Human Mobility in MANET Disaster Area Simulation - A Realistic Approach

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Abstract

Disaster areas have been figured out as a typical usage scenario for mobile wireless ad-hoc networks (MANETs). In contrast to this, there are no specific mobility or traffic models for MANETs. In this paper we present a realistic approach to realize the mobility in disaster areas based on tactical issues of civil protection. The new model is analyzed and compared to Gauss-Markov and Random Waypoint mobility models. Furthermore, we present first simulation results. The mobility model analysis as well as the simulation are based on two real disasters that occurred in Germany in 1999 and 2001. We show that disaster area scenarios have specific characteristics. Thus, they should be considered in MANET performance evaluation.

1. Introduction

Mobile wireless ad hoc networks (MANETs) are an area of intensive research. In many cases, simulation is used for performance studies of algorithms and protocols (e.g. routing protocols in [1], [2], and [3]). As figured out in [4], the results of such evaluations strongly depend on the mobility and traffic models used. Often, random based models (e.g. Random Waypoint or Gauss-Markov) which distribute the nodes equally over the whole simulation area are used. These models are easy to implement and sufficient to obtain first results, but the movement they generate is not really human-like. Some newer approaches take care of these aspects by realizing attraction points in these models (e.g. [5]).

One usage scenario for MANETs is the disaster area scenario (cf. [6]). In case of a disaster, the whole infrastructure may be destroyed. Especially in this situation the civil protection needs a reliable communication not depending on any infrastructure. For this need of reliable communication, we study whether a realistic mobility model for disaster area scenarios has an impact on the results of simulations.

In section 2 of this paper we show that in disaster area scenarios the movement of the single nodes is not randomly distributed over the complete simulation area. For further motivation and to be as close as possible to reality we deal with two real-life scenarios in section 3. Next, we describe our mobility model in detail (section 4). After that, we analyze this model and compare it to some standard mobility models (section 5). Section 6 describes some results simulating voice traffic using our new mobility model. Finally, conclusions and future work are discussed in section 7.

2. Civil Protection

Catastrophes, be it natural ones (like hurricanes or tornados) or human made ones (like explosions or fires) cause an area of destruction. In this disaster area the infrastructure of the private and public systems for mobile communication may have been destroyed as well. Furthermore, in the majority of cases there are injured people who need help. Thus, there will be the civil protection service, including rescue teams and fire brigades. Civil protection forces are strictly structured and their actions are strictly organized. The units do not walk around randomly. There is one leader or a group of leaders (*technical operational command*) which tells everybody where and how to move or in which area to work. In general, the movements are

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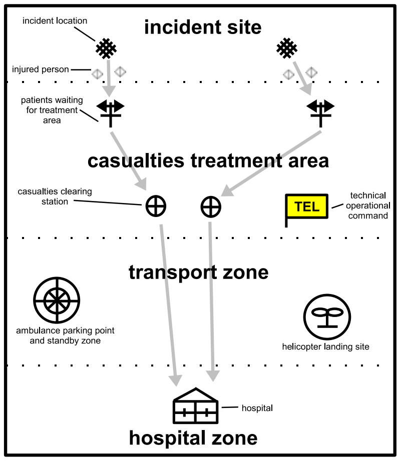

Figure 1. Separation of the room

driven by tactical reasons. These tactics are based on a method called *separation of the room*.

The disaster area and its surrounding is (according to [7] and [8]) divided into different areas: *incident site*, *casualties treatment area*, *transport zone*, and *hospital zone*. These areas are depicted in figure 1. The incident site is the place where the disaster actually happened. In this area there are found affected and injured people as well as fatalities, and the disaster (e.g. fire) has to be minimized. The grey arrows show the way of the patients. The affected and injured people are brought to the casualties treatment area. The casualties treatment area consists of two places: the *patients waiting for treatment area* and the *casualties clearing station*. The patients waiting for treatment area is usually close to the incident site. The people are rescued from danger and wait there for their treatment. Then they are transported to the casualties clearing station, which is still within the disaster area. After an extended first aid they are transported to hospital. The transport zone is an area where transport units (ambulance coaches and rescue helicopters) wait in stand-by areas to take these people to hospitals. The technical operational command is usually located in the casualties treatment area as well.

The units belong to one of these areas. For example, a firefighter belongs to the incident site and an paramedic will work in the casualties treatment area. The units sent to such an area once will typically stay there and do not leave these areas. For the transport, even between the patients waiting for treatment area and the casualties clearing station, there are special transport units.

Thus, the area within which one unit moves, depends on tactical issues, but is restricted to a specific area. These observations result in the mobility model described in section 4. For our mobility model we restrict the modeled spaces to incident site and casualties treatment area.

We are aware of one paper that has done some simulation of a disaster area [3]. This paper is not based on any disaster area concepts mentioned in this section. The model is divided into parts, but these parts can not be mapped to the described areas. Furthermore, there is no specific mobility model developed in [3].

Another aspect (in addition to the movement) to be mentioned is the kind of traffic that is used in disaster area scenarios. Today (in Germany) we use almost only broadcast voice traffic. This voice traffic is hierarchically organized. These facts are also interesting for choosing the kind of traffic used in the simulation of disaster areas. However, as mentioned above, the main focus of this paper is put on the area of movement patterns. Therefore, the facts regarding a new traffic model are not taken into account.

In this section we have figured out that the movement of nodes depends on the different areas. The question is how many nodes belong to one of these areas and how large these areas are. This depends on the dimension of the disaster and on the specific scenario. Thus, the next section shortly describes two real-world scenarios.

3. Realistic Scenarios

In this section we study two real-life disasters that happened in Germany during the past five years. These two scenarios were selected because they are characteristic for the separation of room in disaster areas. Below (c.f. section 6) these two models are used for simulation.

3.1. Wuppertal Railway Crash

The first scenario studied is the suspension railway crash, that happened in Wuppertal in 1999. The suspension railway crash was caused by a forgotten tool. One train hit the tool, was derailed and crashed into the river Wupper. There were 47 people injured and five fatalities. In this disaster there were about 150 units (firefighters, paramedics etc.) in action (according to [9]).

The different areas in this disaster are depicted in figure 2. The whole area is approximately 200m x 200m. There is one incident site, the place where

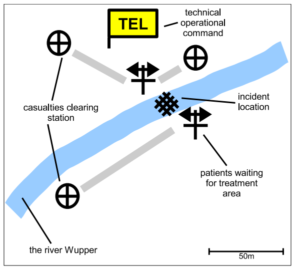

Figure 2. Szenario: suspension railway crash, Wuppertal 1999

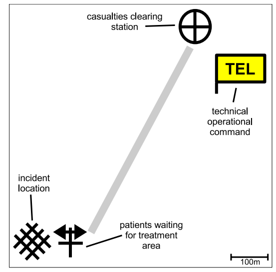

Figure 3. Szenario: fire in roller-coaster, Bruehl 2001

the train crashed into the river. There are two patient waiting for treatment areas, one on each side of the river. The patients are brought to three casualties clearing stations nearby. Furthermore, there is a technical operational command. The place of this is not described in [9]. Anyway, we decide to place it in the north between the two casualties clearing stations.

3.2. Bruehl Roller-Coaster Fire

The second disaster regarded here is a fire in an amusement park near Cologne in 2001. One attraction, the roller-coaster, caught fire. There were 70 people injured. According to [10] about 200 units were in action.

Figure 3 shows the different areas in this disaster. The whole park has a size of about 550m x 500m. There is one incident site, the place where the roller-coaster caught fire. Nearby there is one patient waiting for treatment area. The casualties clearing station is on the other side of the park in the north-east. The technical operational command also operated from the north-east of the amusement park.

4. Disaster Area Mobility Models

In section 3 we described the disasters in Wuppertal and Bruehl. Now, we present assumptions we made and the way we modeled these scenarios for our analysis.

At first we made some general assumptions to reduce the complexity of the models.

- Each unit (one person) modeled as a node takes part in the mobile communication. This is not obvious, because nowadays several persons that belong to one unit sometimes share one mobile terminal. Anyway, in the future each person will own a separate mobile terminal.
- There are no vehicles simulated. It could have been interesting because the speed of vehicles would be higher. On the other hand, the scenarios are quite small, so that walking units are realistic. According to [11]: "Below a speed of about 2m/s, it is more efficient to walk than to run." Persons working in the civil protection in Germany are not allowed to run, because of the higher risk of injury when running. Thus, the maximum speed of a node was modeled with two meters per second.
- In contrast to [3], we do not model or simulate any obstacles. Apart from the question where to put them, the obstacles affect the mobility of the nodes by hindering straight line movement. However, concerning the areas of the separation of room (c.f. section 2), obstacles only appear in the incident location. The other areas are chosen by humans and it is not possible e.g. to build up several tents amidst an area containing a lot of obstacles. At the incident location the units (e.g. firefighters) will destroy larger hindering obstacles. Smaller ones can be ignored, because they only have little impact on the movement. Furthermore, obstacles hinder a straight line communication between two nodes. On the one hand this aspect is quite interesting and realistic. On the other hand we think the aspect of radio propagation is very complex. Radio propagation is not totally suppressed by obstacles. Thus, a complex radio propagation model including obstacles may be added in future.

The different tactical areas described in section 2 are modeled as squares. The size of these areas depends on the number of units working there.

	Wuppertal	Bruehl
technical operational command	15	10
casualties clearing station(s)	30	50
patients waiting for treatment area(s)	15	20
patient transport(s)	30	40
incident site	60	80
all units	150	200

Table 1. Distribution of nodes in the different areas

The number of units depends on the scenario and general tactical considerations [12]. Thus, the distribution of the units in the areas can be seen for each scenario in table 1. Inside the areas the movement of the nodes was modeled with the Random Waypoint mobility model, using the modeling tool *Bonnmotion* [13].

There is also movement between the different areas. The incident site and patients waiting for treatment area have been modeled as overlapping, because in reality the nodes working in the incident site will carry the patients to the entrance of the patients waiting for treatment area. Thus, the movement between incident site and casualties treatment area is implicit. The movement between patient waiting for treatment area and therapy place has been modeled as a direct line (route). The route is shown in figures 2 and 3 as a grey line. The nodes move along this route from one end to the other. When having reached one end, they stop there and wait for a constant time (5 seconds) before setting of again. This behavior models nodes that transport patients on a barrow between the two areas. The speed of the nodes moving on this line was simulated randomly varying, similar to the Gauss-Markov model. The minimum speed was set to one, the maximum as already described above up to two meters per second.

5. Mobility Model Analysis

In this section, the mobility model described in the previous section is analyzed and the results are compared to results of the standard Random Waypoint and Gauss-Markov model. The comparative movements were simulated with *Bonnmotion* [13]. For each scenario ten movement files (30 minutes simulation time each) were generated and analyzed for a transmission range of 50m and 100m. Thus, the sample size of the mean and confidence interval calculation is ten.

The metrics that are used are:

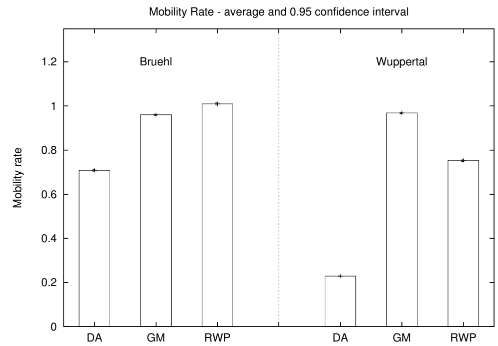

Figure 4. Relative mobility rate according to [3]

- the *relative mobility* calculated according to [3] (“a single value M which is a function of the relative motion of the nodes”)
- the *average node degree*: to how many nodes is one node connected in average (for all nodes throughout the whole simulation time)
- the *average link duration*
- the *mincut*: the minimum number of links between one node and its neighbors. It may be zero in case of network partition. The results were calculated every 10 seconds of the simulation time.

As expected, the analysis of the relative mobility shows that the degree of mobility in the disaster area is at least 0.2 less than in ordinary Random Waypoint or Gauss-Markov. This is reasonable because the movement of the nodes is restricted to dedicated areas and routes. In figure 4, the mean and confidence interval for movements according to our model in the two real-life scenarios (DA) are shown compared to Gauss-Markov (GM) and Random Waypoint (RWP) movements over areas of the same size. In both scenarios the relative mobility in DA is less than in GM and RWP. The rate of the “Wuppertal”-scenario is much lower than the one in the “Bruehl”-scenario. This results from the smaller simulation area and the long way between *patients waiting for treatment area* and *casualties clearing station* in the “Bruehl”-scenario.

By the way, in [3] higher mobility in disaster area scenarios was analyzed. The reason for this is probably the different scenario modeling and the modeled vehicles that move much faster.

The second metric that was used is the average node degree. The mean average node degree

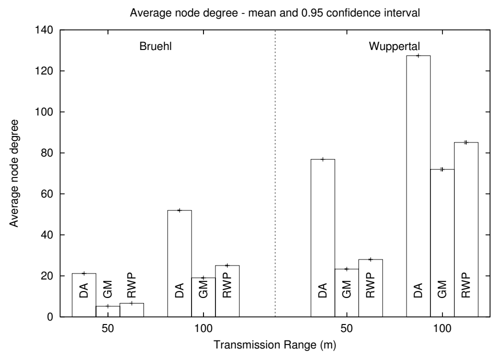

Figure 5. Average node degree

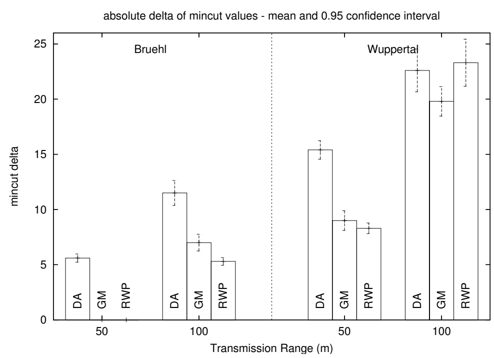

Figure 6. Average absolute delta of mincut (δ_{abs})

(figure 5) in our scenario (DA) is at least 50% higher than in Gauss-Markov (GM) or Random Waypoint (RWP). A higher average node degree in combination with high load may result in problems concerning the medium access. When using CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) all these nodes compete for the same medium. This may result in delays at the packet transmission.

The higher average node degree reflects the higher density that is an impact of assigning nodes to dedicated areas. Another impact is higher average link duration.

A higher density should also result in larger mincut, which was experienced as expected. However, a striking fact is that the mincut is strongly alternating. Often there is a small mincut followed by a higher one. Concentrating on this behavior we calculated the absolute delta of the mincuts δ_{abs} and the maximum mincut between two following values δ_{dif}:

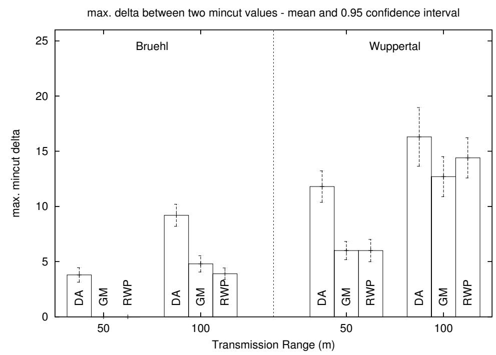

Figure 7. Delta of mincut between two values (δ_{dif})

$$\delta_{\text{abs}} = |\min_{\forall i}(mincut_i) - \max_{\forall i}(mincut_i)|$$

$$\delta_{\text{dif}} = \max_{\forall i}(|mincut_i - mincut_{i+1}|)$$

Results containing high values mean a strongly varying mincut, zero means a partitioned network. For all calculations the mean and confidence intervals of the results are shown in figures 6 and 7. The figures show that there are at least 30% higher values in the mincut deltas of the disaster areas. This can be seen at the absolute (δ_{abs}) calculations as well as at the ones of δ_{dif}, when focusing on the "Bruehl"-scenario. The calculation with 100m transmission range of the "Wuppertal"-scenario show equal values (overlapping confidence intervals). This is caused by the small overall scenario size of 200m x 200m relative to the transmission range of 100m. The partitions of Random Waypoint and Gauss-Markov in the "Bruehl"-scenario calculations with 50m transmission range is caused by the large scenario size of 550m x 500m.

When doing simulation, the strongly alternating mincut may be observed as varying bandwidth (or connectivity) between different areas of the ad hoc network. Bandwidth fluctuations may result in overload. The results of this analysis show that our disaster area model has characteristics compared to Gauss-Markov and Random Waypoint.

Furthermore, this is a scenario where power control is definitely needed. If power control is used, the average node degree could be adjusted to optimal values and the mincut problem would also be solved.

In the next section, we evaluate the impact on the results of simulations.

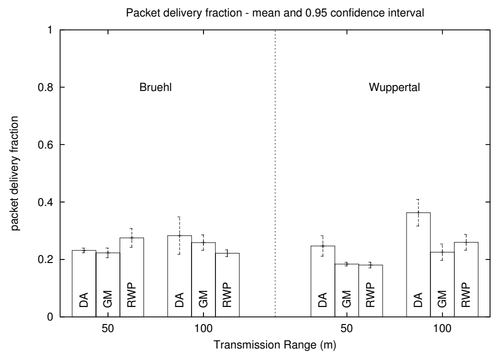

Figure 8. Packet delivery fraction (mean and 0.95 confidence interval)

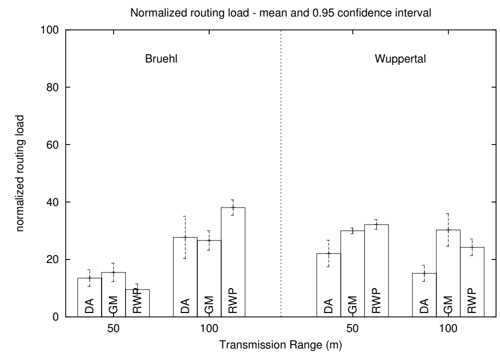

Figure 9. Normalized routing load (mean and 0.95 confidence interval)

6. Simulation

In this section the impact on simulation of the examined observations is shown. The simulations were done with the network simulator *ns-2* [14]. Simulation was done using implementations of the MANET routing protocol AODV [15] over an implementation of IEEE802.11b (Wireless LAN). Simulations were done with a transmission range of 50m and 100m. Simulation time was set to five minutes. The load was modeled as realtime point to point voice traffic. There are no results available describing a value for realistic inter-arrival time of voice traffic calls in disaster areas. However, it can be assumed that the amount of traffic will probably be higher than in other scenarios. In other scenarios, 7.5 seconds is used as a mean when simulating a high amount of traffic (cf. [16]). Thus, the inter-arrival time of the calls was exponentially distributed with a mean of 7.5 seconds. The length of a call was modeled according to lognormal distribution with $\mu = 3.287$ and $\sigma = 0.891$. This results in an average call length of about 40 seconds. These values are based on a field study [17]. The voice traffic was simulated using Voice over IP (VoIP) (codec G.729) with a data rate of 8Kbps.

The metrics that were used to analyze the results are:

- packet delivery fraction:

$$\frac{\text{data packets received}}{\text{data packets sent}}$$

- normalized routing load:

$$\frac{\text{number of routing packets sent}}{\text{number of data packets received}}$$

- transmission delay: time a packet needs for being transmitted

The packet delivery fraction average value (figure 8) when simulating with the disaster area scenario is equal (regarding confidence intervals) to Gauss-Markov and Random Waypoint. The average value of the “Wuppertal”-scenario is about 0.1 better than the others. One reason for this is the higher average link duration and within this the higher density.

The normalized routing load (figure 9) of the disaster area model is similar to the others. A reason for the lower values in the “Wuppertal”-scenario is again the higher density and within this the shorter links. In the “Bruehl”-scenario the load is higher because of the long route that may crash quite often.

Obviously, altogether the average packet delivery fraction is quite low, because only about one third of all packets is delivered. Furthermore, the routing load is quite high. At least more than 10 routing packets for each data packet received. A reason for both may be overload. In order to examine these observations in detail, attention should be drawn to one concrete simulation. The results shown in figures 10 to 13 are from a simulation with a transmission range of 50m. Anyway, simulations using 100m transmission range were also done and the results were basically the same.

A close look at the packet delivery fraction and normalized routing load of the concrete simulation (in intervals of 20 seconds) yields to figures 10 and 11. In the beginning of the simulation, the packet delivery fraction is high. It is close to 100%. With ongoing simulation time, the amount of data traffic increases, resulting in overload. All three mobil-

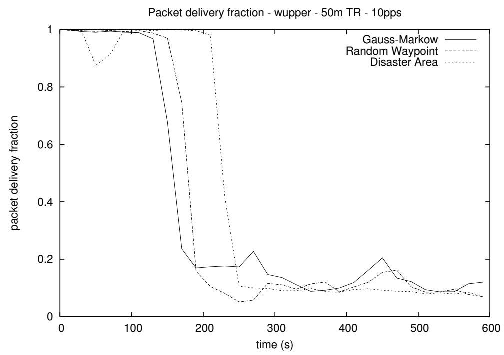

Figure 10. Packet delivery fraction (Wuppertal, transmission range 50m)

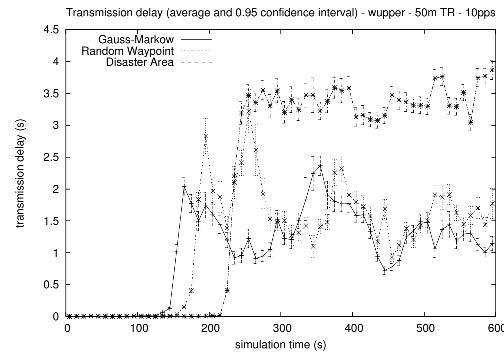

Figure 12. Transmission delay (Wuppertal, transmission range 50m)

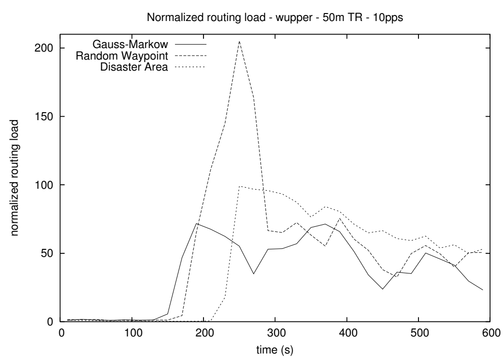

Figure 11. Normalized routing load (Wuppertal, transmission range 50m)

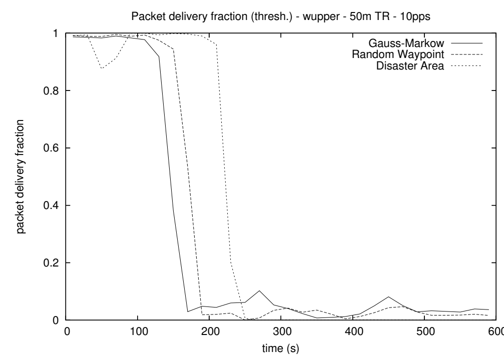

Figure 13. Packet delivery fraction (threshold) (Wuppertal, transmission range 50m)

ity models show basically the same performance. The packet delivery fraction decreases to approximately 0.1 and the normalized routing load increases up to approximately 75. However, simulating with the disaster area model is different. At first it is possible to endure the higher load about 50s longer, probably because of the shorter links (higher density). But finally the performance degrades and then it is even worse than the others. It shows a lower packet delivery fraction and a higher routing load. The reason for this is probably the poor behavior of CSMA/CA in situations of overload in combination with the higher density, as pointed out in section 5.

Taking into consideration the application that was simulated (VoIP), the transmission delay is important. A packet that is too late will not be of any use for the voice data communication. According to [18] a time of 150ms is advised as a threshold. Figure 12 shows the transmission delay in the scenario. As expected, the transmission delay strongly increases in case of overload. When calculating the packet delivery fraction only with packets that arrive in time (below the threshold of 150ms) the results are even worse. Figure 13 shows that there is a packet delivery fraction of zero in case of overload, which would lead to a total breakdown of voice. This is not supposed to happen in disaster areas, so further research is needed.

7. Conclusion and Future Work

Disaster area scenarios have the advantage of structured movement based on civil protection tactics. Therefore, it is possible to create a realistic mobility model for disaster areas. According to this model, two real-life disasters were modeled.

The models were analyzed regarding relative mobility, average node degree, average link duration, and mincut. The analysis shows that the disaster area model, compared to Gauss-Markov and Random Waypoint, offers specific behavior. There is less mobility, the average node degree and link duration are higher, caused by the higher density of the nodes. On the other hand, there is a higher variance of the mincuts and within this also more variance concerning bandwidth and connectivity of the network. First simulations were also performed yielding packet delivery fraction, normalized routing load, and transmission delay. The simulations confirm the results of the mobility model analysis. There is high risk of overload caused by the higher density and strongly alternating mincut. Concluding, we have shown that the disaster area scenario is an interesting structured scenario with lots of room for further studies.

One interesting aspect for further studies is the impact of power control in disaster area scenario simulation. Another aspect is an extension of the mobility model to group mobility models. The nodes that transport patients will probably do it as a group. In this context, the reference point group mobility model [19] may be included. Furthermore, it could be interesting to model obstacles that hinder communication. Further locations like stand-by areas with cars that move faster will increase the mobility rate and may unveil further characteristics. It may also be interesting to model larger scenarios and do performance evaluation of ad hoc routing protocols in order to figure out which one is most suitable for disaster area scenarios.

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