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An Evaluation of Two Swarm Intelligence MANET Routing Algorithms in an Urban Environment

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***Abstract*—We study through simulation the performance of two swarm intelligence MANET routing algorithms in a realistic urban environment. The two algorithms, ANSI and AntHocNet, implement the swarm intelligence paradigm for routing in different ways: while ANSI applies a reactive approach in which ants are only sent out when no route is available between the source and destination of a communication session, AntHocNet integrates reactive and proactive mechanisms whereby the algorithm sends out ants at regular intervals during the entire duration of running sessions in order to continuously adapt and improve existing routes. The two swarm intelligence routing algorithms are compared to AODV, a state-of-the-art reactive algorithm, and OLSR, a state-of-the-art proactive algorithm. Our objective is to investigate the usefulness of the different approaches adopted by the algorithms when confronted with the peculiarities of urban environments and the requirements of real-world applications. At this aim we define a detailed and realistic simulation setup. We model node mobility by limiting node movements to the streets and open spaces of town, use a ray-tracing approach to model the propagation of radio waves, and investigate different kinds of interactive data traffic patterns, ranging from SMS messaging to VoIP communications.**

***Index Terms*—Mobile ad hoc networks, swarm intelligence, urban MANETs, network simulation, routing.**

I. INTRODUCTION

In recent years, the study of *mobile ad hoc networks (MANETs)* has attracted a lot of interest, mainly from the networking community, but also from the swarm intelligence (SI) community. A significant part of the research has focused on routing, which is particularly challenging in MANETs due to their dynamic nature, and requires algorithms that work in a fully distributed way, are able to self-organize, and show robust and adaptive behavior. As a result, a number of MANET routing protocols have been designed (see [1], [12], [24] for overviews). However, due to the costs and technological difficulty of setting up real and large MANET testbeds, most of this research is carried out in simulation. These simulations are usually based on simplified scenarios, where nodes move randomly in an open area, and rely on idealized models of physical phenomena such as radio propagation and interference. Recently, experiences with real world testbeds (e.g., [29]) have lead to an awareness that results from such simplified simulation scenarios do not reflect well the performance that can be expected in reality. There is therefore now a lot of interest in simulation studies that reflect more complex, realistic situations (see e.g. [15]), and that rely on more accurate models for radio propagation [19]. Urban scenarios are hereby of primary interest, since mesh ad hoc networks in densely populated areas can be both an alternative and a complement to GSM networks, and are already deployed in some cities, such as Philadelphia and Taipei.

In this paper, we investigate the distinctive properties of urban scenarios in terms of radio propagation, mobility patterns, and data patterns, and we study how they affect the effectiveness of different routing algorithms. We consider two well-known SI routing algorithms, *Ad hoc Networking with Swarm Intelligence (ANSI)* [23] and *AntHocNet* [9], [11]. These algorithms both take inspiration from a self-organizing behavior of ant colonies, the shortest paths discovery, and from the principles of the related framework of *ant colony optimization (ACO)* [6], [10]. However, they apply the ideas behind ACO in different ways. ANSI takes a *reactive* strategy: it only uses ants at the start of a communication session in order to set up a route between the communicating nodes, or when an existing route fails. This way it hopes to reduce the created overhead and improve efficiency. AntHocNet is a *hybrid* algorithm that combines reactive and proactive strategies: it applies ants both at the start of a new session in order to set up an initial route, and for the entire duration of the session in order to extend the first route to a set of multiple routes and to continuously improve existing routes. This approach aims at increased adaptivity and robustness. Another difference between the two algorithms is that, in addition to the use of the number of hops, ANSI evaluates the quality of a route based also on the congestion along the route, while AntHocNet makes use of the signal-to-noise ratio of the wireless connections along the route. Both algorithms are compared to *Ad-hoc On-demand Distance Vector routing (AODV)* [22] and *Optimized Link State Routing (OLSR)* [4], two important reference algorithms in the field of MANET routing. AODV adopts a purely reactive strategy, similar to ANSI: it sets up a route on-demand at the start of a communication session, and uses it till it breaks, after which a new route setup is initiated. OLSR takes a purely proactive approach: it tries to maintain up-to-date routes between all nodes at all times.

We evaluate the algorithms under different scenarios in an *urban environment* derived from the street organization of the Swiss town of Lugano. We model urban mobility by limiting the movements of the nodes to streets and open areas in the town, and adjusting their speed to the typical speed of people in a urban environment. The physical propagation of radio waves through the streets of the town is modeled using a *ray-tracing* approach, which accounts for interactions between radio waves and buildings, such as reflection and diffraction [14]. We also accounted for different possible

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usages of the network, modeling different kinds of interactive applications, including *short messaging service (SMS)* and *voice-over-IP (VoIP)* traffic. The aim of this work is to point out pro and cons of the considered approaches, which were originally developed to mainly address open space situations, when dealing with the challenges of realistic urban scenarios. A subset of the results presented here related to AntHocNet and AODV have appeared in an earlier short paper [8].

The rest of this paper is organized as follows. First, we explain the simulation setup: we show the urban scenario, explain how mobility and radio propagation were simulated, and describe the different types of traffic. Next, we provide a description of the different algorithms. Then, we provide a set of simulation results in which we study the usefulness of the different approaches for MANETs in an urban environment. Finally, we discuss related work and draw conclusions.

II. THE SIMULATION SETUP

For the simulations presented in this paper, we made use of the *QualNet* [25] network simulator, to which we have made adaptations in order to get a realistic simulation of urban conditions. QualNet provides faithful implementations of different network protocols. At the physical and datalink layer we used the IEEE 802.11b algorithm running in distributed coordination function mode and sending 2 Mbps at 2.4 GHz. At the network layer we used the routing algorithms described in Section III; source code of ANSI and AntHocNet for QualNet was obtained from the authors of the algorithms, while implementations of AODV and OLSR are included in QualNet. Finally, at the transport layer we used UDP, as it is known that TCP has difficulties to work well in MANETs [13]. In this section, we first describe the town scenario and the associated node mobility. Next, we explain how we modeled urban radio propagation. Then, we discuss the different data traffic patterns.

A. The urban scenario and node mobility

Lugano is a relatively small old town presenting an irregular street topology common to most European cities. We focused on an area of 1561×997 m^2, which covers most of downtown Lugano. The street structure is shown in Figure 1. The cityscape is composed of streets (the white lanes) and buildings (the gray polygons). In the image, while the bottom part shows a part of the lake area. Streets define the open spaces where nodes are free to move. Buildings are inaccessible to the nodes and play the role of obstacles that put constraints on node movements and shield and reflect signal propagation. Node movements were generated according to an adaptation of the popular *random waypoint mobility* model (RWP) [18]. Under this model, nodes iteratively choose a random destination and speed, move in a straight line to the chosen destination at the chosen speed, and then pause for a certain time. In our urban version of RWP, destinations are only chosen from among the open spaces in town, and nodes do not move along a straight line to their destination, but instead follow the shortest path through the streets of town. In all our simulations, we have chosen node speeds that correspond to realistic inner city movements, with a maximum speed of 3 m/s and a minimum speed of 1 m/s (avoiding in this way the sampling of arbitrarily low speeds, that results in a decrease over time of the total average speed, a well-know problem for RWP models [30]). The pause time of our RWP is always 30 s. Finally, in all experiments we keep 20% of the nodes static, to represent immobile network users in the town or mesh infrastructure devices.

Fig. 1. The Swiss town of Lugano used as urban model for our simulations.

B. Radio propagation

Wireless communication in an urban environment is strongly conditioned by the way radio waves interact with the objects they encounter. In particular, waves produced at street level are blocked by buildings, so that connectivity in urban wireless networks is restricted compared to open space scenarios. Many urban simulation studies for MANETs only account for this effect, using open space propagation models along the line of sight (LoS) and blocking any non-LoS communication (see e.g. [20]). Others use different heuristic approximations, reducing signal strength for each encountered building (e.g., [15]). In the current study, we use a more detailed approach, which incorporates also other propagation effects. The most important of these effects is *reflection off buildings*: as radio rays bounce off building walls, they can travel around corners into side streets. Also, reflection allows a signal to travel further along the LoS through a street than it would in open space, since multiple reflected rays are tunneled in the same direction. This means that crude approximation models that do not account for reflection are too restrictive. Another important effect is *diffraction*, which allows rays to bend around corners to a certain extent. This further improves connectivity to side streets. Other effects include scattering, which is the reflection off small objects and uneven surfaces, and signal variations over time due to changes in the environment, such as the passing of vehicles or people. Both of these last effects are hard to model correctly and greatly increase the computational complexity (see [27]), and were therefore not taken into account.

The modeling of radio propagation was done in preprocessing using *WinProp* [2], which is a commercial software package to calculate radio propagation in realistic indoor and outdoor environments using *ray-tracing*. We started from a two-dimensional map of the center of Lugano, and assumed each building on the map to be of a height sufficient to block radio communication going over it (a height of 5 meters already makes diffraction over the building impossible [27]). Then, we took sample positions every 5 meters along the streets of the town, resulting in 6070 different positions. We placed a transmitter sending with 10 mW at 2.4 GHz in each of these positions, and calculated using ray-tracing the resulting received signal strength in each of the other positions using WinProp. Subsequently, we adapted the radio propagation module of QualNet. The precalculated signal strength values are read into memory. During simulation, the signal strength between a transmitter T and a receiver R is approximated by the precalculated signal strength between a transmitter in the sample point closest to T and a receiver in the point closest to R. This results in a maximal error of 2.5 meters on each side.

C. Traffic patterns

We use traffic patterns that can reflect realistic applications of the network. We assume that the MANET will be used for interactive communication between users. We model this type of applications using *bidirectional point-to-point data sessions*. The data rate is varied, from 1 packet every 30 seconds, representing an interactive *SMS* conversation, up to 25 packets per second, which is sufficient to support good quality *VoIP* applications. The packet size if set to 160 bytes which is the payload used by the G.711 PCM voice codec and can also represent a typical size of an SMS. In order to represent silent periods in the interactive communication, only 40% of all scheduled packets are sent. This corresponds to the typical proportion in VoIP traffic [17].

III. THE ROUTING ALGORITHMS

In our performance study for urban environments we consider the ant-based MANET routing algorithms ANSI and AntHocNet, as well as two reference state-of-the-art algorithms developed in the network community, AODV and OLSR. For each of these algorithms we provide a short description here, including references to more detailed accounts for interested readers.

ANSI [23] takes an approach that is inspired by typical ACO routing algorithms. Nodes send *forward ants* out over the network with the aim of finding a path to an assigned destination and gathering information about it. A destination node receiving such a forward ant returns a *backward ant* to the source in order to update routing tables (also called *pheromone tables*) at the nodes along the followed path, indicating the quality of the route to support the routing of data packets. Different from ACO routing algorithms for wired networks (e.g., AntNet [7]) in which ants are sent out proactively, ANSI takes a *reactive* approach, which means that routing information is only gathered when it is strictly necessary. Forward ants are only used at the start of a new communication session, or when there is a failure in the route used by an ongoing session. This reduces the overhead created by the algorithm, which is an important aspect in resource limited MANETs, but also limits the possibilities to create multiple paths and perform stochastic data load spreading, which are typical features of ACO routing algorithms in wired networks. ANSI relies on the use of *beacon messages* (short messages sent out by all nodes to inform neighboring nodes of their presence) to create one-hop route alternatives, which can be used as backup routes when the route set up by the ants fails. To assess the quality of routes, ANSI uses a combined metric which contains the pheromone value (which indicates how often the links of the route were used by ants and hence gives an implicit evaluation of the goodness of these links), the route's hop count, and the congestion status (in terms of length of link queues) of the nodes along the route.

AntHocNet [9], [11] is a *hybrid* algorithm, which means that it combines both reactive and proactive elements. Its reactive elements are similar to ANSI: it executes a *reactive* route setup process based on the use of ants at the start of a new session, and when existing routes fail. In addition to this, and differently from reactive algorithms, AntHocNet also performs *proactive* actions in order to improve and extend available routes during the course of a communication session. The proactive route improvement is based on a combination of two mechanisms. The first of these is a *pheromone diffusion* process based on periodic beacon messages in which each node include pheromone information about the paths that it has available. Receiving nodes use this information to incrementally update their own pheromone tables (in a way that is similar to Bellman-Ford algorithms), and in turn send this updated pheromone information out in their own periodic messages, so that a field of diffused pheromone arises in the network. However, since the diffused pheromone information propagates slowly (in the low-frequency beacon messages) the resulting routing paths are potentially unreliable (e.g., they can contain loops). Therefore, this information is kept separate from the routing information that was obtained via the reactive route setup. The second mechanism involved in proactive route improvement is precisely aimed at checking the reliability of the diffused routing information. Each source periodically sends out *proactive forward ants* to discover new paths to the destination. These ants follow both regular and diffused pheromone. When a proactive ant reaches the destination, it confirms the reliability of the routing information it has followed, and can establish a new route going backward. The proactive route improvement allows to adapt available routing information to continual changes. This way, better paths can be used and *multiple paths* can be made available. The cost of the process is the creation of larger beacon messages and the periodic transmission of proactive ants. The evaluation of the quality of a route in AntHocNet is based on a metric that combines the hop count and the signal-to-noise ratio along the wireless links of the route (indicating the quality of the radio signal).

AODV [22] follows a *reactive* approach to routing. Nodes that start a data session with a destination that they have no information about, launch a route discovery process that, if successful, set up a single path to route session data. During the session, the only action taken by the routing algorithm is to periodically send out beacon messages, which allows nodes along the path to control whether each link is still alive. When a link failure is detected, intermediate nodes can try to locally rebuild the route or the source can start a new route discovery process.

Finally, *OLSR* [4] takes a *proactive* approach, which means that it tries to maintain correct routing information between all nodes in the network at all times. The algorithm implements *link state* routing, whereby nodes periodically send routing information about their local neighborhood to all other nodes. In order to reduce the control overhead, some optimizations are carried out, including the use of multi-point relays: each node identifies a subset of direct neighbors that is sufficient to forward data to all its two-hop neighbors, in order to be able to efficiently flood routing information over the network.

IV. RESULTS AND DISCUSSION

In this section, we first show some general properties of our urban setup. Then we discuss the results of a number of performance tests we have carried out. In particular, we investigate the performance of the different routing algorithms in scenarios with varying data traffic load and node density, and we make a detailed analysis of the performance in case the network needs to transport data for VoIP applications (the effect of speed was studied in previous work [8], where we observed that it has little impact on performance). All reported data points represent averages over 10 different runs of 500 simulated seconds each.

A. General network properties

We study how the *structural properties of the network* are affected by the fact that we work in an urban environment, in order to form a basis for the understanding of the routing performance results presented further on. The data shown here were obtained by running simulations with an increasing number of nodes in both the urban scenario and an open space scenario of the same dimensions. In Table I, we report results for the average number of neighbors, the connectivity (i.e., the fraction of node pairs between which a path exists), the average length of the shortest path between each pair of nodes, and the average link duration. The *average number of neighbors* is a lot lower in the urban scenario than in the open space scenario, and, while in both it grows linearly with the number of nodes, the increase is steeper for the open scenario. This means that in the urban case there is typically less interference among nodes, but also less good connectivity. The latter is confirmed when we investigate *connectivity*: while the open space scenario is always fully connected, the urban scenario has limited connectivity when there are few nodes in the network. It is interesting to note that the connectivity in urban conditions saturates to a value that is lower than 100%. So even with 400 nodes, where the number of neighbors is higher than in the open scenario with 100 nodes, some nodes manage to stay out of reach because of the irregular structure of the town. The *average path length* is also affected by the environment: paths are about double as long in the urban scenario. The node density has some influence on path lengths in the urban scenario, but less in the open space, since there even 100 nodes are enough to provide almost straight line paths. Finally, we also measured the *average link duration* (not shown in the table). Independent of the node density, we recorded an average duration of about 65 s in open space, and 43 s in the urban scenario. When increasing the maximum speed to 10 m/s, we got 56 sec in open space, and 28 s in the urban scenario. This means that the change rate of the network is higher in the urban environment.

B. Traffic load

We consider an urban scenario with 300 nodes and 10 randomly chosen parallel bi-directional data sessions. We vary their send rate from 0.033 packets/s (1 packet every 30 seconds, corresponding to interactive SMS exchanges) up to 25 packets/s (corresponding to good quality VoIP communications). Figure 2 shows the results for delivery ratio and average end-to-end delay. At the lowest data rate, AntHocNet, AODV, and ANSI all have a relatively low delivery ratio and high delays. AntHocNet shows the best tradeoff between delivery and delay performance (82% and 0.35 s), while AODV can deliver less packets (70%) with a delay almost double that of AntHocNet. ANSI shows a performance close to AODV for delivery but with a very bad delay. OLSR is able to deliver only a very small fraction of the data packets (32%), but for this small fraction has a quite low delay (about 0.05 s). The overall mediocre performance of all the algorithms is because when data packets are sent at a very low rate, routing efforts are disproportional to the low number of packets to be delivered. This is particularly pronounced for the algorithms that rely on a route setup (ANSI, AntHocNet and AODV), as previously constructed routes can hardly ever be reused, and a new route setup is needed almost every time. For AntHocNet, this effect is less strong, since its proactive route maintenance extends the lifetime of existing paths. However, this relatively better performance comes at the expense of a high overhead. This measure (which is calculated as the number of control packets forwarded per received data packet) is shown in Figure 3. ANSI and AODV create less overhead than AntHocNet at the lowest data rates. OLSR scores the worst for this measure, as its purely proactive approach maintaining up-to-date routes between all nodes is inefficient in the given scenario.

As data rates increase, subsequent packets can profit more from previous route setups, and the performance of all algorithms improves, up to the case of 5 packets/s. From 5 packets/s to 10 packets/s all the algorithms show an almost constant response, while a new marked decrease in performance happens at 25 packets/s, which corresponds to VoIP loads. This is due to the fact that the high load of data packets starts to interfere heavily with the control ones. In this case, AntHocNet has a higher delay than AODV, probably due to the fact that it makes use of larger control packets. It is clear that all the algorithms are inadequate to effectively support VoIP applications in the considered urban scenario (see Section IV-D). Figure 3 shows that increasing the data rate the overhead of all algorithms rapidly tends to be the

TABLE I
GRAPH PROPERTIES OF MANETS WITH INCREASING NUMBER OF NODES IN THE URBAN VERSUS OPEN SPACE ENVIRONMENT

	Average # of neighbors		Fraction of connected pairs		Average path length	
# Nodes	*Open Space*	*Urban*	*Open Space*	*Urban*	*Open Space*	*Urban*
100	20	5.6	1	0.77	2.65	5.1
150	30	7.9	1	0.87	2.60	5.0
200	39	11.0	1	0.97	2.55	4.7
250	50	13.5	1	0.98	2.50	4.5
300	61	17.5	1	0.98	2.45	4.3
350	68	19.5	1	0.98	2.50	4.3
400	77	22.5	1	0.99	2.45	4.2

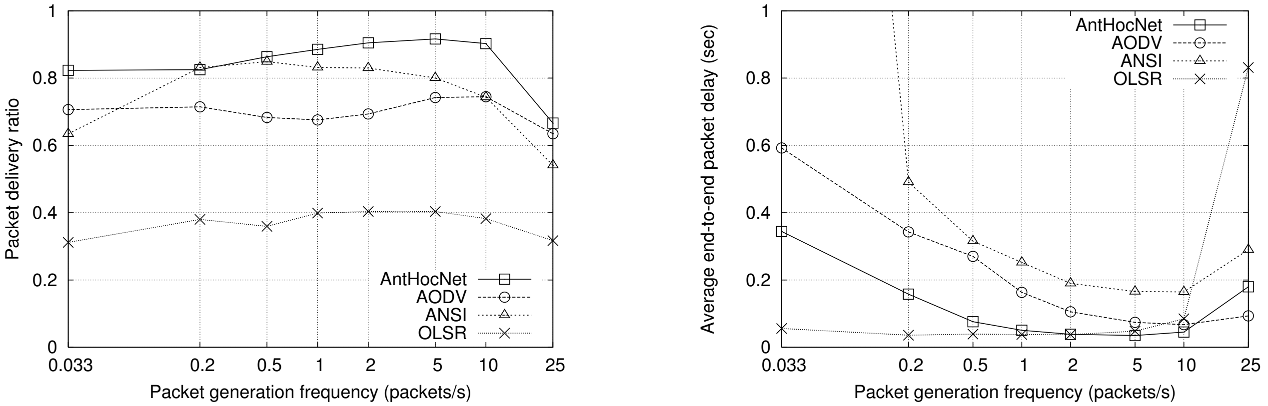

Fig. 2. Delivery ratio and average end-to-end delay for AntHocNet, ANSI, AODV, and OLSR in test scenarios with increasing data send rates.

same, with the exception of OLSR, that always generates a much larger overhead.

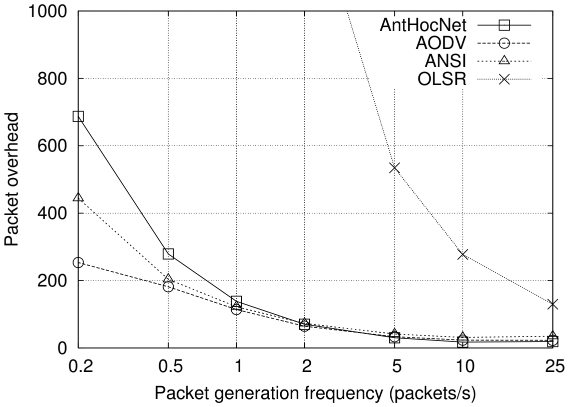

Fig. 3. Control overhead for increasing data send rate.

The overall bad performance of OLSR has been confirmed also in the other tests we have carried out. Therefore, OLSR's results are not included in the graphs shown in the following, in order to improve their readability. OLSR's performance shows the limits of using in MANETs a purely proactive strategy based on a link-state approach.

C. Node density

We study the effect of node density on the performance of the different algorithms: we vary the number of nodes from 100 up to 400 with a step size of 50. Higher densities lead to better connectivity, but also to more radio interference, which are both important factors in the deployment of MANETs. We investigate three types of data load: low (0.033 packets/s, corresponding to interactive SMS exchanges), medium (2 packets/s) and high (25 packets/s, corresponding to VoIP data rates). Figure 4 shows distinct results for delivery ratio and end-to-end delay for each one of these data rate. The general pattern is similar for each of the data rates: delivery increases with density, while delay stays more or less constant. The graphs for delivery follow the same trend with respect to node density as the connectivity (see Table I): first increasing steeply and then stabilizing. This indicates the importance of good connectivity for the use of MANETs in urban scenarios. In terms of delivery, the hybrid AntHocNet algorithm always outperforms the reactive AODV and ANSI algorithms, except for the highest data rate in the densest scenario, where it is still better than ANSI but not than AODV. This confirms that AntHocNet's proactive mechanism is useful, but has its limits when interference gets too high. ANSI outperforms AODV for medium data rates, has comparable performance for low data rates and worse performance for the highest rates. This is despite the fact that ANSI takes the congestion status of the nodes explicitly into account when selecting paths. It is a strong indication that also a SI approach without proactive mechanisms can suffer in cases of high interference. The results in terms of delay confirm these tendencies. AntHocNet again outperforms AODV at all densities for the low and medium data rate, but suffers at the highest rate. ANSI always has the worst performance in terms of delay. In terms of overhead (not shown here) the three algorithms have an

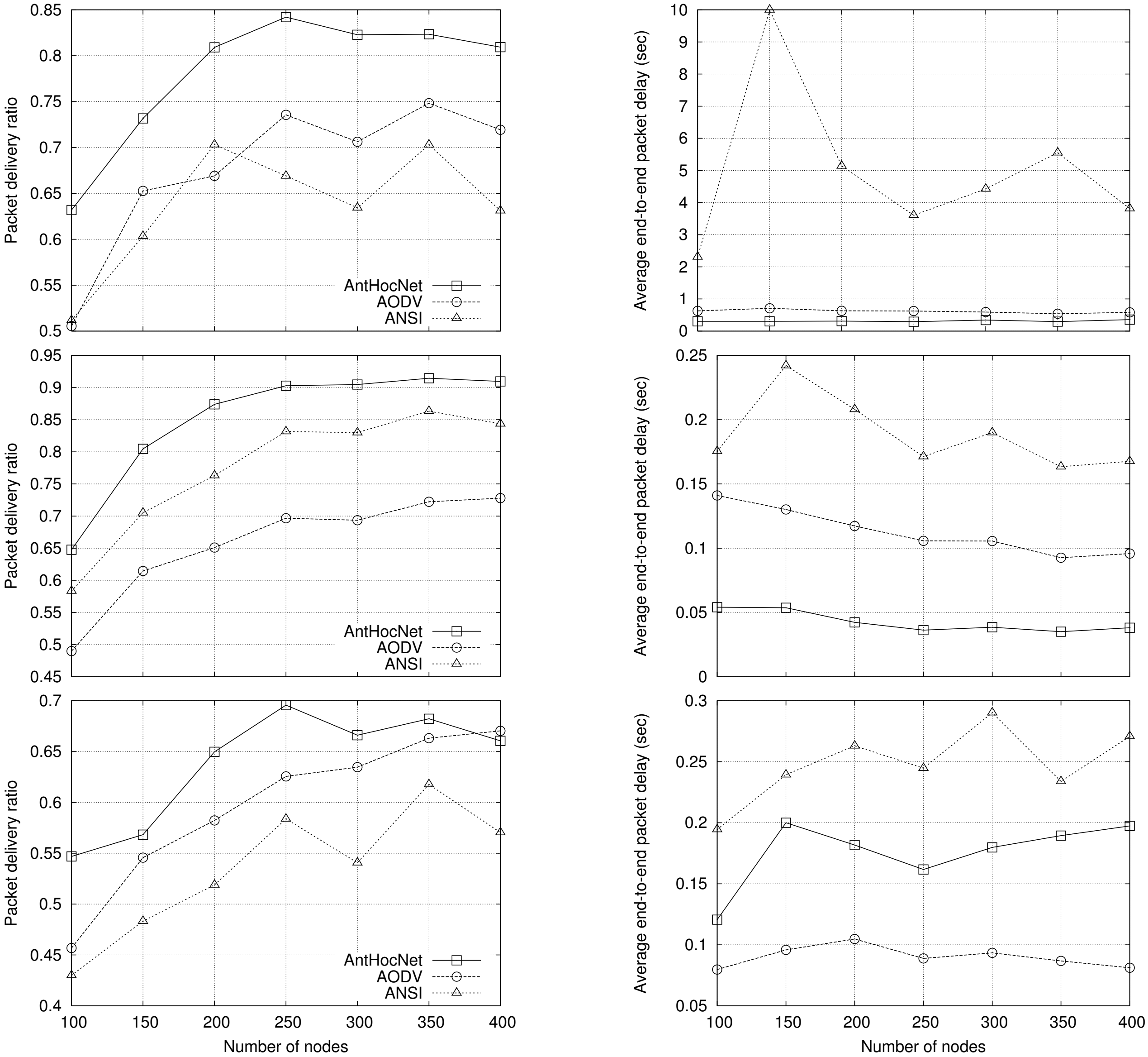

Fig. 4. Packet delivery ratio (left) and average end-to-end delay (right) for scenarios with increasing node density. We report results for three different data traffic rates: 1 packet/30s (top graphs), 2 packets/s (middle) and 25 packets/s (bottom).

equivalent behavior, both for this set of experiments and for those of the next subsection.

D. *Supporting VoIP traffic*

The previous results show that all studied routing algorithms have problems with the highest data rate (25 packets/s), which corresponds to VoIP traffic. Here, we investigate this issue in more detail, in order to find out whether it is possible at all in the given circumstances to support VoIP applications. In Figure 5, we show the delivery ratio and average end-to-end delay for tests with 1 up to 10 sessions of 25 packets/s. To support good quality VoIP, a delivery ratio of 90% is needed, and end-to-end delay should not exceed 0.150 s (see [21]). Another important measure is the *delay jitter*, which we report in Figure 6. This is the variation in the time interval between the arrivals of subsequent packets. Jitter is normally considered in conjunction with delay, as applications deal with jitter by keeping packets in buffer for a short time before delivering them; jitter can therefore be added to delay to count towards the delay limit [21]. Using this approach, we can see that both in terms of delivery ratio and delay, the standards needed to deliver good quality VoIP conversations are not met by any of the algorithms.

The numbers presented here are averages over all the started communication sessions though. In order to get a more precise view, we investigate for each scenario how many of the individual sessions reach the cited requirements. In Figure 7, we show this number as a fraction of the total number of started sessions. We can see that using AntHocNet, at least a few of the sessions can obtain VoIP quality. When only one session is started, it gets the required quality in 90% of the cases. Then, as more sessions are started, the fraction of them that receive VoIP quality decreases, down to less than 10% when 10 sessions run simultaneously. This is because

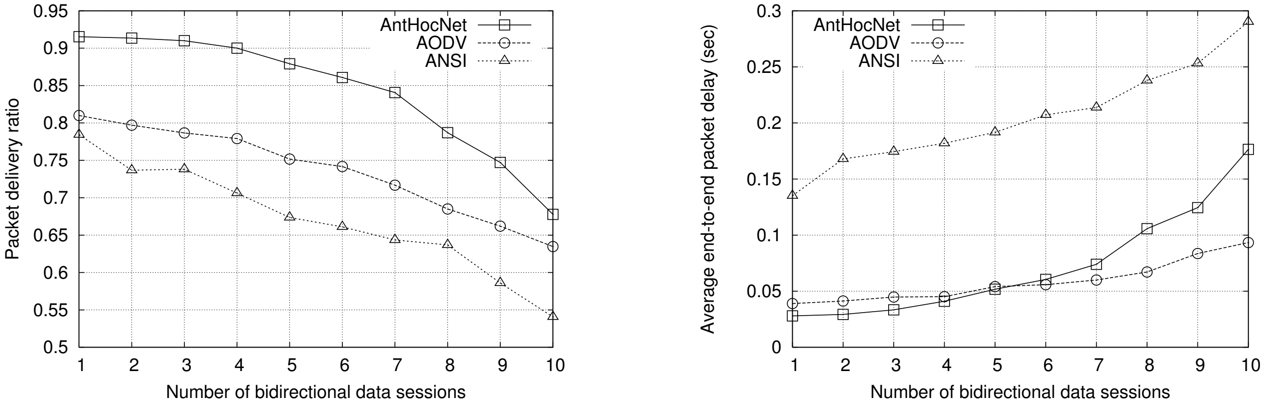

Fig. 5. Delivery ratio and average end-to-end delay in scenarios of 1 up to 10 sessions of 25 packets/s, corresponding to VoIP data rates.

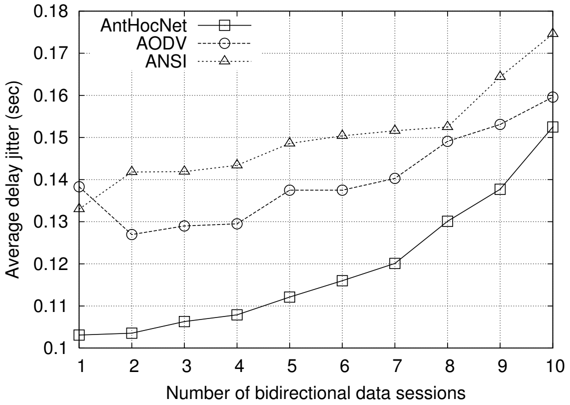

Fig. 6. Average delay jitter for 1 up to 10 sessions of 25 packets/s

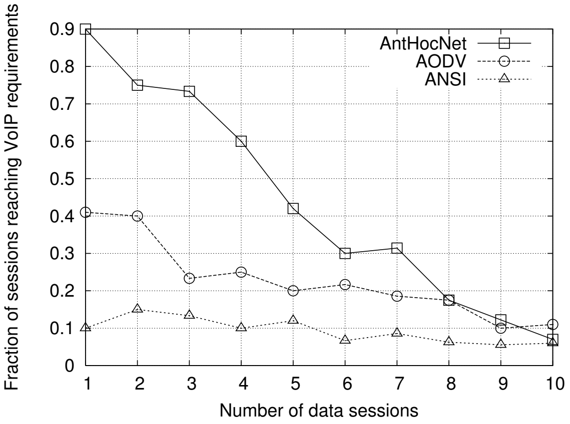

Fig. 7. Sessions reaching VoIP quality requirements in terms of delivery ratio, delay, and jitter as a fraction of the total number of started sessions.

too many sessions are interfering with each other. For AODV and especially for ANSI, the number of sessions receiving the required service quality always remains low.

The results show that using AntHocNet it is in principle possible to support VoIP in the given urban scenario. However, not all sessions can get the required levels of service, and when too many sessions are started, all of them suffer. This indicates that it might be useful to refuse some sessions to start in order to be able to deliver a good service to others. This points to the importance of the use of admission control or some other system for Quality-of-Service support in urban MANETs.

V. RELATED WORK

There exists a lot of work comparing different MANET algorithms (e.g., see [3], [5]), but almost all of it was carried out in open space scenarios with random mobility and idealized signal propagation models. Only recently has there been an increasing interest in using more realistic setups. In [16], the authors propose a scenario with randomly placed building blocks and a simple heuristic propagation model in which only LoS communication is allowed, and evaluate how this influences the performance of AODV compared to open space. Similarly, in [20] the behavior of the DSR routing protocol is investigated in a grid shaped town scenario with only LoS radio propagation. In [15], a similar grid town pattern is used with a different heuristic radio propagation model (here, radio signals are weakened with a fixed amount for every corner they take) to investigate the feasibility of a commercial MANET application.

The use of town maps and realistic ray propagation has been proposed in a few recent publications. In [28], the performance of AODV is evaluated for different traffic types in a London area, pointing out the need for high node density (a result which we also found in Section IV-C). The authors of [26] make a detailed simulation of the Munich city center, and evaluate how the performance of AODV in this scenario compares to that in open space simulations. Our work is to our knowledge the first that compares different routing strategies, including different SI routing algorithms applying diverse strategies, in such a detailed simulation of an urban environment.

VI. CONCLUSIONS

We have reported the results of extensive simulation studies investigating the performance of different routing algorithms in a realistic urban environment. Specifically, we have evaluated the performance of two SI routing algorithms, ANSI and AntHocNet, and compared them to two reference algorithms from the networking community, AODV and OLSR. The four algorithms differ considerably in their design approach.

ANSI applies ideas from SI in a reactive approach, whereby control overhead is limited by focusing only on the routing information that is strictly necessary. AntHocNet uses SI in a hybrid algorithm, combining a reactive approach to route setup with a proactive mechanism to improve and extend existing routing information. AODV is a purely reactive algorithm, and OLSR is a purely proactive algorithm. The aim of the study was to investigate the advantages of the different approaches in relation to the characteristics of urban environments and to concrete application models for real-world MANETS. As a setting for our urban environment, we chose the Swiss town of Lugano. We created urban node mobility by limiting node movements to streets and open spaces, used ray tracing techniques to model the propagation of radio waves, and applied different types of traffic loads to reflect different kinds of utilization of the network, including SMS traffic and VoIP communication. To our knowledge, the level of detail and concreteness of our study has not been achieved in previous MANET simulation studies evaluating different SI and other routing algorithms.

We first investigated general properties of the network in the urban environment compared to equivalent settings in an open space scenario. We found that in the urban scenario, the local density experienced by each node is lower and grows more slowly with an increasing number of nodes. Moreover, connectivity in the network is worse, average path lengths longer, and link durations shorter. Next, we compared the routing algorithms in a number of tests where we varied data traffic load and node density. We found that AntHocNet profits from the lower local density in urban settings to let its proactive mechanism work efficiently. However, at high rates, it suffers from interference. Nevertheless, also the reactive algorithms ANSI and AODV experience equivalent problems in these settings. OLSR always gives the worst performance. At very low rates, all algorithms have difficulties since their routing efforts are disproportional to the amount of data to be delivered. The same results were confirmed in tests with node densities, where we also found that high node density is important for good performance of all algorithms. Finally, we studied in detail the bad performance of the different algorithms for the highest data loads, corresponding to VoIP applications. We investigated how many sessions could receive service levels that are sufficient to support good quality VoIP conversations, and found that AntHocNet performed much better than the other algorithms in this respect. We found that VoIP traffic is possible using AntHocNet if the total number of sessions can be limited.

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