-end delay for scaling the number of background traffic sessions.



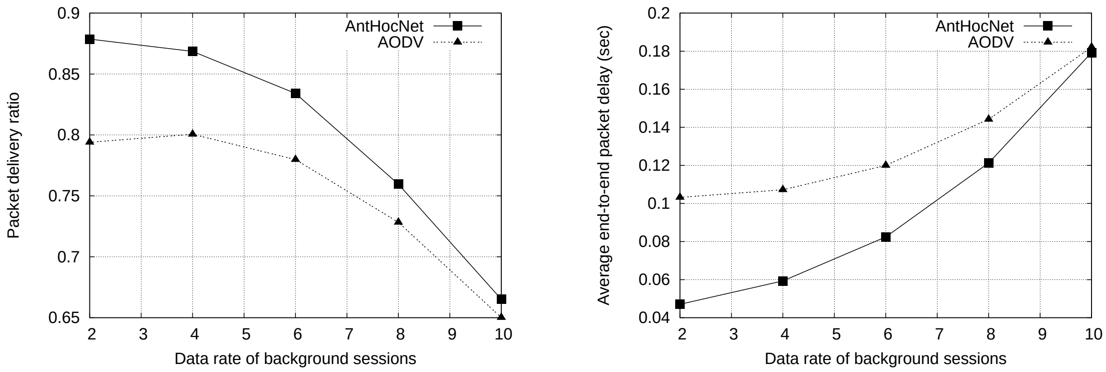
(a) (b)

Figure 13: (a) Average delay jitter and (b) delivery ratio for scaling the number of background traffic sessions.

end up with 30 background sessions for 400 nodes. Results are shown in Figures 10 and 11. The behavior is quite similar to that reported in Figures 6 and 7 both in terms of absolute performance (which are only slightly lower) and relative performance between the algorithms. This confirms the good adaptivity and scalability of both algorithms, as well as the advantage of AntHocNet over AODV.

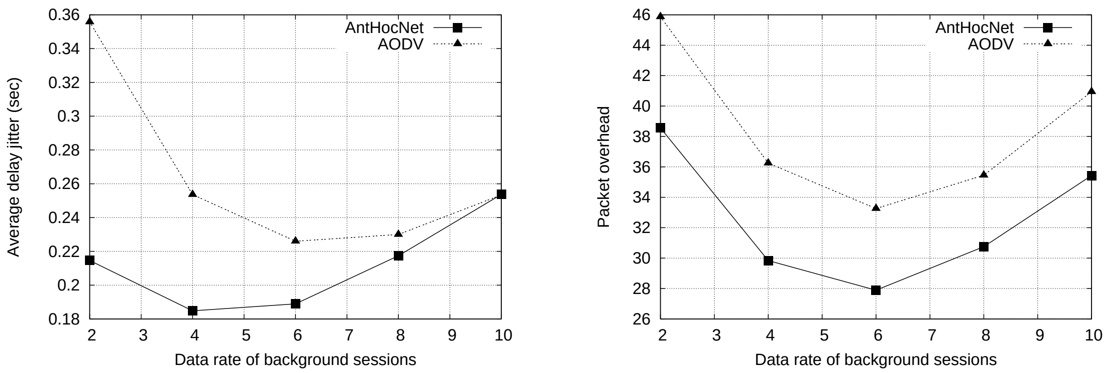
3.6 Scaling the background traffic

A more systematic and challenging test on the effect of increasing the traffic load, and, more specifically, the background traffic, is provided by the scenario described in this section. We keep the number of nodes fixed to 350, and add to the truck traffic of 20 CBR sessions a background traffic ranging from 0 to 40 CBR sessions. The results shown in Figures 12 and 13 make clear that this scenario is more challenging than previous ones. The performance of both algorithms degrades rapidly with the increase in background traffic. Moreover, the difference in



(a) (b)

Figure 14: (a) Delivery ratio and (b) average end-to-end delay for increasing the data rate of background traffic sessions.



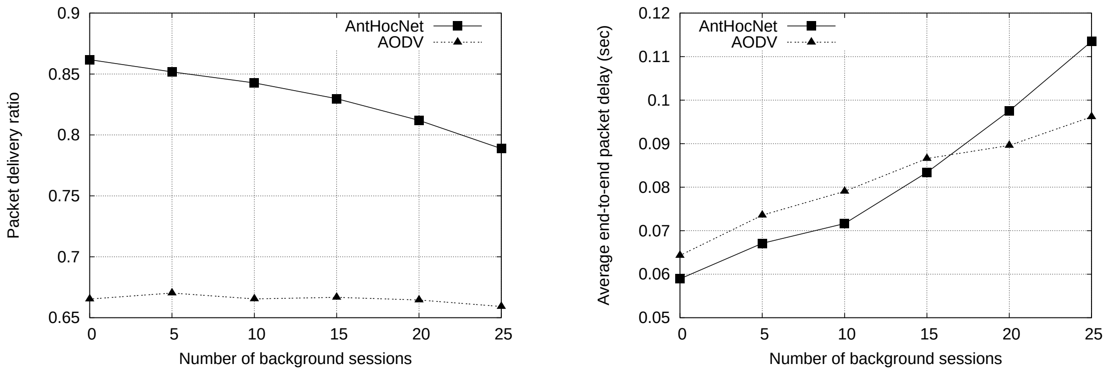
(a) (b)

Figure 15: (a) Average delay jitter and (b) delivery ratio for increasing the data rate of background traffic sessions.

performance between AntHocNet and AODV gets smaller going toward 40 sessions, but it is still significant. However, it is clear that both the algorithms are reaching, at different rates, a dramatic reduction in terms of the delivered service (e.g., with 40 background sessions, AODV is able to deliver only 77% of the packets with an average delay of 130ms and average jitter of 410ms). Nevertheless, the overhead of both algorithms does not explode, which must be seen as an indication of robustness.

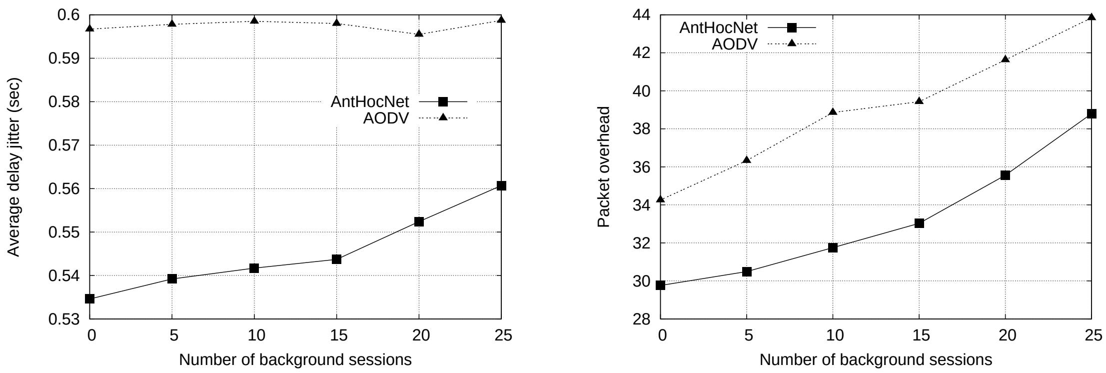
3.7 Increasing data rate of background traffic

The scenario of this section deals with the characteristics of the traffic load in terms of data generation rate, which complements the experiments of the previous section. Using the basic scenario of 20 CBR background sessions and 20 CBR truck sessions in a network of 350 nodes, we increased the data generation rate of the background sessions from 2 to 10 packets/s. It is expected that a network with a nominal node bandwidth of 2 Mbit/s, and an effective band-



(a) (b)

Figure 16: (a) Delivery ratio and (b) average end-to-end delay for scaling the background traffic on top of bidirectional traffic between the trucks and the depot.



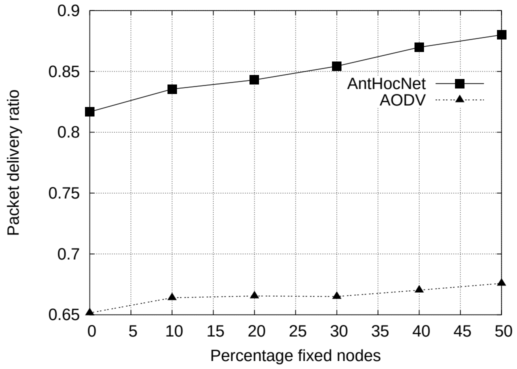
(a) (b)

Figure 17: (a) Average delay jitter and (b) delivery ratio for scaling the background traffic on top of bidirectional traffic between the trucks and the depot.

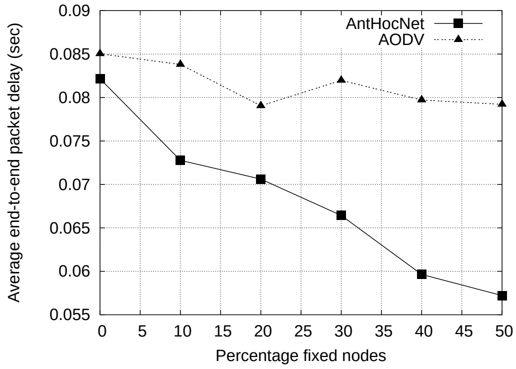
width which is much less due to the MAC layer protocol, is not able to fully support the highest data generation rates. Results reported in Figures 14 and 15 confirm this. Both algorithms' performance shows a dramatic drop at rates higher than 4 packets/s. AntHocNet's performance are clearly superior for low rates (up to 6 packets/s) but then they become equivalent to those of AODV. At 10 packets/s the performance of both algorithms has dropped to unacceptable levels. It is interesting to notice that in terms of packet overhead AntHocNet is able to keep its advantage over AODV also for the highest rates. Moreover, the fact that the overhead of both algorithms is relatively stable seems to indicate that the dramatic reduction in performance is more due to inefficiencies at the MAC layer than at the routing layer.

3.8 Increasing background sessions on top of bidirectional truck traffic

In all previous scenarios we used CBR sessions, all the communications were essentially unidirectional and the trucks were communicating exclusively with the depot according to a client-

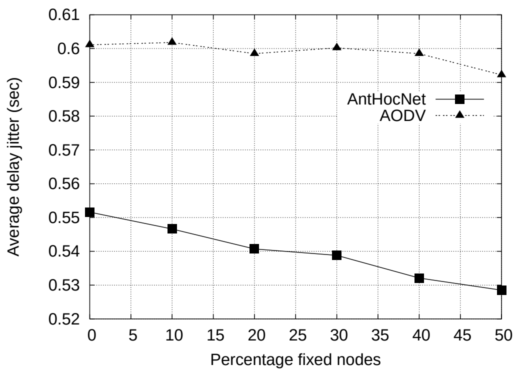


(a)

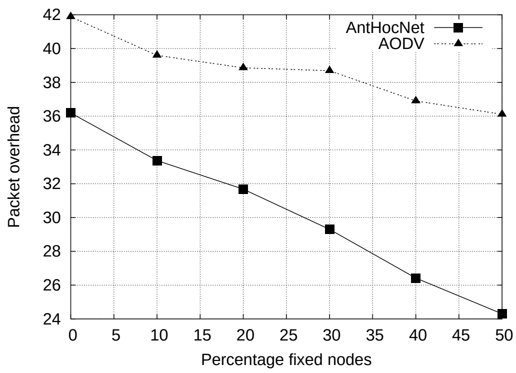


(b)

Figure 18: (a) Delivery ratio and (b) average end-to-end delay for scaling the fraction of fixed nodes while offering constant bidirectional TRAFFIC-GEN traffic between trucks and depot.



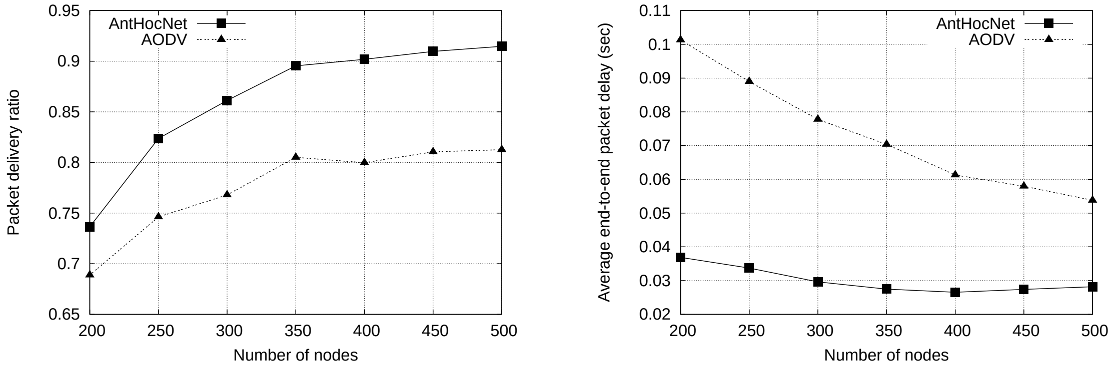
(a)



(b)

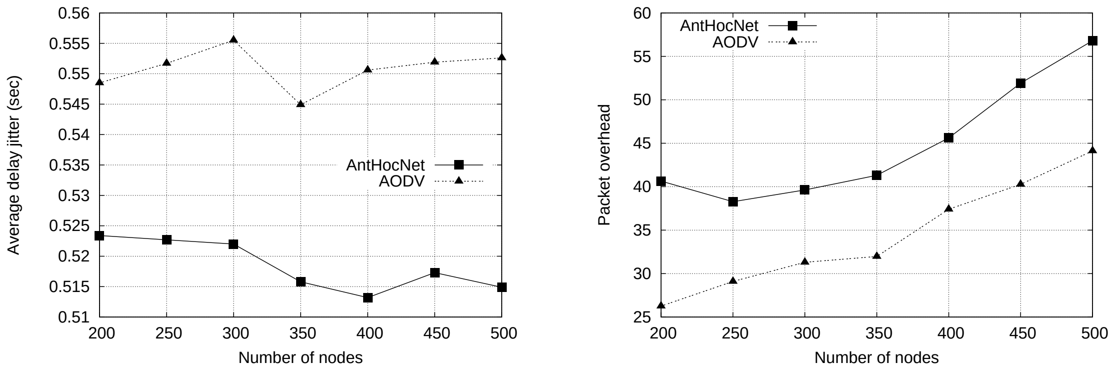
Figure 19: (a) Average delay jitter and (b) delivery ratio for scaling the fraction of fixed nodes while offering constant bidirectional TRAFFIC-GEN traffic between trucks and depot.

server model. In this set of experiments, we use communications of the TRAFFIC-GEN type (with an average of 2 packets/s and packet payload of 256 bytes). In particular, trucks communicate bidirectionally with the depot (e.g., to exchange up-to-date information about local traffic and/or to reschedule deliveries). This means that for each session sending data from truck node t to the depot there is also a session sending data from the depot to t. 10 bidirectional TRAFFIC-GEN sessions are established in this way, while the number of background sessions ranges from 0 to 25. Results in Figures 16 and 17 show a little degradation of performance with the increase of the background sessions. Performance degradation is more evident for AntHocNet. But on the other hand, AntHocNet performs clearly better than AODV also in this scenario. The larger delay than AODV's for more than 20 sessions showed in Figure 16(b) is largely compensated by the superior number of packets delivered, as reported in Figure 16(a).



(a) (b)

Figure 20: (a) Delivery ratio and (b) average end-to-end delay for scaling the number nodes keeping constant TRAFFIC-GEN traffic among the nodes.



(a) (b)

Figure 21: (a) Average delay jitter and (b) delivery ratio for scaling the number nodes keeping constant TRAFFIC-GEN traffic among the nodes.

3.9 Increasing the fraction of fixed nodes for bidirectional truck traffic

This scenario is similar to that of the previous section as well to that discussed in Subsection 3.4. We increase the fraction of fixed nodes over a total of 350 nodes maintaining the traffic load constant. Traffic is of type TRAFFIC-GEN (2 packets/s, 256 bytes payload). 10 bidirectional sessions are active between truck nodes and the depot as before. Background traffic is generated by 10 unidirectional sessions. Increasing the number of fixed nodes, the routing task is expected to become easier. However, as observed in previous scenarios, AntHocNet's rate of improvement when increasing the fraction of fixed nodes is much faster than that of AODV. The performance gap between AntHocNet and AODV is particularly striking in terms of delivery ratio.Also in terms of overhead AntHocNet shows an advantage over AODV. Notice that there is a remarkable difference between the values of the average end-to-end delay and those of the average jitter. This is due to the TRAFFIC-GEN's generation of the packet interarrival times according to a negative exponential distribution with 0.5 seconds average.

3.10 Scaling nodes for irregular traffic

In this scenario 10 bidirectional TRAFFIC-GEN sessions (2 packets/s, 256) are active between truck nodes. In this way trucks can communicate in a peer-to-peer fashion (e.g., to exchange information about local traffic and/or to reschedule deliveries in a fully decentralized way). The background traffic is generated by 10 unidirectional TRAFFIC-GEN sessions with the same characteristics of those of the truck nodes. As before, both algorithms are able to profit of the increase in connectivity determined by the increased node density, as shown in Figures 20 and 21. However the gap between AntHocNet's and AODV's performance is quite large and in favor of AntHocNet for the whole range of considered node densities. The anomaly with respect to all the other scenarios, consists in the fact that this time the superior performance of AntHocNet comes at the expenses of slightly higher overhead. The reasons behind this fact are still object of investigation.

4 Summary

We have discussed the characteristics of the demonstrator for routing in MANETs that we have implemented. The purpose of the demonstrator as stated in the project's technical annex consists in testing the effectiveness of the solutions developed for routing MANETs considering a city-like environment containing basic elements of real-world scenarios such as buildings/obstacles, street-constrained movements, and realistic traffic patterns. As discussed in Section 2, with the support of the QualNet simulator, we have set up a simulation environment with such characteristics taking the city of Lugano (Switzerland) as reference. We have run extensive simulation experiments in order to test the performance of AntHocNet, the biologically-inspired routing algorithm we developed, in such a realistic environment. The performance of AntHocNet has been assessed versus that of AODV and OLSR. However, OLSR resulted inadequate to deal with the challenges posed by the environment, so that we did not include its results in the reported plots.

To provide a sound validation of the algorithms, we have considered many different scenarios varying a wide number of aspects such as the number of nodes, the percentage of nodes which were fixed, the amount of background traffic, and the send rate of the traffic. We have also considered different types of traffic, such as unidirectional and bidirectional traffic, and client server versus peer-to-peer organization of the communication. Finally, we have also investigated the performance of the algorithms in the face of disruptive events. Over the wide range of experiments reported, AntHocNet shows better performance than AODV (and OLSR). Specifically, it delivery more data, with less delay and delay jitter. Moreover, in most tests, AntHocNet uses less overhead than AODV to provide this better service.

These results complete those obtained in obstacle-free open spaces and wired networks discussed in Deliverables D5, D6, D7, D3.2, and published in [7, 10, 8, 9, 6].

The ensemble of all these results show that our biologically inspired approach can outperform existing state-of-the-art MANET routing algorithms over a wide set of scenarios, and in particular in realistic environments. Encouraged by these results, IDSIA is currently starting work to implement the AntHocNet algorithm on a real MANET testbed.

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