Evaluation of MANET Routing Protocols in a Realistic Emergency Response Scenario

Christian Raffelsberger
Alpen-Adria-Universität Klagenfurt
Klagenfurt, Austria
Christian.Raffelsberger@aau.at

Hermann Hellwagner
Alpen-Adria-Universität Klagenfurt
Klagenfurt, Austria
Hermann.Hellwagner@aau.at

***Abstract*—We evaluate the performance of several routing protocols for mobile ad-hoc networks (MANETs) in an emergency response scenario. The simulated scenario uses a disaster area mobility model and a wireless shadowing model to represent realistic first responder movements in a hybrid indoor/outdoor environment. The resulting scenario imposes some challenges on the MANET routing protocols such as intermittent connectivity and network partitions. The simulation results show that nodes have diverse connectivity characteristics which are challenging for state-of-the-art MANET routing protocols.**

I. INTRODUCTION

Emergency response and recovery operations are highly collaborative efforts. Establishing communication and the dissemination of data between first responders are critical tasks. Thus, emergency response operations are a promising application area for mobile ad-hoc networks (MANETs). Networks in an emergency response operation can be established in an ad-hoc manner if fixed infrastructures are not available (e.g., because they have been destroyed or are overloaded). Such hastily formed networks are diverse in terms of connectivity and network equipment. Connectivity settings may range from almost fully connected networks to very sparse networks. Apart from these two extremes, the network may be intermittently connected, providing separated "islands" of well-connected nodes, that are not connected with nodes in other partitions. For instance, different search and rescue teams may be separated from each other as they are out of communication range but members of the same team are well-connected.

First responders show specific mobility patterns that influence the network performance. Due to the mobility of the rescue workers, the network topology constantly changes over time. Additionally, first responders may work both indoors and outdoors. These characteristics impose some challenges on the ad-hoc networks, especially on the MANET routing protocols. MANET routing protocols are usually evaluated in generic scenarios [1][2]. However, to get accurate evaluation results, it is important to evaluate routing protocols under the specific settings of the target application domain. In this work we introduce a realistic emergency response scenario that uses a disaster area mobility model as well as a wireless shadowing model and evaluate the performance of several state-of-the-art MANET routing protocols in this scenario.

The remainder of this paper is structured as follows. Section II briefly describes the evaluated routing protocols. Section III describes the emergency response scenario and the simulation environment, including descriptions of the mobility model and the wireless shadowing model. Section IV presents the evaluation results. Related work can be found in Section V and Section VI concludes the paper.

II. PROTOCOL DESCRIPTIONS

We evaluate the performance of several state-of-the-art wireless routing protocols, namely AODV, BATMAN, DYMO and OLSR, in a specific emergency response scenario. This section briefly introduces the evaluated routing protocols. A more detailed description and comparison of MANET routing protocols can be found in [3].

The Ad-hoc On-demand Distance Vector (AODV) [4] protocol is a well-known reactive routing protocol. The main idea of AODV, and other reactive routing protocols, is that routes are only established if they are needed. If a route needs to be established, a node broadcasts a route request (RREQ) packet. Intermediate nodes, that know a path to the destination, or the destination itself return a route reply (RREP) packet to the initial issuer of the RREQ. This RREP contains the route to the destination. If a node detects that the path got invalid (e.g., due to mobility) it sends out a route error (RERR) message to inform other nodes.

Dynamic MANET On-demand (DYMO) [5] is a successor of AODV. Similarly to AODV, RREQ and RREP messages are used to find and establish routes in the network. However, intermediate nodes do not only record the route to the source and destination of the RREQ but also the routes to intermediate nodes. In this way nodes learn about routes in the network without issuing additional RREQ messages.

Optimized Link State Routing (OLSR) [6] is a proactive protocol. Nodes exchange routing information periodically and every node maintains a path to all other nodes. Like other link state protocols, all nodes have a complete view of the network. The main difference of OLSR to traditional link state routing protocols is the concept of multipoint relay (MPR) nodes. Every node selects those 1-hop neighbors as MPRs, that are needed to reach all of its 2-hop neighbors. Only MPRs need to forward routing control messages and issue link updates. Additionally, only links to MPRs are considered in the route calculation process. Hence, the concept of MPRs reduces

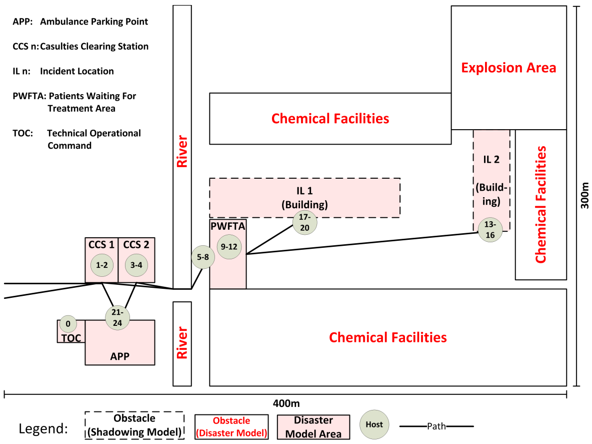

Fig. 1. Map of the simulation area

the routing overhead and processing complexity compared to traditional link state protocols.

The Better Approach To Mobile Ad-hoc Networking (BATMAN) [7] is another proactive routing protocol. Its main design goal was to reduce complexity of the routing protocol. The BATMAN protocol does not try to find the complete path between a source/destination pair. Instead it only determines which 1-hop neighbor is best suited to reach a certain destination. All nodes regularly broadcast originator messages (OGM) that contain their address and are spread in the entire network. Every node keeps track from which neighbor it received how many OGMs of a certain node. If a node needs to send a data packet to a destination, it forwards the packet to the neighbor that provided most OGMs for that destination. This step is repeated until the destination is reached.

III. Scenario Description and Simulation Environment

The scenario represents a disaster response operation after an explosion in a chemical facility. Fig. 1 shows a map of the area. In total there are 25 mobile nodes that represent first responders that carry a WiFi-enabled device (e.g, a smart phone). In the scenario all first responder nodes regularly send data to the host that is located in the command center. We have chosen this traffic model because information about the status of first responders and the scene (e.g., data from body sensors, photos taken by the first responders) are important to improve the situation awareness at the command center.

A. Mobility Model

A realistic disaster area mobility model by Aschenbruck et al. [8] is used to represent the movements of the first responders on the disaster site. Two first responder teams (i.e., hosts 13 to 16 and hosts 17 to 20) search and rescue victims from damaged buildings. These buildings represent the *incident locations (IL)*. The first responders move to a random position within the incident location they are assigned to. Subsequently, they exit the incident location at a defined exit point and move to a *patients waiting for treatment area (PFTA)* that is located near the gate of the facility, before they return to a random position within their assigned IL. Four nodes (i.e., hosts 9 to 12) move randomly within the PFTA, whereas four additional nodes (i.e., hosts 5 to 8) move between the PFTA and the two *casualties clearing stations (CCS)* outside the facility. There are two nodes in every CCS (i.e., hosts 1 and 2 as well as hosts 3 and 4) that do not leave their assigned area. Ambulances (i.e., hosts 21 to 24) move between the *ambulance parking point (APP)* and the two CCS, where they pick up patients and transport them to a hospital, which is not part of the simulation area. Finally, one node (i.e., host 0), which represents the incident commander, is located in the *technical operational command (TOC)* area. Ambulances move with a speed of 5-12 m/s, whereas other rescue workers move with 1-2 m/s. Several obstacles restrict the available paths for first responders (e.g., the chemical facility is only reachable via a bridge) and first responders use the shortest available path between these obstacles.

B. Wireless Shadowing Model

One important aspect of the scenario is that some nodes (i.e., nodes that enter the incident locations IL1 and IL2) also temporarily operate inside buildings. These nodes have a much shorter communication range indoors because the wireless signal is attenuated by walls and other obstacles within the buildings. We use an obstacle model by Sommer et al. [9] to capture these effects. If a transmission is attenuated by an obstacle (i.e., the obstacle obstructs the line of sight between sender and receiver) the following loss is applied to the signal:

$$L_{obstacle}\,[dB] = \beta \cdot n + \gamma \cdot d_m$$

where β is the attenuation in dB per border of the obstacle (e.g., the wall of a building), n is the number of intersections between sender and receiver, d_m is the distance the signal has to travel inside the obstacle and γ is the attenuation in dB/m that represents the inner structure of the obstacle. We have instantiated the obstacle model with $\gamma = 0.5\,dB/m$ and a per-wall attenuation of $\beta = 18\,dB$.

C. Simulation Environment and Setup

The simulations were performed using the INETMANET framework [10] for the OMNet++ network simulator [11]. The INETMANET framework provides implementations for several MANET routing protocols, including AODV, DYMO, BATMAN and OLSR. For the OLSR protocol the expected transmission count (ETX) metric was used instead of hop count. INETMANET includes two implementations of the DYMO protocol and we used the more recent DYMO-FAU implementation. The DYMO specification suggests to limit the buffer size to 50 packets and delete packets that are older than 5 seconds. We added the same constraints to the AODV packet buffer. Apart from these modifications, all experiments were performed using the default parameters of the respective MANET routing protocol. Wireless nodes were modeled as IEEE 802.11g nodes with a maximum transmission rate of 54

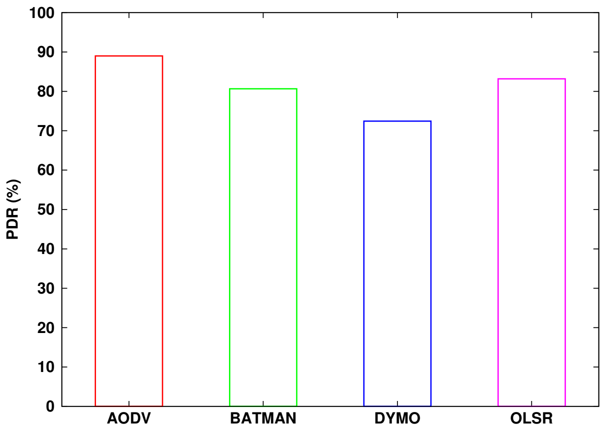

Fig. 2. Average packet delivery ratio of the four routing protocols

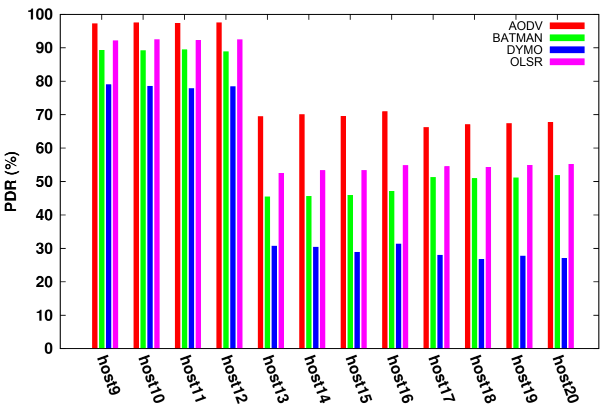

Fig. 3. Average packet delivery ratio of the mobile nodes operating inside the facility

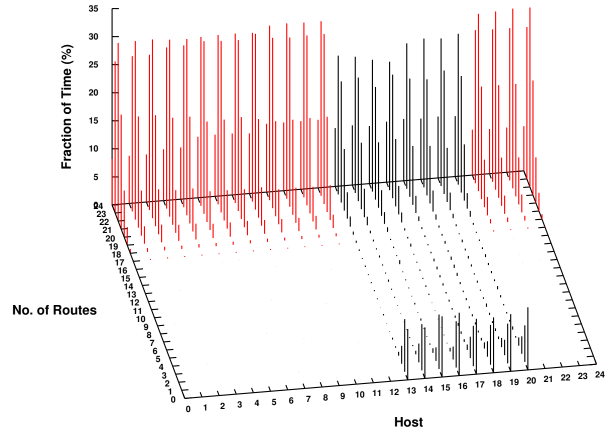

Fig. 4. Connectivity established by OLSR (i.e., number of routes reported by OLSR)

Mbps and a transmission range of about 100 meters. Every experiment lasted 3000 seconds and was repeated 10 times.

To simulate network workload, every node sent UDP packets following an on/off traffic pattern to the node that is located in the technical operational command center (i.e., host 0 in Fig.1). The on time was i.i.d. between 3 seconds and 7 seconds and the off time was i.i.d. between 5 seconds and 10 seconds. During on time 10 packets/second with a packet size of 1024 bytes were sent.

Three well-known metrics are used to evaluate the performance of the protocols: packet delivery ratio (PDR), hop count and end-to-end delay. The PDR describes the fraction of packets that could be successfully routed to the destination. The hop count is a measure for the length of the path (i.e., the number of nodes that forward a packet). The end-to-end-delay expresses the time a packet needs to travel from source to destination. We did not measure the control overhead of the routing protocols because the network is quite small and the routing overhead is not significantly affecting network performance.

IV. Evaluation Results

One of the most important metrics of a routing protocol is the packet delivery ratio (PDR). Fig. 2 shows the average PDR of the evaluated routing protocols. AODV achieves an average PDR of 89%, followed by OLSR with 83%, BATMAN with 81% and DYMO with 72%. Although the overall packet delivery ratio is above 70% for all protocols, some nodes experience significantly higher packet loss rates. Evaluating the PDR for every host (i.e., how many packets of a certain host arrive at the operational command center) shows the differences between the nodes outside the chemical facility and the nodes working inside the facility. Some of the latter nodes also temporarily operate indoors. Basically, all nodes that operate in front of the facility (i.e., hosts 1-4 and 21-24) achieve a PDR of nearly 100%, whereas the PDR of the nodes within the facility is much lower. Fig. 3 shows the PDR of the hosts that are located within the chemical facility. These hosts experience a packet loss rate of up to 70% (in the case of DYMO). This high packet loss is caused by higher mobility and by temporary work indoors (i.e., hosts 13-20 enter buildings). The performance of the routing protocols also differ more for these intermittently connected nodes. AODV accomplishes to deliver twice as many packets as DYMO, the worst performing protocol for these hosts and about 50% more as OLSR, the second best protocol. In [12] similar differences between the PDR of AODV and DYMO are reported. However, as AODV and DYMO are both reactive and have similar path finding and repair mechanisms, the difference in the packet delivery ratio needs to be further investigated.

The realistic first responder movements and the hybrid indoor/outdoor environment results in a network that is diverse in terms of connectivity. The evaluated proactive protocols BATMAN and OLSR calculate routes to all nodes in the network. The generated routing tables can be used to show the connectivity in the network, as perceived at the network layer. Fig. 4 depicts how many routes are reported by OLSR for which fraction of simulation time. The figure shows that some nodes in the network (i.e., hosts 13 to 20) are not connected to any other node for about 10% of the simulation time (i.e., about 300 seconds). Moreover, these nodes are

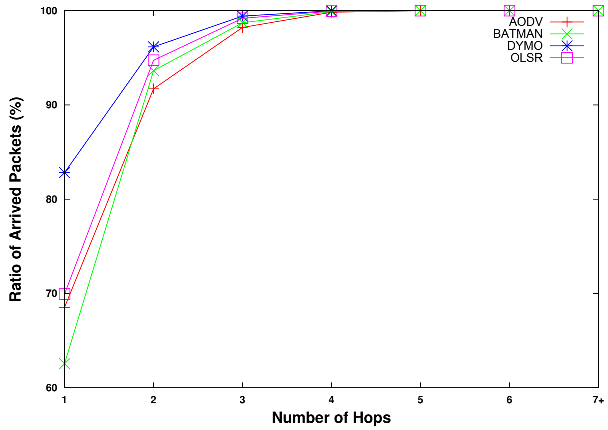

Fig. 5. Cumulative distribution function of the hop count

connected to less than three other nodes for about 25% of the simulation time. These results cleary show that the network is inhomogeneous in terms of connectivity. The network regulary becomes partitioned and is rarely fully connected (i.e., OLSR reports routes to all other nodes in the network for less than 15% of the time).

Fig. 5 shows the cumulative distribution function (CDF) of the hop count. In general, the paths in the network are very short. All protocols delivered over 90% of the packets within two hops. The reactive protocols AODV and DYMO delivered all packets within 6 hops. In OLSR and BATMAN some successfully delivered packets experienced a hop count of up to 28 for OLSR and up to 32 (i.e., the maximum TTL set at the IP layer) for BATMAN. This is an indication that OLSR and BATMAN produce temporary rooting loops. Such routing loops occur if the routing tables are not consistent and packets traverse repeatedly the same nodes, until the routing tables converge or the packets are dropped at the IP layer (i.e., the time-to-live expires). Consequently, routing loops decrease the packet delivery ratio. DYMO delivers most of the packets within one hop. However, this may result from DYMO's low PDR for the hosts that are farther away (i.e., more than one hop) from the command center.

Moreover, the packet delivery delay has been evaluated. In general, all routing protocols achieve similar results and deliver packets with very low delays. As AODV and DYMO buffer packets until a route is found, some packets experience higher delays. However, as all packets have the same destination, only the first few packets within an on-period are delayed, unless mobility causes route failures.

V. Related Work

Although disaster response operations are often used in research papers to motivate the need for mobile ad-hoc networks, it has been little researched how standard MANET routing protocols perform in emergency scenarios.

Johansson et al. [13] studied three MANET routing protocols (DSDV, AODV and DSR) under different scenarios, including a disaster area scenario. The disaster scenario consists of three groups of nodes, representing three rescue teams and two fast moving nodes that represent vehicles. Additionally, it contains obstacles that block the movement of nodes and constrain which nodes can communicate. However, compared to our work, no disaster-specific mobility model was used but members of the rescue teams move randomly and vehicles follow a predetermined path. The obstacle model is also less precise. An obstacle just completely blocks communication if it intersects the line-of-sight between two nodes. On the contrary, the obstacle model used in our work calculates the signal attenuation of an obstacle based on real world measurements.

Reina et al. [14] used the same disaster area mobility model as our work, to evaluate the performance of three reactive routing protocols, namely AODV, DSR and a modified version of AODV, called AOMDV, that supports multi path routing. In comparison to our work, no wireless shadowing model was used. The authors measured the packet delivery ratio, throughput, routing load and end-to-end delay in the network. Three different emergency scenarios, that have been introduced by Aschenbruck et al. [15], are considered. The scenarios include up to 200 nodes on a simulation area of 550m x 500m. Although these settings are quite different from our scenario, AODV outperforms the other protocols, similarly to our work.

Wister et al. [16] evaluated if AODV and DYMO are appropriate routing protocols for rescue task applications. However, the evaluations were performed in a generic scenario. Nodes are randomly placed on the simulation area and move according to the random way point mobility model. The authors evaluated the protocols based on packet delivery ratio, throughput, routing overhead and energy consumption. Although the authors concluded that DYMO is more appropriate than AODV for rescue tasks in disaster situations, the evaluated scenario is too generic for a reliable conclusion. Our work shows that a more realistic emergency response scenario exhibits some distinct features that are not covered by generic models.

VI. Conclusion

Emergency response operations are a promising but challenging application area for ad-hoc networks. This work revealed that MANETs for emergency responses provide diverse connectivity characteristics and may get partitioned. Current state-of-the-art MANET routing protocols assume an end-to-end path between source and destination. However, as the presented results show, this assumption is not true for a typical emergency response operation. As a result, some nodes are intermittently connected which results in higher packet loss. On the other hand, parts of the network are very well connected. Future work should investigate how to cope with these diverse connectivity settings. A possible approach is to integrate mechanisms from disruption tolerant networking (DTN) [17], such as storing packets until a path becomes available or opportunistically selecting a custodian that forwards the packet. In the future, we plan to examine how these DTN mechanisms can be integrated into existing MANET protocols to increase the performance for intermittently connected nodes, without decreasing the performance in the well-connected parts of the network.

This work has introduced a single emergency response scenario. Future work could also include to develop further scenarios. For instance, scenarios that include more nodes could evaluate the scalability of the MANET routing protocols. Similarly, introducing higher network loads could show how the protocols behave under network contention.

ACKNOWLEDGMENT

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 261817, the BRIDGE project.

REFERENCES

[1] A. Boukerche, "Performance evaluation of routing protocols for ad hoc wireless networks," *Mobile Networks and Applications*, vol. 9, no. 4, pp. 333–342, Aug. 2004.

[2] C. Mbarushimana and A. Shahrabi, "Comparative study of reactive and proactive routing protocols performance in mobile ad hoc networks," in *Proceedings of the 21st International Conference on Advanced Information Networking and Applications Workshops (AINAW '07)*. IEEE, 2007, pp. 679 –684.

[3] A. Boukerche, B. Turgut, N. Aydin, M. Ahmad, L. Bölöni, and D. Turgut, "Routing protocols in ad hoc networks: A survey," *Computer Networks*, vol. 55, no. 13, pp. 3032–3080, Sep. 2011.

[4] C. Perkins, E. Belding-Royer, and S. Das, "Ad hoc on-demand distance vector (AODV) routing," IETF RFC: 3561, 2003.

[5] I. Chakeres and C. Perkins, "Dynamic MANET on-demand routing protocol," IETF draft-ietf-manet-dymo-10, 2007.

[6] T. Clausen and P. Jacquet, "Optimized link state routing protocol (OLSR)," IETF RFC: 3626, 2003.

[7] A. Neumann, C. Aichele, M. Lindner, and S. Wunderlich, "Better approach to mobile ad-hoc networking (B.A.T.M.A.N)," IETF draft-openmesh-b-a-t-m-a-n-00, 2008.

[8] N. Aschenbruck, E. Gerhards-Padilla, M. Gerharz, M. Frank, and P. Martini, "Modelling mobility in disaster area scenarios," in *Proceedings of the 10th ACM Symposium on Modeling, Analysis, and Simulation of Wireless and Mobile Systems (MSWiM '07)*. ACM, 2007, pp. 4–12.

[9] C. Sommer, D. Eckhoff, R. German, and F. Dressler, "A computationally inexpensive empirical model of IEEE 802.11p radio shadowing in urban environments," in *Proceedings of the 8th International Conference on Wireless On-Demand Network Systems and Services (WONS '11)*. IEEE, 2011, pp. 84–90.

[10] A. Ariza-Quintana, E. Casilari, and A. Cabrera Triviño, "Implementation of MANET routing protocols on OMNeT++," in *Proceedings of the 1st International Conference on Simulation Tools and Techniques for Communications, Networks and Systems & Workshops (Simutools '08)*. ICST, 2008.

[11] A. Varga and R. Hornig, "An overview of the OMNeT++ simulation environment," in *Proceedings of the 1st International Conference on Simulation Tools and Techniques for Communications, Networks and Systems & Workshops (Simutools '08)*. ICST, 2008.

[12] D. Arora, E. Millman, and S. W. Neville, "Assessing the performance of AODV, DYMO, and OLSR routing protocols in the context of larger-scale denser MANETs," in *Proceedings of the 2011 IEEE Pacific Rim Conference on Communications, Computers and Signal Processing (PacRim '11)*. IEEE, 2011, pp. 675 –679.

[13] P. Johansson, T. Larsson, N. Hedman, B. Mielczarek, and M. Degermark, "Scenario-based performance analysis of routing protocols for mobile ad-hoc networks," in *Proceedings of the 5th annual ACM/IEEE International Conference on Mobile Computing and Networking (Mobicom '99)*. ACM, 1999, pp. 195–206.

[14] D. Reina, S. Toral, F. Barrero, N. Bessis, and E. Asimakopoulou, "Evaluation of ad hoc networks in disaster scenarios," in *Proceedings of the 3rd International Conference on Intelligent Networking and Collaborative Systems (INCoS '11),*. IEEE, 2011, pp. 759–764.

[15] N. Aschenbruck, M. Frank, P. Martini, and J. Tölle, "Human mobility in MANET disaster area simulation - a realistic approach," in *Proceedings of the 29th Annual IEEE International Conference on Local Computer Networks (LCN '04)*. IEEE, 2004, pp. 668–675.

[16] M. A. Wister, P. Pancardo, F. D. Acosta, and D. Arias-Torres, "Performance evaluation of AODV and DYMO as a plattform for rescue task applications in MANETs," in *Proceedings of the International Conference on Advanced Information Networking and Applications (WAINA '11)*. IEEE, 2011, pp. 670 –675.

[17] T. Spyropoulos, R. N. Rais, T. Turletti, K. Obraczka, and A. Vasilakos, "Routing for disruption tolerant networks: taxonomy and design," *Wireless Networks*, vol. 16, no. 8, pp. 2349–2370, Nov. 2010.