Modelling Mobility in Disaster Area Scenarios

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ABSTRACT

This paper provides a model that realistically represents the movements in a disaster area scenario. The model is based on an analysis of tactical issues of civil protection. This analysis provides characteristics influencing network performance in public safety communication networks like heterogeneous area-based movement, obstacles, and joining/leaving of nodes. As these characteristics can not be modelled with existing mobility models, we introduce a new disaster area mobility model. To examine the impact of our more realistic modelling, we compare it to existing ones (modelling the same scenario) using different pure movement and link based metrics. The new model shows specific characteristics like heterogeneous node density. Finally, the impact of the new model is evaluated in an exemplary simulative network performance analysis. The simulations show that the new model discloses new information and has a significant impact on performance analysis.

Categories and Subject Descriptors: I.6 [Simulation and Modeling]: Model Development

General Terms: Performance, Reliability

Keywords: Disaster Area, Mobility Model, Multi-hop Networks

1. INTRODUCTION

In catastrophe situations, public safety units require robust communication systems. These catastrophe situations are considered at network performance evaluation as disaster area scenario. Due to the fact that any kind of pre-installed infrastructure may have been destroyed by the catastrophe, there is a demand for communication systems independent of such infrastructure. Especially for Mobile Multi-hop Ad hoc NETworks (MANETs) this scenario is seen as a quasi canonical scenario (e.g. [23],[1]). MANETs meet the requirement of being independent of any kind of infrastructure by their very definition.

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When creating a scenario for performance evaluation of a disaster area communication system, modelling the mobility is an important task because the results of the evaluation strongly depend on the model used. Typical assumptions of many models are uniform selection of destinations, nodes are allowed to move over the whole simulation area, and nodes are part of the network all the time (are not switched off and do not leave the network). The goal of this paper is to study the movement of civil protection units in a disaster area scenario and figure out how this movement can be represented in a mobility model.

First of all (section 2), we describe typical movement in a disaster area scenario to point out characteristics to be considered developing mobility models for such a scenario. In section 3 we describe existing models and examine how far the issues observed in the previous section can be considered using these models. Based on the lack of appropriate existing models we introduce a new disaster area mobility model (see section 4).

After that, the paper evaluates whether the movement generated with our new disaster area mobility model shows an impact when compared to existing ones. For the evaluation we take one concrete scenario and model the movement using different models as accurate as the particular model allows us to do (see section 5). Next, we choose and adapt a set of mobility metrics and evaluate the characteristics of the new model (see section 6). After this, we show that the characteristics of the new model have an impact on simulative network performance analysis (section 7). Finally, we conclude the paper and point out topics for future work (section 8).

2. CIVIL PROTECTION

In catastrophe situations, the users of communication systems that need reliable communication are civil protection forces, including rescue teams and fire brigades. These forces are strictly structured and their actions are strictly organised. 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 driven by tactical reasons. These tactics are based on a method called *separation of the room*.

The disaster area and its surrounding is divided into different areas (cf. e.g. [21]): *incident site*, *casualties treatment area*, *transport zone*, and *hospital zone* (cf. figure 1). The *incident site* is the place where the disaster actually happened. In this area affected and injured people as well as

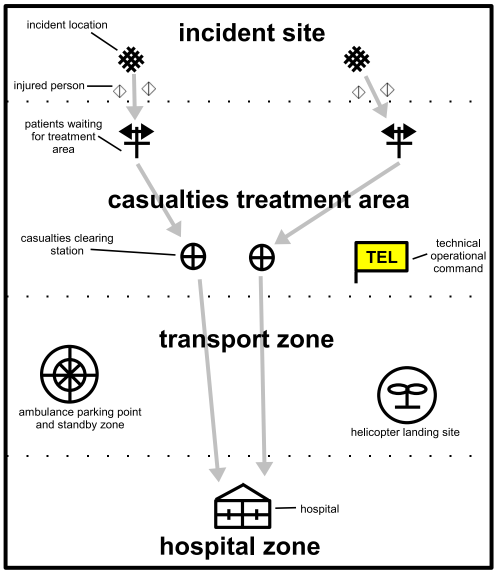


Figure 1: Separation of the room

fatalities are found and the disaster (e.g. fire) has to be minimised. 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.

Each unit belongs to one of these areas. For example, a firefighter belongs to the *incident site* and a paramedic will work at one place in the *casualties treatment area*. The units sent to a specific location once will typically stay close to this location. Some of them are transport units which carry patients to the next area, the others do not leave the area. Thus, the area within which a unit moves depends on tactical issues but is restricted to one specific area.

The areas beside the *incident location* (e.g. places where tents are set up) are chosen by humans such that there are no obstacles inside these areas. 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. So there are only obstacles between different areas. Thus, they only affect transport units.

For the transport between the *patients waiting for treatment area* and the *casualties clearing station*, there are typically transport troops. These troops are pedestrians e.g. four that carry a patient on a barrow. These troops pick up a patient and transport him on the direct way to his destination. Thus, they choose the optimal (shortest) paths avoiding obstacles.

The hospitals are typically far away and not part of the disaster area communication network. The vehicles of the *transport zone* (e.g. ambulance coaches) transport the patients to the hospital. Thus, these transport units typically arrive and leave the network perpetually. After a unit has arrived in the stand-by area it joins the communication network. When there is a (tactical) request for a transport, one of the units in the stand-by area picks up the patient and brings him to the hospital. Thus, it leaves the communication network after having picked up the patient. These transport units as well as the troops above choose optimal paths and will avoid obstacles. Beside ambulances there may also be helicopters as faster transport units. However, helicopters typically use different communication channels and do not join the local disaster area communication network.

Especially transport units and troops often move in tactical formation (e.g. four people carrying an injured person on a barrow or three persons in an ambulance coach). This would imply a group mobility model. However, only the nodes that have a communication device are of interest for communication network analysis. Nowadays, only one node of such a tactical formation has a communication device. Thus, from the communication perspective in disaster areas (at the moment), there is no group movement. In the future, it may be affordable or necessary to provide each unit with its own communication device. Thus, group mobility is an extended or optional aspect.

As mentioned above, the transport units that take a patient to the hospital are typically vehicles. Thus, there are heterogeneous speeds in a disaster area. Some units (vehicles) move faster than others (pedestrians).

As a conclusion, the analysis yields the following main characteristics:

- Heterogeneous area-based movement
- Movement on optimal paths avoiding obstacles
- Nodes join and leave the scenario in specific areas
- Group mobility (optional)

The following section deals with existing mobility models and examines with which of these models the characteristics can be modelled.

3. RELATED WORK

In recent years a lot of different mobility models have been proposed and used for performance evaluation of networks (cf. [7]). For network performance analysis abstract models like the abstract Random-Waypoint-Mobility-Model [14] or Gauss-Markov-Mobility-Model [20] are mainly used. Both models describe random-based movement and distribute the nodes over the complete simulation area. Recently, there were several studies (e.g. [5], [29], [19]) that analyse the Random-Waypoint-Model with respect to implicit (unwanted) assumptions and characteristics. A distribution and movement of the nodes over the complete simulation area does not fit to the characteristics of a disaster area. There are extensions (e.g. [5]) which add attraction points to this model in order to generate more realistic non equally distributed movement: The probability that a node selects an attraction point or a point in an attraction area as next waypoint is larger than the choice of other points. The nodes visit some points more frequently than others. Several realistic scenarios (e.g. pop concerts) can be modelled quite realistically by using this extension. However, the nodes still move over the complete simulation area.

There also is a pixel-oriented approach [16], in which the complete simulation area is divided into little parts (pixels). While creating the movement of a node the probability moving into a neighbour-pixel is considered. There may be higher probabilities for some pixels (areas) but the nodes still move over the complete simulation area.

Other models e.g. the Reference Point Group Mobility Model (RPGM) [10] consider movement of groups and relative movement inside groups. The movement of a node in a group is calculated in relation to the movement of the group reference point. This approach may be used to realize the optional group mobility characteristic. Hence, the choice of the way of the reference points is a challenge. The existing model uses a Random Waypoint approach. By doing so the groups move over the complete simulation area.

Furthermore, there are models which take obstacles into consideration (e.g. [12], [30]). The paths between the obstacles (e.g. walls of buildings in a campus scenario) are calculated using algorithms based on Voronoi-diagrams. However, using Voronoi-diagrams does not provide the direct or shortest path. Instead, the distance to all obstacles is maximised.

Other approaches divide the simulation area in sub-areas. In each sub-area one of the general models described above (e.g. RWP) is used [6], [9]. The nodes are also allowed to switch the areas and thereby switch to another mobility model. These models realize different kinds of areas. Hence, the movement between these areas is neither based on tactical issues nor on optimal paths. Furthermore, the nodes can switch from area to area and thus move across the complete simulation area.

Models following a user-oriented approach ([24], [25]) model the movement of a node based on the movement-paths of a typical user (e.g. all movement during a workday). Furthermore, there is an approach basing on social connections [22]. There are also models for vehicular traffic [17], which base on road-maps and speed information. These models do not fit for disaster areas due to their specific assumptions.

Furthermore, there is one approach [13], where some simulations of a disaster area were done. In these simulations, the movements are neither based on any specific mobility model nor are the disaster area concepts similar to the ones in the previous section considered.

Besides this, there is also the possibility of using movement traces (trace-based simulation). The challenge concerning trace-based simulation is the acquisition of representative traces. For example, there is an approach using traces of a (ego-shooter) network game [26]. Concerning this approach, (in our opinion) the traces can not be expected to be representative for real movement traces. Furthermore, there are traces from a campus scenario [15]. These traces can not be expected to be representative for disaster area movement.

In general, there are a lot of different models: There are general ones which model uniform movement over a simulation area; on the other hand there are specific models which may be used for modelling movement in specific scenarios. The models differ in their level of abstraction and number of implicit assumptions. None of the existing approaches or models represents all characteristics we figured out in the previous section. Thus, to the best of our knowledge, there is no existing realistic mobility model for a disaster area scenario.

4. THE DISASTER AREA MOBILITY MODEL

In section 2 we figured out main characteristics of movements in a disaster area scenario. In this section, we describe the way our new disaster area mobility model represents these characteristics. The optional group mobility characteristic is left for future work.

4.1 Heterogeneous area-based movement

To realize area-based movement, the simulation area F is divided into disjunct tactical (sub-)areas. These areas are classified according to the concept separation of room (cf. section 2) in *incident location (IL)*, *patients waiting for treatment area (PWT)*, *casualties clearing station (CCS)*, *ambulance parking point (APP)*, and *technical operational command (TOC)*. Technically a disaster area scenario S consists of a simulation area F, a set of tactical (sub-)areas R, and a set of obstacles H. A tactical area $r \in R$ is a tuple:

$$\begin{aligned} r = \quad & (l_r, P_r, e_r, a_r, N_r^{stat}, V_r^{stat}, T_r^{stat}, G_r^{stat}, \\ & N_r^{trans}, V_r^{trans}, T_r^{trans}, G_r^{trans}, Z_r^{trans}) \end{aligned}$$

where:

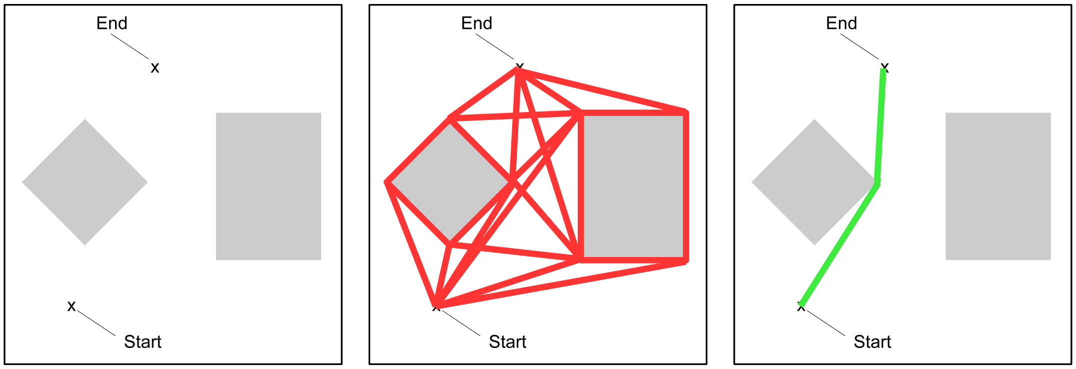
- $l_r \in \{\mathrm{IL}, \mathrm{PWT}, \mathrm{CCS}, \mathrm{APP}, \mathrm{TOC}\}$, the tactical classification of the sub-area,
- $P_r \subset F$ a (polygonal) part of the area F,
- e_r and a_r two points on the border of P_r (see below),
- N_r^{trans} and N_r^{stat} two sets of nodes (see below),
- V_r^{trans} and V_r^{stat} intervals $[v_{min}; v_{max}]$ for velocities of the sets of nodes N_r^{trans} and N_r^{stat}
- T_r^{trans} and T_r^{stat} intervals $[t_{min}; t_{max}]$ for the pause time of the set of nodes N_r^{trans} and N_r^{stat}
- G_r^{trans} and G_r^{stat} sizes of groups,
- Z_r^{trans} a sequence of points or movement cycle of the transport nodes (see below).

Each tactical area r has an entry-point e_r and an exit-point a_r. Nodes that transport patients can leave the area only via these points. The modelling is motivated by entry and exit registration points for the patients in disaster areas.

Each node is assigned to one of the tactical areas. Moreover, a node belongs to one class: Either it is stationary (stays in the distinct area, moves only inside P_r) or it is a transport node (carries patients to the next area, based on Z_r^{trans}). N_r^{stat} are the stationary nodes assigned to the area, while N_r^{trans} are the transport nodes assigned to the area.

For *technical operational command* and *casualties clearing station* areas there are only stationary nodes. Thus:

$$\forall r \in R | l_r \in \{\mathrm{CCS}, \mathrm{TOC}\} : N_r^{trans} = \emptyset, Z_r^{trans} = \emptyset$$



(a) map (b) visibility graph (c) optimal path

Figure 2: Example for finding an optimal path

In *incident location* areas all nodes are transport-nodes:

$$\forall r \in R | l_r = \mathrm{IL} : N_r^{stat} = \emptyset, Z_r^{stat} = \emptyset$$

The area and the class the node belongs to define the movement of the node. Different areas and classes allow different speed intervals distinguishing between pedestrians and vehicles. Stationary nodes move according to the random waypoint model. A unit inside the area gets a new order, moves to the point, works there for a certain time, and gets the next order.

Transport nodes move from one area to another following a movement cycle Z_r^{trans} choosing one velocity of the interval V_r^{trans} for the whole cycle. The cycle depends on the class of the tactical area the node is assigned to:

Incident location: $r \in R | l_r = \mathrm{IL}$
The transport nodes ($n \in N_r^{trans}$) of an *incident location* start in the exit point a_r of their area. There they select a random point $rand \in P_r$ in the *incident location* and move to this point. From there they move via the exit point a_r of their area to the entry point of a randomly chosen *patients waiting for treatment area* $e_{\mathrm{PWT}_{rand}}$. Finally, they move back to the exit point a_r of their *incident location*. This cycle models a unit picking up a patient in his *incident location* and carrying the patient to a *patients waiting for treatment area*. The cycle for the transport nodes of this area is: $Z_r^{trans} = a_r, rand, a_r, e_{\mathrm{PWT}_{rand}}, a_r$. At the points $rand$ and $e_{\mathrm{PWT}_{rand}}$ the node waits for a uniformly distributed pause time chosen from T_r^{trans}. This models the first aid and the handing over of a patient.

Patients waiting for treatment area: $r \in R | l_r = \mathrm{PWT}$
The cycle of the transport nodes of the *Patients waiting for treatment area* is similar to the one of the incident location. The difference is that the patients are carried from a *patients waiting for treatment area* to a *casualties clearing station*. The cycle for the transport nodes of this area is: $Z_r^{trans} = a_r, rand, a_r, e_{\mathrm{CCS}_{rand}}, a_r$

Ambulance parking point: $r \in R | l_r = \mathrm{APP}$
The transport nodes ($n \in N_r^{trans}$) move after entering the scenario at the entry e_r of the *ambulance parking point* to a random point $rand \in P_r$ inside the area. After a randomly chosen pause time they leave the parking point using the exit a_r. From there they move to the exit $a_{CSS_{rand}}$ of a randomly chosen *casualties clearing station*. After waiting some time at this exit they leave the scenario. This movement cycle models units in an ambulance (vehicle) entering the scenario, waiting for a mission on a parking position in the *ambulance parking point*, picking up a patient at a *casualties clearing station* exit and finally leaving the simulation area to take the patient to a hospital. As the details concerning entering and leaving are described separately in section 4.3, the cycle can be found there as well.

4.2 Movement on optimal paths avoiding obstacles

The optimal path for the movement of the transport units between the different areas is determined by methods of robot motion planning (cf. [4]). The simulation area F is regarded as a planar, static region with polygonal obstacles H. We further assume that the obstacles are simple polygons (without holes and non-self-intersecting). We take this assumption to enable the use of standard algorithms of robot motion planning. For the motion planning all areas are also regarded as obstacles, because the transport units are not allowed to transport the patients through other areas. Thus, without loss of generality we assume P_r to be a simple polygon as well.

For finding the shortest paths avoiding obstacles, visibility graphs are used. A visibility graph is a graph where its vertices are the vertices of the obstacles (polygons). There is an edge between two vertices if the vertices can "see" each other meaning the edge does not intersect the interior of any other obstacle.

Furthermore, the start and end position of the movement between the areas (the entry and exit points of the areas) have to be added as vertices to the graph. The shortest path between two points consists of an appropriate subset of the edges of the visibility graph [4].

Thus, after having calculated the visibility graph containing all possible shortest paths between the areas avoiding obstacles, the shortest movement path between two areas for each transport unit can be calculated. The edges of the visibility graph are weighted according to the Euclidean distance. Dijkstra's algorithm can be used on the visibility graph.

Figure 2 shows an example. In figure 2(a) a map is shown. There are two polygonal obstacles and a start and end point which may be entry and exit points of an area. Figure 2(b) shows the visibility graph. There are edges between the vertices of the polygons as well as the start and end point when the edge does not intersect the interior of another polygon.

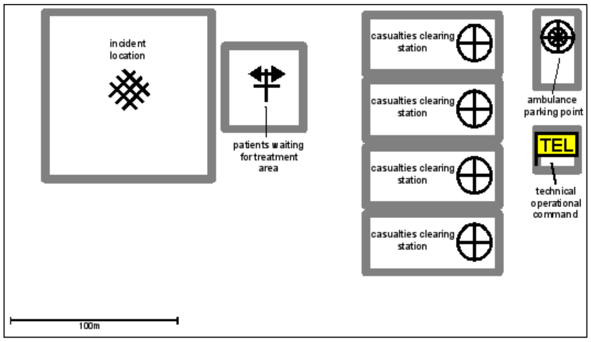


Figure 3: Scenario - tactical map

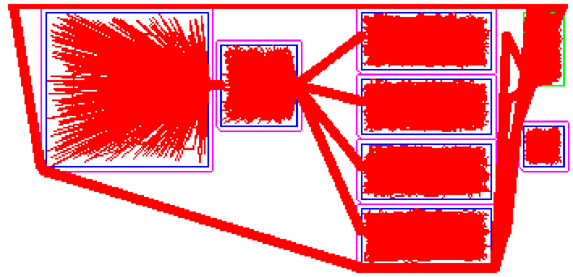


Figure 4: Movements for the scenario

Area	Nodes (overall)	Transport Units
incident location	15	15
patients waiting for treatment area	39	37
casualties clearing stations	60 (4*15)	0
ambulance parking point	30	28
technical operational command	6	0
all areas	150	80

Table 1: Distribution of devices

Figure 2(c) shows the resulting shortest path between the start and end point. The edges are weighted according to their Euclidean distance and Dijkstra's algorithm is used.

The approach above assumes the nodes to be points of infinitely small size. To implement larger nodes or groups of nodes with a certain spreading, the gap between two obstacles has to be large enough. To implement this, all obstacles are enlarged with the maximal spreading of the group. For this purpose Minkowski sums (cf. [4]) can be used. Thus, visibility graphs can also be used to calculate optimal paths for nodes of larger size.

4.3 Nodes join and leave the scenario

As mentioned above, vehicular transport units (e.g. ambulances) typically leave the disaster area to carry patients to hospital. Thereby they also leave the communication channel. In (tactical) consequence of the leaving transport units, new ones arrive and wait at the *ambulance parking point*. These facts are modelled in the movement cycle of the vehicular transport nodes. After having picked up a patient at the *casualties clearing station* exit $a_{CSS_{rand}}$, they drive from there to the global scenario exit point a_S on a direct path. Here they are switched off. Then they move on the border to the scenario entry point e_S near the *ambulance parking point* and move there arriving through its entrance e_r, where they are reset and switched on again. This models the leaving of ambulances that take patients to hospital and new ones arriving. The following movement cycle results for the transport nodes of an *ambulance parking point*: $Z_r^{trans} = e_r, rand, a_r, a_{CCS_{rand}}, a_S, e_S, e_r$. This modelling allows us to realize joining and leaving nodes with a constant number of nodes. However, by doing so the number of active nodes in the scenario varies.

5. MODELLING A DISASTER AREA SCENARIO

After having described our new disaster area mobility model we describe one specific scenario based on a disaster area manoeuvre. Based on this, we model the movement using our new model and other less detailed existing ones. In the following sections, the goal is to show that the more detailed modelling yields specific characteristics that have an impact on the results of performance evaluation. Thus, we implemented our new model in the motion generator Bonnmotion [27] which provides implementations for several models described in section 3.

5.1 The Scenario

The scenario is based on a large catastrophe manoeuvre. The manoeuvre took place in May 2005 in Cologne, Germany, in preparation of the World Youth Day 2005 and the FIFA Soccer Worldcup 2006. The scenario was that more than 250 people were injured by a catastrophe in an event hall. The different areas (described in section 2) for this scenario are depicted in figure 3. The whole area is approximately 350m x 200m. There is one *incident site*, the event hall. There is one *patients waiting for treatment area*, directly in front of the hall. The patients are taken to four *casualties clearing stations*. Furthermore, there is a *technical operational command* and an *ambulance parking point*.

More than 955 disaster area units (firefighters, paramedics, etc.) and 279 vehicles of four administrative districts joined the manoeuvre over the time. As communication system, several broadcast voice channels of the analog German national radio system, called BOS-system (68-87.5 MHz and 146-174 MHz), were used.

Only a subset of the 955 units was equipped with own communication devices. We approximate the number of these devices used by 150. The distribution of the devices to the different areas can be found in table 1.

5.2 Disaster area mobility model

We modelled this scenario with the disaster area mobility model as described in section 4. As speed ranges for pedestrians and vehicles we used 1-2m/s and 5-12m/s, respectively. We only modelled the units with communication devices. In particular, we did not model the optional group mobility characteristic.

The entrance and exit points are set on the middle of the areas vertical border. The scenario entry and exit points for the vehicular transport units were set left and right on the upper border of the scenario (for a complete Definition see appendix). A resulting sample movement (paths of all nodes) is depicted in figure 4. The different areas as well as entry and exit point can be clearly identified.

5.3 Random Waypoint with attraction points

We modelled the scenario with the Random WayPoint (RWP) mobility model as well as with the RWP model with attraction points. The RWP model is, although a simple one, the one most frequently used in the research community. By comparing the new disaster area model to RWP, the goal is not to show that there are differences as this could be expected. The goal is to characterise the disaster model in comparison to the model most frequently used to estimate the impact on the evaluation results in the literature. Furthermore, by showing results for the RWP model the results may become more intuitively comprehensible.

The extension with attraction points aims at similar characteristics like the disaster area model (especially explicitly modelling areas with higher node density). Thus, it may be seen as a very rough modelling for disaster areas. It is interesting to figure out whether our complex model has significant characteristics different from this extension to the RWP model.

For both models we used the same size of the simulation area of 350m x 200m. The attraction points of the extension were placed into the centres of the tactical areas (cf. figure 3). With both models it is not possible to model heterogeneous speeds. Thus, we modelled both models once with the speed ranges of pedestrians (1-2m/s) and once with the speed ranges of vehicles (1-12m/s). We decided not to extends the models concerning heterogeneous speed ranges for different nodes as other (especially analytical) studies assume uniform speed ranges and we want to estimate the impact on the evaluation results in the literature.

6. MODEL EVALUATION

After deriving models for the scenario, we want to evaluate the characteristics of the resulting movement. The goal is to show, whether the new disaster area model has specific impact. First, we describe the metrics used. We have to extend existing ones to support varying number of nodes. Finally, we present evaluation results using these metrics.

6.1 Metrics to characterise Mobility

In the literature, several different mobility metrics can be found. In [3] several metrics are proposed in a framework and classified as protocol independent metrics and protocol performance metrics, respectively. In this section, we focus on protocol independent metrics. Protocol dependent metrics will be used in the next section. We use (protocol independent) metrics of two classes: (1) *pure movement metrics* and (2) *link based metrics*. The existing metrics do not consider a varying number of nodes. In contrast to this, in our new disaster area model some nodes do leave the simulation area (switch off) and others come in later (switch on). Thus, the existing metrics have to be enhanced.

For the metrics of the first class, the nodes should be weighted according to the fraction of time they are switched on. Concerning the first class, there are straightforward ones, like the average velocity:

$$V_n^{on} = \sum_{i=1}^{n} \frac{t_i^{on}}{\sum_{j=1}^{n} t_j^{on}} * \frac{d_i^{on}}{t_i^{on}} = \frac{\sum_{i=1}^{n} d_i^{on}}{\sum_{j=1}^{n} t_i^{on}} \quad (1)$$

where n is the number of nodes, d_i^{on} the distance a node i moved while he is switched on, and t_i^{on} the time a node i is switched on.

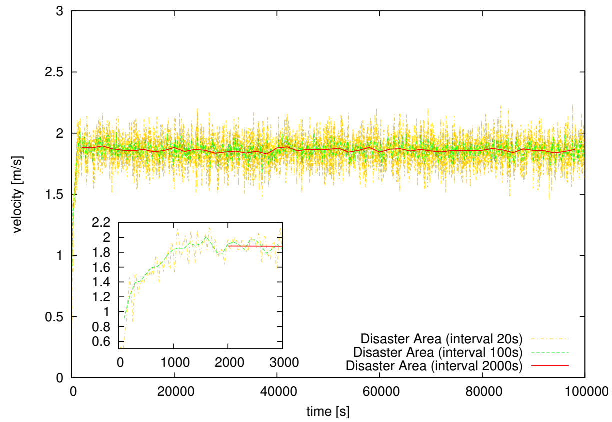


Figure 5: Average velocity over time

Johansson et al. [13] proposed a metric for the relative mobility. The relative mobility can be extended similar to

$$M^{on} = \sum_{x,y} \frac{t_{x,y}^{on}}{T^{on}} M_{xy} = \frac{1}{T^{on}} \sum_{x,y} \int_{t_0}^{t_0+T} |v^{on}(x,y,t)| dt \quad (2)$$

$$T^{on} = \sum_{x,y} t_{x,y}^{on} = \sum_{x=1}^{n} \sum_{y=x+1}^{n} t_{x,y}^{on} \quad (3)$$

$$M_{xy}^{on} = \frac{1}{t_{x,y}^{on}} \int_{t_0}^{t_0+T} |v^{on}(x,y,t)| dt \quad (4)$$

where T is the observed duration and where $t_{x,y}^{on}$ is the time node x and y are simultaneously switched on and

$$v^{on}(x,y,t) = \begin{cases} 0 & x \text{ or } y \text{ off at } t \\ \frac{d}{dt}(l(x,t) - l(y,t)) & x \text{ and } y \text{ on at } t \end{cases} \quad (5)$$

where $l(x,t)$ is the location of node x at time t. Thus, the relative mobility is the average relative velocity of two nodes averaged over all pairs of nodes.

Link based metrics depend on links between two nodes. A link between two nodes a and b exists if a is inside the communication range of b and if a and b are switched on. Whether a link exists or not depends on the propagation model assumed. For simplicity reasons, often times a circular range around a node is assumed. Based on links, several metrics can be defined. One is the *average node degree*; it shows to how many nodes one node is connected on the average. It is a measure for the node density. Another is the *average time to link break*. In contrast to the average link duration only links that break are counted. This metric shows how often links and - based on this - routes break.

Furthermore, range based metrics (e.g. [18], [3]) have been proposed. These metrics contain a range around the node (e.g. transmission range or communication range) as one parameter. The choice of this range parameter is not trivial. Determining a range (e.g. communication range), allows us to directly calculate links. Thus, we decided to focus on the link based metrics as they may also be used with more realistic propagation models.

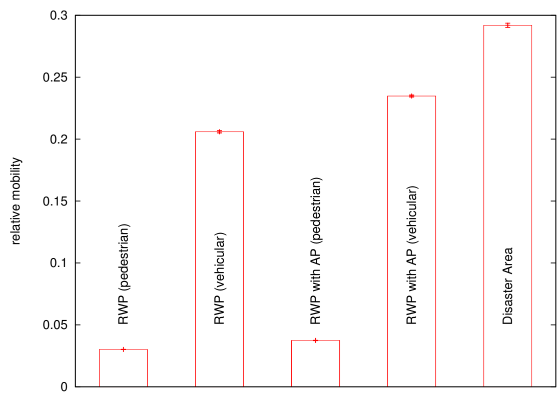


Figure 6: Relative mobility

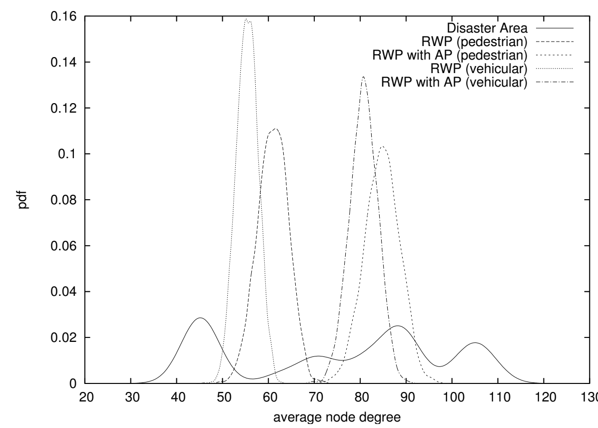


Figure 7: Average node degree distribution

6.2 Evaluation

First we examine how long it takes until the new model reaches a steady state. The average velocity was calculated for intervals of 20, 100, and 2,000s. Figure 5 shows the average velocity (calculated by eq. 1) over time for one simulation run of 100,000s for the disaster area model. The disaster area model needs at most 5,000s to reach a steady state. Thus, we assume an initial phase of 5,000s for the generation of the following movement traces.

Thus, we generated 20 movement traces of length 3000s (after the initial phase) for each model. Figure 6 shows the relative mobility (calculated by eq. 2); mean and 0.95 confidence intervals of the 20 replications. The relative mobility of the disaster area model is even larger than the one of the RWP models with higher velocity. The larger relative mobility for the disaster area model is caused by the smaller areas. The destinations inside these areas are reached faster. Thus, the probability that two nodes move with small relative distance is smaller. This yields a larger relative mobility.

The model also has an impact on the link based metrics. We calculated them for communication ranges from 10m to 200m for all 150 nodes of each of the 20 replications. Figure 7 shows the average node degree distribution density functions for the different models for a communication range of 100m. The RWP models show unimodal distributed average node degrees with small variance. The disaster area model yields a heterogeneous average node degree. There are nodes which have a lot of neighbours while others only have a few. In the disaster area model not all nodes are affected by the restriction to the areas. The transport units that move between the areas lead to this specific node degree. Due to the high node density inside the areas power control would be preferable. However, the algorithms have to be sophisticated, because simple reduction of transmission power would partition the network and separate the nodes with low average node degree. Thus, one challenge for future work is to find power control algorithms for this scenario.

Furthermore, the average time to a link break shows significant differences (cf. figure 8). While it raises with larger communication range for the RWP models, it stays quite constant for the disaster area model. The joining and leaving nodes cause link breaks when they leave the scenario. Note: for the nodes inside the areas the links are perpetual over the whole time. Thus, they do not affect this metric.

Overall, compared to the commonly used synthetic RWP model the new heterogeneous disaster area model with its spatial node distribution shows specific characteristics and significant differences. There is a higher relative mobility paired with heterogeneous average node degree and a lower average time to link break. None of the models we studied in addition to the RWP model showed similar results. These specific characteristics do also have an impact on the results of performance evaluation.

7. SIMULATIVE EVALUATION

In this section we show that using the new disaster area model has an impact on simulative network performance analysis. As example for a communication system we use a MANET. We perform simulations using ns-2.29 and extended it to support nodes that are switched on and off. Before a node is switched on it is reset.

We used the TwoRayGround propagation model with a uniform communication range of 100m. As MAC protocol IEEE 802.11b Wireless LAN with 11 MBit/s was chosen. As routing protocol we used the On-Demand Multicast Routing Protocol (ODMRP) [28].

The traffic was modelled as disaster area multicast voice traffic using a three state semi-markov model as proposed in [2]. In analogy to the manoeuvre there is one multicast talk group for each *casualties clearing station*, one for the *incident location* and *patients waiting for treatment area*, and one global command talk group. The global command talk group is really important as it is the connection of the *technical operational command* to the specific tactical areas. Thus, there are five talk groups used for local communication and the command talk group for global communication. We modelled the voice traffic according to the MELPe [8] codec (developed for tactical communication) with 1.2kbps and Forward Error Correction (FEC) of 1:2. This results in 21 byte IP payload every 67.5ms. For each new call, a sender was selected randomly from the group members (equally distributed). For simplicity reasons, the transport nodes that can leave the scenario (switch on and off) are no senders.

As simulation time we chose 3,000s and performed 10 replications for each mobility model. We chose such a large simulation time due to long movement cycles of the different transport units.

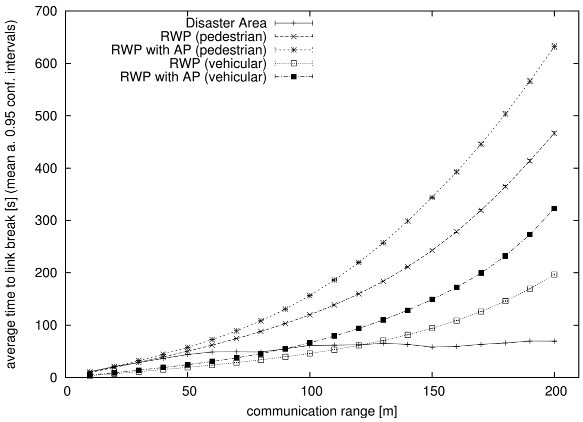


Figure 8: Average time to link break

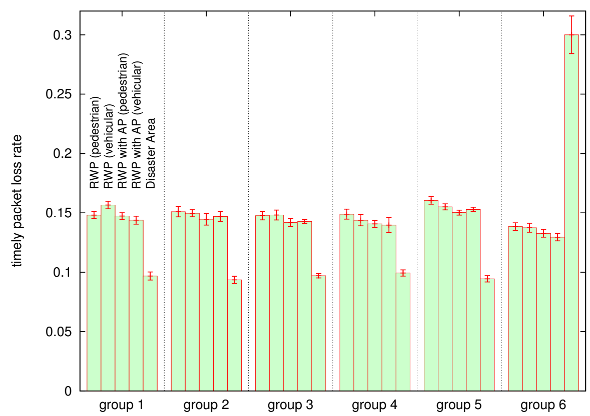


Figure 9: Timely packet loss rate

To examine whether the disaster area mobility model has an impact on the performance of the network, we measured the *timely packet loss rate* - a combination of packet loss rate and packet delay - for each talk group:

$$PLR_G^{\delta} = \frac{\sum_{\forall n \in G} |P_n - R_n^{\delta}|}{\sum_{\forall n \in G} |P_n|}$$

where G is a talk group, R_n^{δ} is the number of application data packets of the talk group G received by nodes n with a delay smaller than δ, and P_n is the number of application data packets a node n of the group G should have received. The traffic simulated is voice traffic. Thus, the packet delay δ has a decisive impact on application data. A packet that is too late will not be of any use for the voice data communication. Thus, we assumed a packet with a transmission delay larger than a threshold as lost. According to [11] a time of 150ms can be assumed as a threshold.

Figure 9 shows the average PLR_G^{150ms} and 0.95 confidence intervals for 10 replications for each talk group and mobility model. For the different RWP models the PLR_G^{150ms} is about 15% for all talk groups.

For disaster area mobility model the PLR_G^{150ms} for the local talk groups (groups 1-5) is about 5% smaller compared to the RWP models. In the disaster area mobility model the nodes using a local talk group are positioned inside one area. There may be collisions due to the higher node density, but the number of hops the packets are transmitted is small (a lot of one-hop connections).

For the global command talk group (group 6) the PLR_G^{150ms} of the disaster area mobility model is twice as high as for the RWP models. This is caused by the wider distribution of the nodes to the tactical areas. The global command talk group is used for inter-area communication. Thus, the paths for this talk group are longer. Furthermore, on these longer paths the packets are forwarded through the quite clustered tactical areas (cf. the large average node degree in section 6.1). Thus, the packets of the global command talk group are more likely to get lost or at least delayed on the MAC layer.

Overall the simulation results confirm the results of the previous section. The heterogeneous average node degree causes larger packet losses for the global command talk group. From a tactical point of view this talk group is the one most important for the success of the mission. If the tactical commands are lost the whole mission may fail. Thus, the disaster area mobility model shows decisive impact on the results of this exemplary performance evaluation in a disaster area scenario.

8. CONCLUSION AND FUTURE WORK

In this paper we proposed a new mobility model for disaster area scenarios. Disaster area scenarios exhibit structured movement based on civil protection tactics. Therefore, it is possible to create a realistic mobility model for disaster areas. The new model supports heterogeneous area-based movement on optimal paths avoiding obstacles with joining/leaving of nodes.

According to the new model we modelled one disaster area scenario based on a manoeuvre. To examine the impact of more realistic modelling, we compare it to the existing commonly used RWP model. The new model shows significant differences. There is a higher relative mobility paired with heterogeneous node density and even for larger communication ranges a lower average time to link break. These specific characteristics do also have an impact on the results of performance evaluation.

The impact of the new model on network simulation was examined. The new model allows a realistic traffic modelling. Traffic groups can be combined with tactical areas. The timely packet loss rate is larger for the global command talk group in the disaster area scenario. Thus, modelling with the new model discloses new information and has a significant impact on performance analysis.

In the future, we plan to extend the model evaluation concerning further scenarios and comparison to other existing mobility models. Furthermore, the impact of the optional group mobility feature has to be evaluated. Additionally, we want to carry out a performance analysis e.g. of power control algorithms and routing protocols in disaster area scenarios.

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APPENDIX

In this appendix a complete definition of all tactical areas for the disaster area model is given. The scenario modelled is the one described in section 5.1.

$$R_{DA} = \{r_{\text{CCS1}}, r_{\text{CCS2}}, r_{\text{CCS3}}, r_{\text{CCS4}}, r_{\text{TOC}}, r_{\text{IL}}, r_{\text{PWT}}, r_{\text{APP}}\}$$

$$\begin{aligned}
r_{\text{CCS1}} &= (\text{CCS}, ((220,5),(300,5),(300,40),(220,40)),\\
&\quad (220,20),(310,20),\\
&\quad \{n_0,..,n_{14}\},[1:2],[0:20],1,\\
&\quad \emptyset,[..],[..],0,\emptyset)\\
r_{\text{CCS2}} &= (\text{CCS}, ((220,46),(300,46),(300,80),(220,80)),\\
&\quad (220,60),(310,60),\\
&\quad \{n_{15},..,n_{29}\},[1:2],[0:20],1,\\
&\quad \emptyset,[..],[..],0,\emptyset)\\
r_{\text{CCS3}} &= (\text{CCS}, ((220,86),(300,86),(300,120),(220,120)),\\
&\quad (220,100),(310,100),\\
&\quad \{n_{30},..,n_{44}\},[1:2],[0:20],1,\\
&\quad \emptyset,[..],[..],0,\emptyset)\\
r_{\text{CCS4}} &= (\text{CCS}, ((220,126),(300,126),(300,160),(220,160)),\\
&\quad (220,140),(310,140),\\
&\quad \{n_{45},..,n_{59}\},[1:2],[0:20],1,\\
&\quad \emptyset,[..],[..],0,\emptyset)\\
r_{\text{TOC}} &= (\text{TOC}, ((320,75),(345,75),(345,100),(320,100)),\\
&\quad (330,75),(330,76),\\
&\quad \{n_{60},..,n_{65}\},[1:2],[0:20],1,\\
&\quad \emptyset,[..],[..],0,\emptyset)\\
r_{\text{IL}} &= (\text{IL}, ((25,5),(125,5),(125,100),(25,100)),\\
&\quad (25,50),(125,50),\\
&\quad \emptyset,[..],[..],0,\\
&\quad \{n_{66},..,n_{80}\},[1:2],[0:20],1,\\
&\quad ((25,50),rand,(25,50),e_{\text{PWT}_{rand}},(25,50)))\\
r_{\text{PWT}} &= (\text{PWT}, ((133,25),(180,25),(180,75),(133,75)),\\
&\quad (133,50),(180,50),\\
&\quad \{n_{81},n_{82}\},[1:2],[0:20],1,\\
&\quad \{n_{83},..,n_{119}\},[1:2],[0:20],1,\\
&\quad ((180,50),rand,(180,50),e_{\text{CCS}_{rand}},(180,50)))\\
r_{\text{APP}} &= (\text{APP}, ((320,5),(345,5),(345,50),(320,50)),\\
&\quad (325,5),(325,50),\\
&\quad \{n_{120},n_{121}\},[1:2],[0:20],1,\\
&\quad \{n_{122},..,n_{149}\},[5:12],[0:20],1,\\
&\quad ((325,5),rand,(325,50),a_{\text{CCS}_{rand}},(5,0),(345,0)))
\end{aligned}$$