Challenges and Limits of Flooding and Gossip Routing based Route Discovery Schemes

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***Abstract*—Motivated by our experience from previous testbed-based studies, we discuss the performance of flooding based route discovery schemes. Based on an empirical case study, the limits of routing in IEEE 802.11 wireless multi-hop networks are highlighted. We show that the route discovery itself can already lead to problems even when there are no or few data flows.**

***Index Terms*—Wireless Mesh Network (WMN), Gossip Routing, Probabilistic Flooding, Testbed**

I. Motivation

The IETF MANET working group has published multiple RFCs of routing protocols for application in (mobile) wireless multi-hop networks while the IEEE is currently standardizing the IEEE 802.11s mesh networking protocol. Most protocols apply flooding as a service to some extend. Reactive protocols flood route requests to a destination if no matching entry is available in the routing table. The destination replies with a packet that either can be a unicast traveling back a particular route or alternatively the packet can be flooded towards the source. In contrast, proactive protocols disseminate information to all nodes in the network periodically. When a data packet has to be sent, either a route is available or the packet is dropped immediately.

Flooding is therefore a crucial part in routing protocols and it is normally assumed to "just work". Due to the broadcast nature of the wireless medium, multiple copies of the same packet will traverse the network and one of them should eventually arrive at the destination. If flooding actually works this way in real world networks, good performance of the routing, i.e., reachability, throughput, delay, etc. can be expected. However, the scientific community currently lacks detailed empirical studies. Simulations and analytical approaches often use simple models for the radio propagation when routing protocols are evaluated. Based on our experience in the DES-Testbed we have learned that many assumptions do not hold and several parameters, e.g., timeouts had to be significantly re-configured to make communication in a wireless multi-hop network even possible.

The fundamental issues of wireless communication are known since decades, e.g., packet collisions [1], the *near-far problem* [2], and noise that significantly reduces the transmission range [3] and impacts the performance of multi-hop wireless networks [4]. Even under these conditions, we normally assume that flooding works.

Flooding has a high overhead because every node forwards each packet once and bandwidth is wasted unnecessarily. Many gossip routing protocols have been proposed as improvements. The flooding is probabilistic and depends on the forwarding probability p. On each packet reception, a random number $r \in [0, 1]$ is selected. The packet is forwarded for $r \leq p$ and it is dropped otherwise. More complex gossip routing protocols consider other information like the node degree or the number of received copies to dynamically adapt p to the topology and properties of the network.

As we have shown in two testbed-based studies [5], [6], flooding and gossip routing do indeed work well in some scenarios and gossip routing actually shows an improvement. Despite these positive results, we also observed that routing still has problems to connect all nodes [7] and that an application like localization [8] will experience problems because the applied routing protocol is not able to discover routes to all nodes. Therefore we discuss in this publication a *work-in-progress* study of flooding and gossip routing and show that there are limits that have to be considered. We argue based on the preliminary results that a rethinking is probably required in the research domain of routing as traditional approaches do not scale well and will limit the performance.

This paper is structured as follows. The related and preliminary work is discussed in Section II and a gossip routing protocol is introduced that is used in our study. Subsequently in Section III, the experiment setup is elaborated and the measured data is evaluated and discussed. The paper ends with some conclusions in Section IV.

II. Related and Preliminary Work

Several approaches have been proposed to improve the performance of flooding in wireless networks. There are *gossip routing* based schemes [9], [10], *reliable broadcast* schemes [11], [12], and *multi-point relays* (MPRs) [13]. All of them showed some improvements over native flooding. The gossip routing protocols and MPRs reduced the number of forwarded packets while the reliable broadcast schemes could achieve a high reachability that was traded-off by a high redundancy.

In our previous studies we observed that the *gossip3* protocol by Haas et al. [10] provided high reachability. This gossip routing variant gives each packet two chances to be forwarded. If the packet is not forwarded because $r > p$, it is not dropped but stored. A timer is started and the number of received duplicates counted. If less duplicates than a threshold m are received until the timeout, the packet is forwarded. m is a pre-configured value that has to be selected with care because it does not consider the node degree $d(n)$ of individual nodes n. Haas et al. showed in their simulation-based study that gossip3 in AODV could reduce the *routing load* while the *packet delivery fraction* was not affected even in a mobile network where a large number of route discoveries can be expected.

MPRs were proposed to reduce the number of neighbors that will forward (broadcast) packets sent by a node. Each node determines a subset of $1-$hop neighbors so that all $2-$hop neighbors can be reached via this set. The approach is an integral part of the *Optimized Link State Routing* (OLSR) protocol. Qayyum et al. showed in simulations that the approach provided better performance than flooding [13].

In [5], [6] we presented that gossip routing does indeed show improvements in real world scenarios but that the results are also strongly dependent on the position of the source node. We were able to observe in some scenarios that at a particular value $p = p_c$ the fraction of nodes that received the packets was suddenly increased. p_c is called critical value in the research domain of *percolation theory* that is often referred as foundation or inspiration for gossip routing. We were also able to show that a bimodal behavior can be observed: either few nodes receive the packet or almost all of them. In these experiments only a single source sent packets at a time. It was a best case scenario without other route management packets or contending data flows in the network.

III. Empirical Study

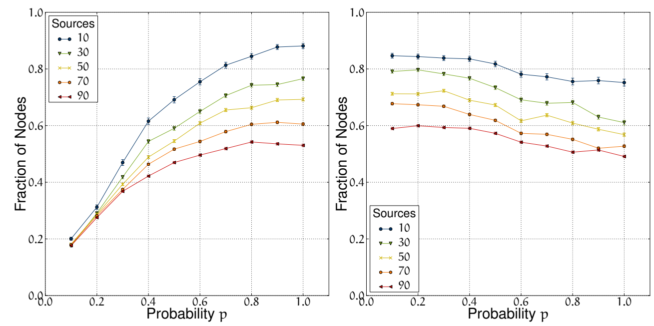
The motivation of our study comes from our experience with various routing protocols that we evaluated in the DES-Testbed. Either the performance, i.e., throughput and goodput were much lower than expected or no communication was possible at all between several nodes. This comes at a surprise, as we know that the testbed topology is fairly densely meshed [14]. To give a specific example, in an experiment with the *Dynamic Source Routing* (DSR) protocol we observed many *route error messages* or failed route discoveries [7]. With two OLSR daemons we observed that the routers did not have a complete view of the topology and thus were missing entries for some destinations in the routing table. A localization algorithm that was evaluated in the testbed and that relied on a routing protocol had severe issues as the network-wide propagation of broadcast packets did not work reliably and thus a leader election algorithm failed, respectively produced multiple leaders [8]. Therefore the following experiments shall give more insight about the problems.

A. Experiment Setup

105 routers of the DES-Testbed participated in the experiments that are deployed over three buildings and multiple floors. Several gossip routing protocols were implemented as daemons based on the DES-SERT routing framework [15]. In this study we take a detailed look at two particular gossip routing variants. The first one is called *simple gossip scheme* in the following and has only the forwarding probability p as parameter that we increased in 0.1 steps. For $p = 1.0$ the daemon will flood all packets which enables us to evaluate if there is an improvement by applying a probabilistic scheme. The second variant is *gossip3* that has been introduced in Section II. We set $m = 1$ as this configuration has shown good performance in our previous studies. Higher values of m will eventually result in a flooding: either the packet is forwarded by chance ($r \leq p$) or after the timeout because $d(n) < m$. Packets are sent every second and have a destination address that is not available in the network to mimic route requests of a reactive protocol or the periodically sent packets of a proactive protocol. Two payload sizes were configured to learn if there are significant differences when the packets take more time on the medium. Depending on the particular routing protocol, we expect different packet sizes to occur in the real world. $10 - 90$ sources sent packets at the same time to determine if the protocol scales. We run 10 repetitions for each of these configurations, In each repetition the set of source routers is randomly selected but the sets are kept equal for both gossip routing protocol to ensure comparability.

Parameter	Values
gossip variants	2
routers	105
forwarding probability p	$[0.1 - 1.0]$ in 0.1 steps
duplicate threshold m	1
packets per configuration	30
payload size [byte]	$0, 384$
packet interval [s]	1
simultaneous sources	$10, 30, 50, 70, 90$
repetitions	10

Table I: Summary of the experiment parameters



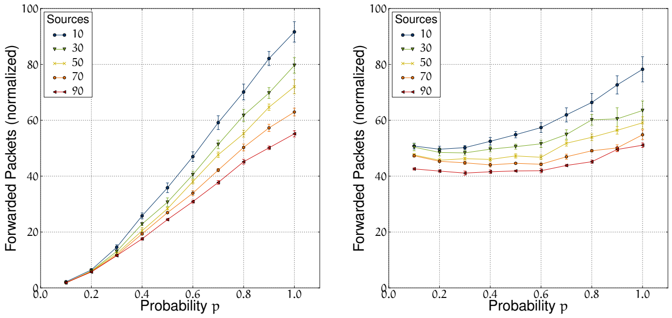
(a) Simple gossip scheme

(b) gossip3

Figure 1: Average *reachability* as function of p with payload size = 0 byte

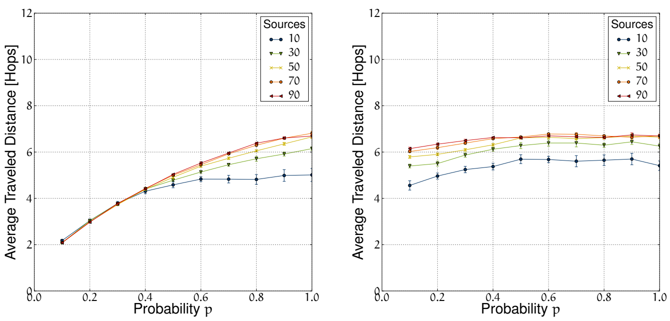
B. Evaluation

1) Reachability: As shown in Figure 1a, the reachability increases with higher values for p. The graphs show the average fraction of nodes that received the packets sent by the sources including the 95% confidence intervals. 100% reachability is never achieved on average and the more sources



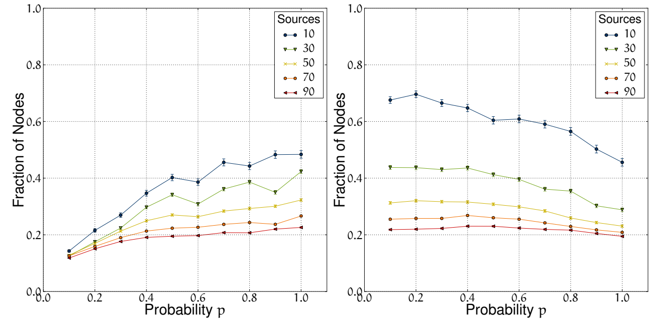
(a) Simple gossip scheme (b) gossip3

Figure 2: Average number of *forwarded packets* as function of p with payload size = 0 byte



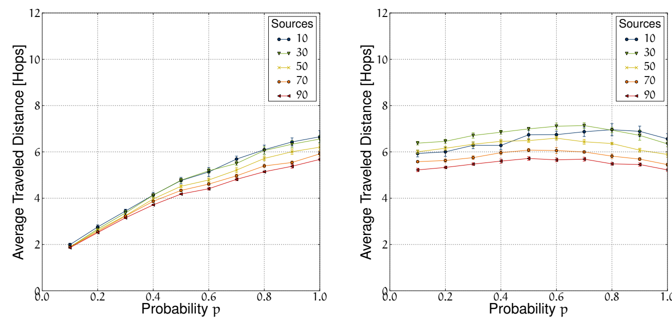
(a) Simple gossip scheme (b) gossip3

Figure 3: *Average traveled distance* per packet as function of p with payload size = 0 byte



(a) Simple gossip scheme (b) gossip3

Figure 4: Average *reachability* as function of p with payload size = 384 byte



(a) Simple gossip scheme (b) gossip3

Figure 5: *Average traveled distance* per packet as function of p with payload size = 384 byte

there are, the lower the highest fraction that can be achieved. When 90 of the 105 nodes generate packets at the same time, we can expect that only slightly more then 50% of nodes will receive them.

In Figure 1b, we can see the same graphs for gossip3 but the parameter p has a totally different effect. It is actually much better to set $0.1 \leq p \leq 0.3$ (for $m = 1$) as higher probabilities will have a negative effect. Nevertheless, with an optimal parametrization gossip3 is able to achieve a higher reachability in most cases than the simple variant for any number of simultaneous sources > 10.

2) Forwarded Packets: The number of forwarded packets normalized by the number of emitted packets is shown in Figure 2. For the simple scheme there is a linear increase but gossip3 shows a decreasing shape for low values of p before the graphs begin to rise. Combined with results from the previous section we can state that $0.2 \leq p \leq 0.3$ is an optimal configuration. Nevertheless, when the number of sources increases the number of forwarded packets falls significantly indicating that the “gossiping dies out” on the first few hops.

3) Distance: Figure 3 shows the average distance that the packets traveled through the network. The testbed has a diameter of around 10 hops depending on which links are actually considered, i.e., if links with a *packet delivery ratio* below a particular threshold are ignored. Therefore we expected around 5 hops on average as it is also shown in the figure (for 10 simultaneous sources). When more nodes transmit at the same time, the distance increases but as we have seen in Section III-B1, the reachability is actually not increased. It seems like the packets are unable to reach particular areas in the network.

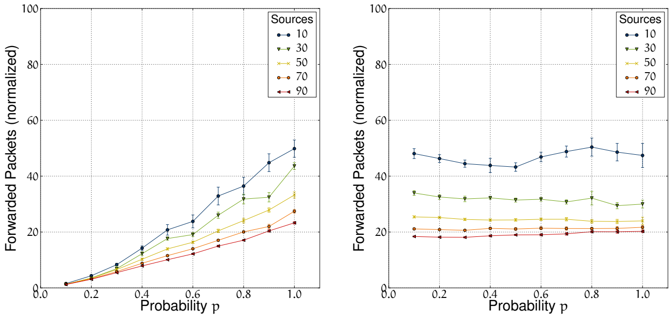
4) Packet Size: When we increase the packet size, the reachability drops even further in all cases as shown in Figure 4. gossip3 can only show an improvement over the simple scheme for 10 simultaneous sources.

On the first sight, the traveled distance (Figure 5) did not change that much but on second look we notice, e.g., that the graphs for 10 and 90 sources “switched places”. Suddenly when 10 sources are active, the packets travel over more hops than before and more hops than in the case with 90 sources.

As last we observe in Figure 6 that the number of forwarded packets did dramatically decrease which explains the low reachability.

C. Discussion

So what are the conclusions from the testbed-based study? First of all, we have to note that the experiment setup can still be considered as a best case scenario. There are no mobile nodes, no/few people in the building when the experiments were run, and most notably there were no data flows as



(a) Simple gossip scheme

(b) gossip3

Figure 6: Average number of *forwarded packets* as function of p with payload size = 384 byte

we just emulated the route discovery of a routing protocol. Despite these optimal conditions we have shown that flooding and gossip routing will not achieve high reachability in all scenarios. This can be explained by how broadcasts are actually handled in IEEE 802.11. There is no *request to sent*, no acknowledgements, and the packets are transmitted with low data rates. In the case of an *Independent Base Service Set* (IBSS), i.e., the ad-hoc mode, the nodes will always fall back to 1 Mbps. Therefore the packets take a long time on the medium which increases the chance of collisions and increases the overall noise level.

As we stated in Section I, the fundamental problems are well known yet at the same time they are currently not in the focus of multi-hop wireless routing. OLSR for example will sent *topology control* messages every 5 sec (and HELLOs every 2 sec) per default. While this is above our setting, a lower interval is required in mobile networks as we have learned; otherwise the routing information is severely outdated. In contrast, the B.A.T.M.A.N. protocol will flood *originator messages* every second. We also experimented with other packet intervals above 1 sec and while the reachability was slightly higher, the problem remains to a significant degree. We have not yet seen such negative results from other studies but as most experiments have been run in simulation environments, we assume that the problems that we experienced did not occur with the used radio propagation models.

The consequences are that routing protocols will have to run a reactive route discovery multiple times until a reply is finally received and proactive protocols will probably have no entries for a subset of the nodes. The route discovery and management overhead has to be decreased significantly and dynamically based on the current data flows and the topology of the network. Data link layer solutions include an increase of the broadcast data rate or maybe CTS-to-self packets. This is the focus of our ongoing research and the next studies.

IV. Conclusion

As we have shown with our empirical study in an indoor and outdoor testbed, many routing protocols will suffer from the deficiencies of their route discovery. We cannot assume that flooding in IEEE 802.11 wireless networks will "simply work". Neither will a packet be received by all nodes in the network, nor can we expect that flooding or gossip routing scales well. To increase the performance of routing protocols, novel approaches are required.

References

[1] S. Rayanchu, A. Mishra, D. Agrawal, S. Saha, and S. Banerjee, "Diagnosing wireless packet losses in 802.11: Separating collision from weak signal," in *Proc. INFOCOM 2008. The 27th Conf. Computer Communications. IEEE*, 2008, pp. 735–743.

[2] R. Pickholtz, D. Schilling, and L. Milstein, "Theory of spread-spectrum communications–a tutorial," vol. 30, no. 5, pp. 855–884, 1982.

[3] R. K. Schmidt, T. Köllmer, T. LeinmÏler, B. Böddeker, and G. Schäfer, "Degradation of transmission range in vanets caused by interference," *PIK - Praxis der Informationsverarbeitung und Kommunikation*, vol. 32, pp. 224–234, October-December 2009.

[4] K. Jain, J. Padhye, V. N. Padmanabhan, and L. Qiu, "Impact of interference on multi-hop wireless network performance," in *Proceedings of the 9th annual international conference on Mobile computing and networking*, ser. MobiCom '03. New York, NY, USA: ACM, 2003, pp. 66–80. [Online]. Available: http://doi.acm.org/10.1145/938985.938993

[5] "Gossip routing in wireless mesh networks," in *Personal Indoor and Mobile Radio Communications (PIMRC), 2010 IEEE 21st International Symposium on*, sept. 2010, pp. 1572 –1577.

[6] B. Blywis, M. Günes, S. Hofmann, and F. Juraschek, "A Study of Adaptive Gossip Routing in Wireless Mesh Networks," in *Ad Hoc Networks*, ser. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, O. Akan, P. Bellavista, J. Cao, F. Dressler, D. Ferrari, M. Gerla, H. Kobayashi, S. Palazzo, S. Sahni, X. S. Shen, M. Stan, J. Xiaohua, A. Zomaya, G. Coulson, J. Zheng, D. Simplot-Ryl, and V. C. M. Leung, Eds., vol. 49. Springer Berlin Heidelberg, 2010, pp. 98–113. [Online]. Available: http://dx.doi.org/10.1007/978-3-642-17994-5_7

[7] B. Blywis, M. Günes, D. J. H. Gutzmann, and F. Juraschek, "A testbed-based study of uni- and multi-path dynamic source routing in a wmn," in *Wireless Days (WD), 2010 IFIP*, oct. 2010, pp. 1 –5.

[8] B. Blywis, M. Günes, F. Juraschek, and S. Gliech, "A localization framework for wireless mesh networks - anchor-free distributed localization in the des-testbed," in *Indoor Positioning and Indoor Navigation (IPIN), 2010 International Conference on*, sept. 2010, pp. 1 –10.

[9] X.-Y. Li, K. Moaveninejad, and O. Frieder, "Regional gossip routing for wireless ad hoc networks," *Mob. Netw. Appl.*, vol. 10, no. 1-2, pp. 61–77, 2005.

[10] Z. J. Haas, J. Y. Halpern, and L. Li, "Gossip-based ad hoc routing," *IEEE/ACM Trans. Netw.*, vol. 14, no. 3, pp. 479–491, 2006.

[11] P. Orlik, J. Zhang, B. Bhargava, G. Ding, G. Ding, Z. Sahinoglu, and Z. Sahinoglu, "Reliable broadcast in zigbee networks," in *In Proceedings of SECON*, 2005.

[12] W. Lou and J. Wu, "Toward broadcast reliability in mobile ad hoc networks with double coverage," *IEEE Transactions on Mobile Computing*, vol. 6, pp. 148–163, 2007.

[13] A. Qayyum, L. Viennot, and A. Laouiti, "Multipoint relaying for flooding broadcast messages in mobile wireless networks," in *Proceedings of the 35th Annual Hawaii International Conference on System Sciences (HICSS'02)-Volume 9 - Volume 9*, ser. HICSS '02. Washington, DC, USA: IEEE Computer Society, 2002, pp. 298–. [Online]. Available: http://portal.acm.org/citation.cfm?id=820747.821299

[14] B. Blywis, M. Günes, F. Juraschek, O. Hahm, and N. Schmittberger, "Properties and Topology of the DES-Testbed (2nd Extended Revision)," Freie Universität Berlin, Tech. Rep. TR-B-11-04, July 2011. [Online]. Available: http://edocs.fu-berlin.de/docs/receive/FUDOCS_document_000000010697

[15] B. Blywis, M. Günes, F. Juraschek, P. Schmidt, and P. Kumar, "DES-SERT: A framework for structured routing protocol implementation," in *IFIP Wireless Days conference (WD'09)*, Paris, France, 12 2009.