Multi-path OLSR Performance Analysis in a Large Testbed Environment

Andrzej Szwabe[1], Pawel Misiorek[1], Maciej Urbanski[1],
Felix Juraschek[2], and Mesut Güneş[2]

[1] Institute of Control and Information Engineering
Poznan University of Technology
M. Sklodowskiej-Curie 5, 60-965 Poznan, Poland
`{Andrzej.Szwabe, Pawel.Misiorek, Maciej.Urbanski}@put.poznan.pl`
[2] Institute of Computer Science
Distributed Embedded Systems
Freie Universität Berlin, Germany
`{jurasch, guenes}@inf.fu-berlin.de`

Abstract. Optimized Link State Routing (OLSR) protocol is a leading proactive routing protocol for Mobile Ad-hoc Networks (MANETs). Since the OLSR protocol in its standard version does not support multi-path packet forwarding, we have developed and implemented its multi-path extension. As a result of a slightly modified path computation algorithm and the application of backpressure Max-Weight Scheduling (MWS) policy, the MANETs can utilize the extended functionality based on OLSR. The experiment results presented in this paper compare the performance of the standard and extended OLSR versions in a large congested MANET (i.e., in large-scale DES-Testbed located at Freie Universitat Berlin).

Keywords: Wireless multi-hop networks, multi-path routing, OLSR, backpressure policy, large-scale experimentation

1 Introduction

As a result of a multi-path routing application, the unpredictable nature of a multi-hop wireless network can be compensated for. Firstly, the availability of multiple routes enables a more reliable transmission in the frequently changing wireless network environment e.g., in the case of a sudden relaying node breakdown [1]. Secondly, the multi-path routing provides load balancing, which may be especially valuable in MANETs due to limited resources of these networks. Moreover, such an approach can be regarded as a method leading to network capacity maximization in the case of multiple routes for which a parallel transmission without interferences is possible [2].

Each protocol architecture realizing distributed algorithms derived from the Network Utility Maximization (NUM) framework [3] implies the application of a backpressure-oriented multi-path routing protocol. At the same time, the optimization of the traditional backpressure algorithm has been recently intensively investigated within the area of research on wireless multi-hop networks [2,4,5]. As part of research in this area, we have proposed a multi-path extension of the OLSR protocol [6] – the leading proactive routing protocol for multi-hop wireless networks [1,7]. This solution can be seen as a preliminary routing protocol enabling multi-path packet forwarding. The pure unconstrained backpressure routing (allowing to use all the possible paths) usually leads to significant delays as it permits to forward packets away from their destination. The proposed multi-path extension of the OLSR protocol can be regarded as an optimized backpressure-like routing solution, for which routes are limited to a collection of paths, rather than including all possible paths as is the case in the traditional backpressure algorithm [7].

The proposed extension to OLSR preserves the proactive nature of the protocol. The solution does not impose any modifications on the standard topology sensing and neighborhood dissemination phases of the protocol execution - it is based on the novel route calculation algorithm aimed at determining multiple routes to each destination [7].

We have started the standardization process regarding the proposed solutions. As a result, two IETF Internet Drafts were published [8,9], concerning multi-path packet forwarding extension and backpressure-based traffic engineering extension for OLSRv2, respectively.

This paper contributes the experimental evaluation results of the proposed extension based on tests performed on DES-Testbed [10], which is a large-scale wireless testbed. In particular, we present the results on performance comparison of the standard single-path OLSR and the proposed multi-path extension.

The rest of the paper is structured as follows. After presenting the description of DES-Testbed (Section 2), we present the assumptions of the proposed backpressure-oriented multi-path extension of OLSR (Section 3). In the next chapter (Section 4), the experiment setup is presented together with the evaluation of the results. The paper rounds off with the discussion on related works (Section 5) and conclusions (Section 6).

2 DES-Testbed

The DES-Testbed is a multi-radio WMN located on the campus of the Freie Universität Berlin. Currently it consists of more than 100 indoor and outdoor nodes as shown in Figure **??**. The hybrid DES-Nodes consist of a *mesh router* and a *sensor node* in the same enclosure, thus forming an overlapping WMN and WSN. The DES-Nodes are deployed in an irregular topology across several buildings on the campus. A snapshot of the network topology is depicted in Figure 1 with the DES-Vis 3D-visualization tool. Besides the DES-Testbed, several in-parallel IEEE 802.11 networks exist to provide network access to students and staff members on the campus. These networks are not under our control and thus contribute to external interference. We treat this as a condition that is also likely to be expected in a real world scenario. For a detailed description of the architecture of the DES-Testbed, we refer the reader to the technical reports [11,12].

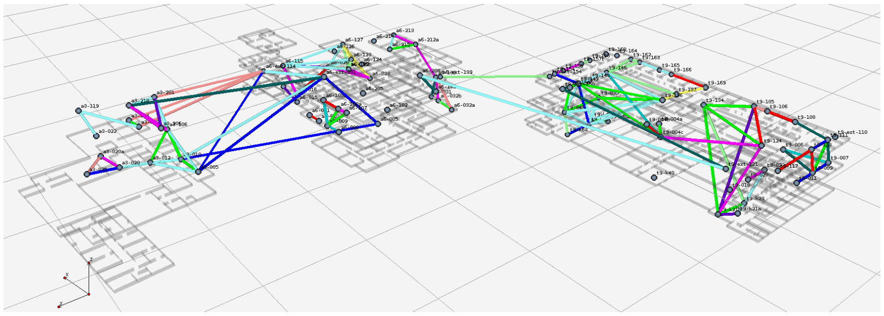


Fig. 1. Snapshot of the DES-Testbed topology. The DES-Nodes are distributed over three buildings on the campus of the Freie Universität Berlin. Outdoor DES-Nodes are deployed to improve the connectivity between the adjacent buildings. Different colors are used for the different channels of the displayed links.

Each DES-Node in the DES-Testbed is equipped with three IEEE 802.11 wireless network interfaces (WNICs). One of the interfaces is a Ralink RT2501 USB stick, and the other two are Mini PCI cards with an Atheros AR5413 chipset. The cards use the *rt73usb* and *ath5k* drivers, which are part of the Linux kernel. For the experiments presented in this chapter, we used the Linux kernel 2.6.34. While the Ralink WNICs are IEEE 802.11b/g devices using the $2.4GHz$ band, the Atheros WNICs additionally support the IEEE 802.11a standard on $5GHz$.

3 Multi-Path OLSR

The multi-path routing approach experimentally evaluated in this paper is based on solutions presented in [1, 7]. The idea of novel route calculation technique is based on a multiple use of the shortest path algorithm for a specially modified topology graph. Instead of running the algorithm for the case of the computing node as the origin of any route, all the neighbors of the computing node, except the one being currently examined as a possible next hop, are removed from the topology graph along with their adjacent edges. Then the Dijkstra's shortest path algorithm is run for the chosen neighboring node as a route origin [7]. The procedure is repeated for each neighbor of the computing node. As a result, the computing node obtains several routing tables (one table per neighbor), which can be easily merged into its final routing table with multiple entries for every possible destination. The implemented version of modified protocol provides the routing entries containing information on the destination node address, the next-hop node address, and the number of hops on the shortest route through a given next hop to a given destination [1].

The modified route calculation algorithm can be described as a diagram as shown in Figure 2 [7]. The example of the algorithm execution is illustrated in Figure 3.

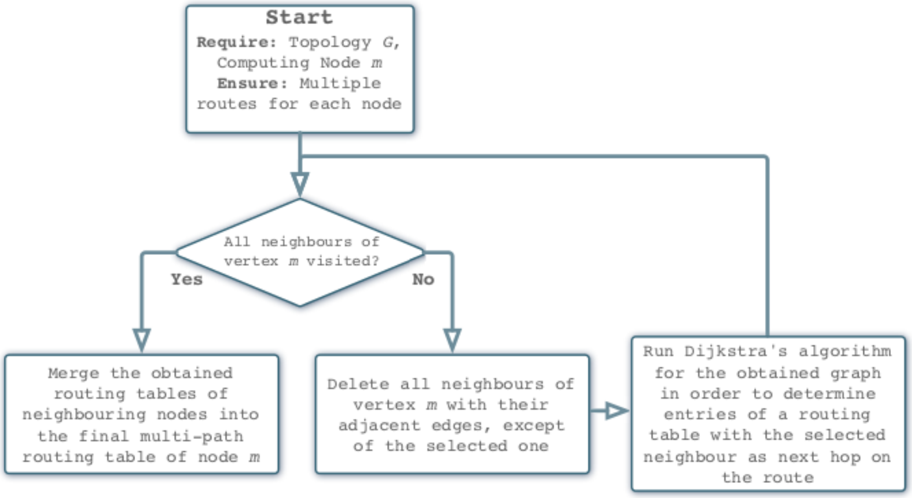


Fig. 2. Algorithm for calculation of multiple routes

The OLSR protocol extension has been designed to cooperate with backpressure-like scheduling. As a result of modified protocol operation, the transmitting node is able to provide the backpressure-based scheduler with the possible choices of the next hop for every destination node. The solution is a variation of the unconstrained backpressure approach (the flooding). It is aimed at the restriction of all possible next-hop choices to a collection of reasonable choices for a given destination - all the neighbors of the computing node, for which the destination node is unreachable without further contribution from one of the remaining neighbors of the computing node, are excluded from the set of proposed next hops.

Given the fact that a routing decision is made on each hop on the path, the proposed solution is not fully loop-resistant. Moreover, the topology information can be delayed or may not be synchronized. However, in such cases the backpressure rule can help avoid routing decisions resulting in loops or backward traffic, since the backlog levels never increase on a path from the source to the destination for a given flow [7].

Flexibility is one of the additional advantages of the proposed solution. Firstly, the routing table can be easily recalculated and some enhancements for our method can be introduced. Such enhancements can be based, e.g., on eliminating entries whose shortest routes are too long, which is particularly valuable when the delay factor is essential. Secondly, the number of hops can be replaced by some other metric (e.g., ETX based), which enables the application of various policies for routes exclusion. As stated in [7], the important advantage of the proposed multi-path extension of OLSR is the fact that all the possible next hops

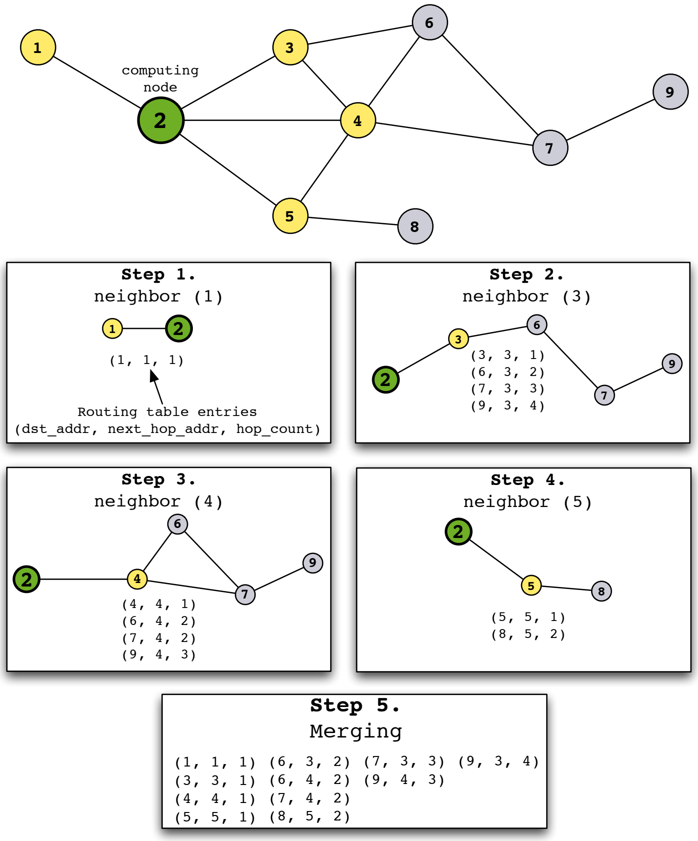


Fig. 3. An example of the multiple routes calculation (for node 2)

for each destination are calculated jointly at a stroke (similarly as in the case of the single-path Dijkstra's algorithm used in the standard version of OLSR [6]).

4 Experiments

4.1 Experiment Setup

In this section, the experimental evaluation of the proposed extension is presented, which is based on the results of the tests conducted on *Distributed Embedded Systems Testbed* (DES-Testbed). The evaluation consists in a comparison of the proposed multi-path extension (MP OLSR) to the standard single-path OLSR (SP OLSR).

The OLSRd agent [13] fully compliant with RFC 3626 [6] was used for each experiment. For the case of the custom multi-path extension, functionalities of this daemon were extended by a plug-in which adopts multi-path algorithm and additional signaling for announcement of queue levels. The setting of main OLSR parameters [6] which were used during the experiment are listed in Table 1. The additional signaling was realized by custom OLSR messages called QRMs (Queue Reporting Messages) and URMs (Urgency Reporting Messages). The details of the additional signaling functionality are beyond the scope of this paper and can be found in [9]. The settings of signaling frequency parameters (QR_INTERVAL and UR_INTERVAL) are presented in Table 2. The queue level signaling protocol was implemented according to [9] with the exception of packetbb formatting. The implementation operated in the application layer without the need to modify any of the underlying layers.

The backpressure-based scheduling and forwarding functionality was implemented as a loadable Linux kernel module [14]. The kernel module was integrated with standard packet processing chains. The module captured packets at the output of the post-routing chain and then packets were queued and served according to the backpressure rule. Additionally, the module contained a subsystem for communication with *olsrd* agent based on *netlink*, aimed at exchanging information on queue levels. Both the multi-path extension of the OLSRd agent and the Linux kernel module responsible for packet forwarding and scheduling were remotely installed on DES-testbed before the execution of the experiments.

4.2 Experiment Scenario

The experimentation was focused on a realistic case of a network state in which aggregated traffic volume exceeds the network capacity.

We have used 25 nodes from the DES-Testbed. During experimentation, each node used one 802.11a compliant wireless interface in an ad-hoc mode. The longest path in the acquired topology contained 5 hops. The *minstrel* rate-control was employed to adjust bit-rate dynamically according to the varying quality of the links. The illustration of the network topology captured just before the start of the first execution of the experiment (i.e., the initial topology measured for

Table 1. Relevant OLSR parameters

HELLO_INTERVAL	3s
TC_INTERVAL	5s
NEIGHB_HOLD_TIME	9s
TOP_HOLD_TIME	15s
HYST_THRESHOLD_HIGH	0.85
HYST_THRESHOLD_LOW	0.2

Table 2. Additional signaling parameters

QR_INTERVAL	$0.2s$
UR_INTERVAL	$0.06s$

the idle network) is presented in Figure 4. The metric based on the number of hops [6] was used for the path calculation with local link quality awareness.

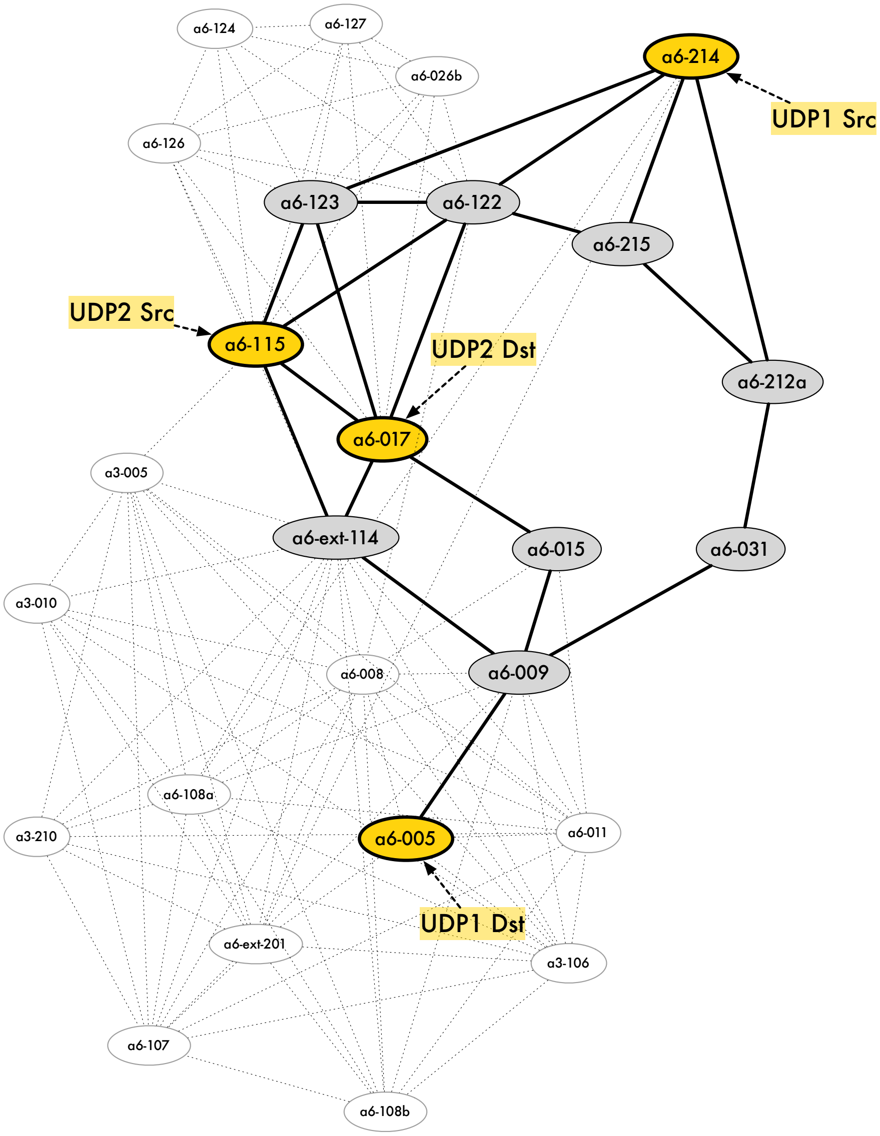


Fig. 4. The topology used in the presented experiments

In order to ensure reliability of the results obtained in an environment in which external interferences are present, the experiment was conducted multiple times (13 executions). Before the start of each experiment execution, OLSRd was run on each participating node for at least 45 seconds, in order to establish the initial topology. Each experiment execution consisted of two phases. In the first one the test on standard single-path OLSR scenario was conducted whereas in the second one the backpressure-based extension of OLSR was tested. In order to avoid route flapping, we slightly modified parameters of the OLSR RFC hysteresis strategy for link establishment, i.e., HYST_THRESHOLD_HIGH and HYST_THRESHOLD_LOW [6]. These parameters determine which links are considered valid. The value of HYST_THRESHOLD_LOW was decreased to 0.2, whereas the value of HYST_THRESHOLD_HIGH was increased to 0.85. These changes improved route stability during the experiment execution. Additionally, the RTS/CTS mechanism was enabled during the experimentation, and was constantly triggered because of the UDP packet size (1470 bytes of payload).

In each experiment execution, two UDP CBR flows (*UDP1* and *UDP2*) were generated using *iperf*. The rate of each flow was set to 4Mbps in order to ensure network saturation, which was necessary to demonstrate the operation of the backpressure policy. *UDP1* was transmitted from node *a6-214* to node *a6-005*, whereas *UDP2* was transmitted between nodes *a6-115* and *a6-017*. *UDP1* required the multi-hop path, whereas flow *UDP2* used a single-hop connection. In each phase of the experiment, *UDP2* was initiated 40 seconds after the start of *UDP1*. *UDP2* was stopped after 80 seconds of its functioning. The goal of the experiments was to present that in the case of simultaneous service of both flows (*UDP1* and *UDP2*), the multi-hop *UDP1* flow gains higher end-to-end throughput when it is served in the multi-path mode.

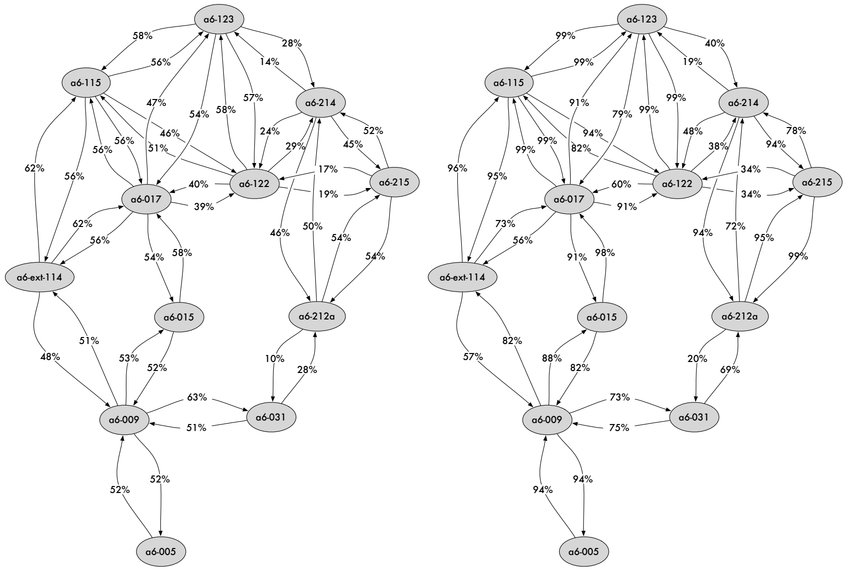
4.3 Evaluation of Results

Table 3 presents the comparison of the aggregated results obtained for the tested scenario.

Table 3. End-to-end throughput measured during the transmission of the `UDP2`.

Scenario	**Single-path**		**Multi-path**		**Relative multi-path throughput gain**	
	UDP1	UDP2	UDP1	UDP2	UDP1	UDP2
Average	0.296 Mbps	4.075 Mbps	0.366 Mbps	3.788 Mbps	+23.6%	−0.07%
Variance	0.068 Mbps	0.053 Mbps	0.036 Mbps	0.019 Mbps		

The experiment illustrates the case of network operation outside its capacity (the start of the first flow - multi-hop *UDP1* - caused the network saturation). We observed that the UDP transmissions influenced the network topology by eliminating the links of lower quality. In consequence, during the experiment execution the effective network topology (see Figure 5) was much sparser than the one observed before the start of the experiment and illustrated in Figure 4. The results of the experiment (see Table 3) showed that during the parallel transmission of both UDP flows, the throughput of multi-hop flow *UDP1* was



(a) Single-path (b) Multi-path

Fig. 5. Percentage of successfully transmitted HELLO messages during the experiments.

higher for the multi-path case. For *UDP2* flow, the overall throughput decreased in comparison to single-path. This behaviour is caused by Urgency mechanism [7], which facilitates proportionally-fair medium allocation in the wireless neighbourhood. This decrease enabled a proportionally higher gain in *UDP1* throughput. We also observed that in the case of the multi-path routing, the network topology was more stable due to the backpressure mechanism application. More precisely, the backpressure-based packet forwarder suspended the packet forwarding to the link layer each time when it was informed (basing on QRMs and URMs) that the packets ready to send by some other node had higher backpressure-based priorities. At the same time, no node ever stopped the transmission of OLSR control messages, which resulted in a more stable network topology (see Figure 5). We observed that the variance of end-to-end throughput of both *UDP1* and *UDP2* was smaller for the multi-path forwarding scenario.

In order to show the operation of the backpressure mechanism, we provided a more detailed description of the sample experiment iteration. Figures 6 and 7 present the end-to-end throughput reported by *iperf* server running on destination nodes. In the case of the multi-path mode, the multi-hop transmission of *UDP1* is more stable than in the case of the single-path mode. As far as single-path OLSR and FIFO scheduling is concerned, the effective transmission of multi-hop *UDP1* was not possible due to the channel occupation by *UDP2*. As soon as *UDP2* transmission finished, a burst of *UDP1* packets could be seen. On the other hand, the multi-path approach allowed better distribution of packets among

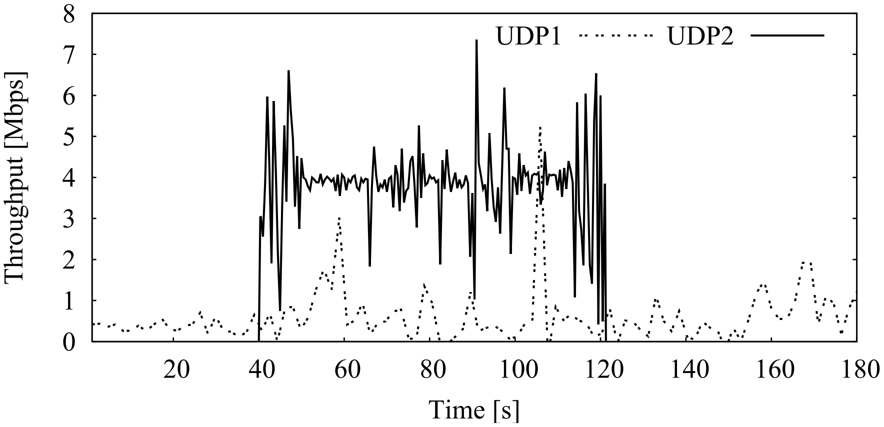


Fig. 6. Reported end-to-end throughput during the multi-path phase of a sample experiment execution.

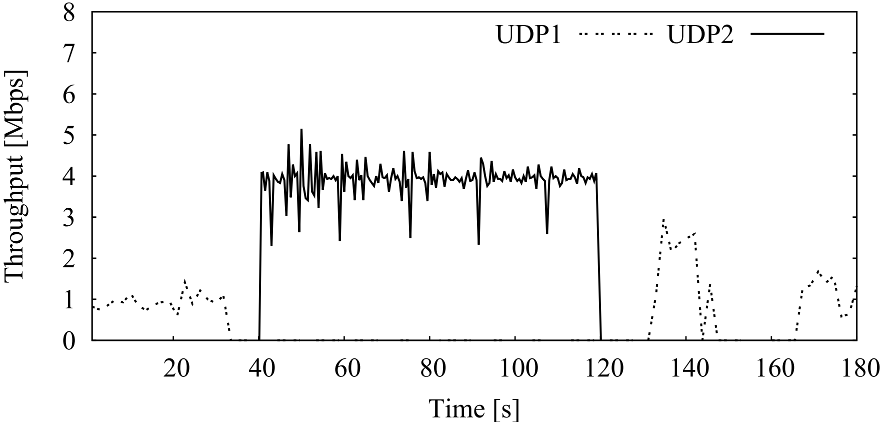
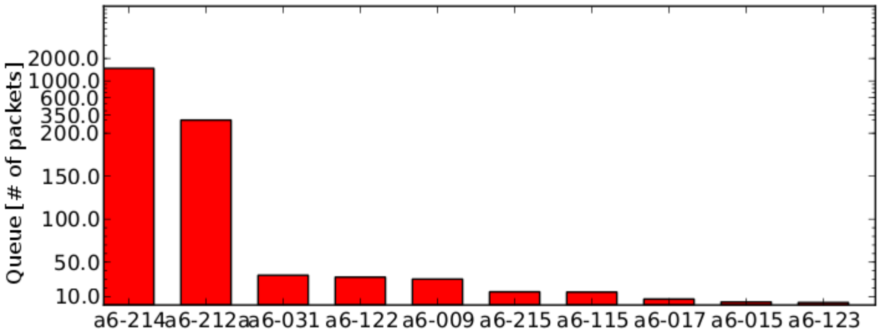


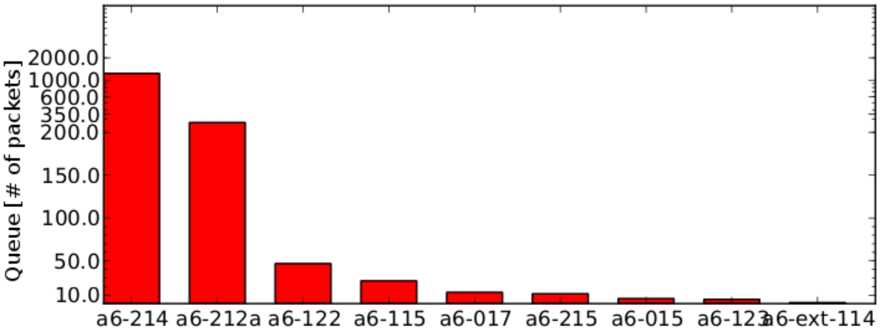
Fig. 7. Reported end-to-end throughput during the single-path phase of a sample experiment execution.

the available links - the interruption of the *UDP1* transmission could be avoided as a result of the utilization of alternative paths.

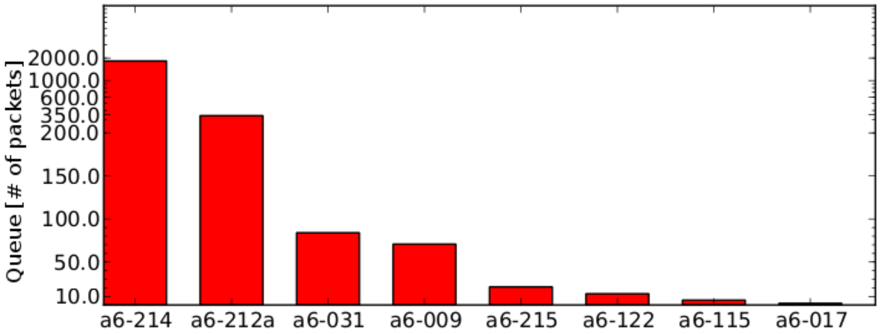
Since the system realizing backpressure-supported multi-path packet forwarding maintains queues above the MAC layer [1], an additional queuing function analysis is possible, which enables the illustration of backpressure principle operation. Figures (8(a)-8(c)) show the average queue levels measured on the nodes which took part in the transmission of *UDP1*. It can be observed that queue levels are decreasing along the paths from the flow source to its destination. Additional observation can be made when comparing the average queue levels measured during the time of parallel transmission of *UDP1* and *UDP2* with the average queue levels measured during time when *UDP2* was not active (Figures 8(b)-8(c)). Firstly, it can be concluded that during the transmission of *UDP2*, *UDP1* was



(a) Average queue levels measured during an experiment execution in the multi-path mode (the average taken over all experiment executions).



(b) Average queue levels measured over the period when *UDP2* was not active during a sample experiment execution in the multi-path mode.



(c) Average queue levels measured during the transmission of *UDP2* in a sample experiment execution in the multi-path mode.

Fig. 8. Average queue levels .

transmitting most of the packets using the path which was less sensitive to the parallel transmission of *UDP2*. Moreover, it may be seen that when the network became more congested, the multi-hop flow was forced to ’signal’ its bandwidth requirements more strongly, especially on relying nodes located a few hops from the source.

5 Related Work

The optimization of the traditional backpressure routing has been recently investigated in the context of wireless multi-hop networks [2, 4, 5]. However, none of the mentioned papers is focused on OLSR protocol modification. Moreover, none of the reported work on providing multi-path functionality to the OLSR, is oriented on integration with the backpressure algorithm [15–17]. To our knowledge, none of the existing multi-path OLSR extensions preserves the proactive nature of OLSR. The authors of [15] and [16] use the source routing technique, where routes are determined according to an "on demand" scheme. Similarly, in [17] pairs of routes are calculated for each destination separately.

Working on the solutions evaluated in this paper, we followed the approach presented in [1, 7], which was further continued as a standardization effort and exemplified by IETF Internet drafts [8, 9].

The experimental evaluation of the results in real networks and testbed setups is still gaining in importance because the obtained results can be better transferred to real network setups than using network simulations [18]. For this reason, large-scale wired an wireless testbeds based on different technologies were set up. Since 2003, the PlanetLab project has provided a worldwide interconnection of testbeds managed by Princeton University [19]. Large-scale nation-wide testbeds such as GENI (USA) [20], AKARI and JGN2plus (Japan) [21, 22], and the EU ONELAB project [23], have followed. For the EU, in the scope of the EU FIRE initiative, stand-alone testbeds, testbed federations, and interconnected testbeds have been set up in order to holistically research all aspects of wireless communication in large, heterogeneous networks. For the EU WISEBED project, multiple wireless sensor networks have been put under common administrative control and interconnected over gateways to provide virtually one large wireless sensor network testbed [24].

6 Conclusions

The presented experimentation was focused on a realistic case of a network state in which aggregated traffic volume exceeds the network capacity. We have demonstrated that at least in the case of some scenarios, multi-path transmission over the wireless ad-hoc networks may lead to higher end-to-end throughput of multi-hop flows. Additionally, we experimentally verified that in the case of saturated network, the application of the proposed backpressure-based multi-path extension of the OLSR protocol ensures more stable multi-hop transmission than the standard OLSR. Finally, we presented the operation of the backpressure mechanism in the large-scale highly-functional wireless testbed. To our knowledge, the results of the experiments presented in this paper are the first demonstration of the backpressure principle successfully applied to OLSR-based multi-path routing realized in a physical MANET.

Acknowledgement

This work was partly supported by the European Commission OPNEX STREP project (FP7-224218, www.opnex.eu) and by Poznan University of Technology under grant 45-085/11 DS-PB.

References

1. Szwabe, A., Misiorek, P., Nowak, A., Marchwicki, J.: Implementation of backpressure-based routing integrated with max-weight scheduling in a wireless multi-hop network. In: 2010 IEEE 35th Conference on Local Computer Networks (LCN). (2010) 983–988
2. Moeller, S., Sridharan, A., Krishnamachari, B., Gnawali, O.: Routing Without Routes: The Backpressure Collection Protocol. (Submitted to ACM/IEEE IPSN 2010)
3. Shakkottai, S., Srikant, R.: Network optimization and control. Foundations and Trends in Networking **2** (2007) 271–379
4. Bui, L., Srikant, R., Stolyar, A.L.: Novel architectures and algorithms for delay reduction in back-pressure scheduling and routing. In: The 28th IEEE International Conference on Computer Communications (INFOCOM 2009). (2009) 2936–2940
5. Ying, L., Shakkottai, S., Reddy, A.: On combining shortest-path and back-pressure routing over multihop wireless networks. In: The 28th IEEE International Conference on Computer Communications (INFOCOM 2009). (2009) 1674–1682
6. Clausen, T., Jacquet, P.: Optimized Link State Routing Protocol (OLSR). RFC 3626 (Experimental) (2003)
7. Szwabe, A., Misiorek, P.: Integration of Multi-path Optimized Link State Protocol with Max-Weight Scheduling. In: Proc. of IEEE International Conference on Information and Multimedia Technology (ICIMT 2009). Number 458-462, Jeju Island, South Korea (2009)
8. Szwabe, A., Nowak, A., Baccelli, E., Yi, J., Perrein, B.: Multi-path for Optimized Link State Routing Protocol version 2. https://datatracker.ietf.org/doc/draft-szwabe-manet-multipath-olsrv2/ (2011) Work in progress.
9. Szwabe, A., Misiorek, P., Urbanski, M., Baccelli, E.: OLSRv2 Backpressure Traffic Engineering Extension. https://datatracker.ietf.org/doc/draft-szwabe-manet-backpressure-olsrv2/ (2011) Work in progress.
10. : The Distributed Embedded Systems Testbed (DES-Testbed) Webpage. (`http://http://www.des-testbed.net/`)
11. Günes, M., Blywis, B., Juraschek, F.: Concept and Design of the Hybrid Distributed Embedded Systems Testbed. Technical Report TR-B-08-10, Freie Universität Berlin (2008)
12. Günes, M., Blywis, B., Juraschek, F., Schmidt, P.: Practical Issues of Implementing a Hybrid Multi-NIC Wireless Mesh-Network. Technical Report TR-B-08-11, Freie Universität Berlin (2008)

13. : An ad-hoc wireless mesh routing daemon. `http://www.olsr.org` (2009)
14. Szwabe, A., Misiorek, P., Walkowiak, P.: Delay-Aware NUM system for wireless multi-hop networks. In: European Wireless 2011 (EW2011), Vienna, Austria (2011) 530–537
15. Yi, J., Cizeron, E., Hamma, S., Parrein, B.: Simulation and performance analysis of MP-OLSR for mobile ad hoc networks. IEEE Wireless Communications and Networking Conference. WCNC 2008 (2008) 2235–2240
16. Kun, M., Jingdong, Y., Zhi, R.: The research and simulation of multipath OLSR for mobile ad hoc network. IEEE International Symposium on Communications and Information Technology. ISCIT 2005 **1** (2005) 540– 543
17. Mahfoudh, S., Minet, P.: An energy efficient routing based on OLSR in wireless ad hoc and sensor networks. 22nd International Conference on Advanced Information Networking and Applications, 2008 (2008) 1253 – 1259
18. Cavin, D., Sasson, Y., Schiper, A.: On the accuracy of MANET simulators. In: POMC '02: Proceedings of the second ACM international workshop on Principles of mobile computing, New York, NY, USA, ACM Press (2002) 38–43
19. : PlanetLab. (Website) Last visit: 01/2011.
20. : GENI Project. (Website) Last visit: 01/2011.
21. : AKARI. (Website) Last visit: 01/2011.
22. : JGN2plus. (Website) Last visit: 01/2011.
23. : ONELAB Project. (Website) Last visit: 01/2011.
24. : The WISEBED EU research project. (Website) Last visit: 01/2011.