

Tools for evaluation of social relations in mobility models

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Published online: 31 October 2017
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Abstract In MANET-DTN, the main idea is to detect the social relations between nodes in mobility models because the wireless mobile devices are carried by humans and the network uses the social relations to transport messages between isolated islands of the mobile terminals in order to increase the network performance. Today there are a lot of social and non-social mobility models. The problem is how to use these models in MANET-DTN. Therefore, proper evaluation method is needed, that is able to reveal the social aspect of investigated mobility model. Since there are a lot of methods that do not directly exhibit the social aspect of mobility models, in this paper the new evaluation method was proposed based on Louvain method for community detection and the other network graph parameter (average weighted degree). Simulations of evaluation method were made as a comparison between two random mobility models and one social based mobility model in order to point out differences between social and non-social mobility models. All models were evaluated by proposed method and other existing protocol dependent and independent methods. The main idea of the simulations was to analyse how the mobility mod-

els with social and non-social mobility models can affect the network performance and provide new and reliable tool, which enables analysis of the mobility models from social behaviour point of view.

Keywords MANET-DTN · Social behaviour · Mobility model · MANET routing protocols · Evaluation tool · Evaluation method

1 Introduction

Nowadays we live in the wireless world. Rapid developments of the wireless technologies give us the possibility to use many types of the mobile wireless network. Part of this world is also Mobile Ad-hoc Networks (MANET), and Delay Tolerant Networks (DTN) and MANET-DTN networks. MANET-DTN networks consist of autonomous wireless devices that moves and communicate wirelessly with each other using dedicated routing protocols. While MANET network routing protocols function well in the environment, where the end-to-end multihop path is necessary, DTN networks allow devices to deliver messages without end-to-end path connection by using the store-carry-forward technique with some delay. DTN by the selects devices that is are considered as the best carrier of the message to the destination device. Therefore, the connection of MANET-DTN networks also known as hybrid MANET-DTN networks integrates the benefits of the MANET routing protocols in the end-to-end environment where all devices are connected and benefits of DTN forwarding techniques when no end-to-end path exists [1]. Researchers and scientists are still trying to create new routing protocols for these networks [2,3]. They trying to create effective and well-functioning protocols in terms of message delays, delivery success and so on. To

This work was performed in the framework of research project VEGA 1/0075/15, funded by the ministry of education of Slovak Republic.

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obtain this kind of information, they need a proper simulation tool. For this purposes, mobility models were made. Many of them use a random movement of nodes that simulate mobility of devices or this movement used by models does not capture the real life movement of people. For simulation purposes of MANET-DTN networks where nodes are always moving is better, if the mobility of the nodes captures a real mobility of humans as mobile devices carriers. People are social individuals so they live and move in social groups. For this reason is critical to capture this behaviour in order to create a social based mobility model. Therefore, social mobility models become popular simulation tools in MANET-DTN networks and many researchers and scientists rely on social behaviour [4–7] and also social mobility models are useful in simulations where positioning systems are tested [8].

1.1 Motivation and innovation

In MANET-DTN networks environment is common that mobility of nodes causes disconnection of the network into disconnected islands of the nodes. In order to simulate the real movement of nodes and network disconnections, it is appropriate to use mobility model that uses human mobility patterns. Routing protocols and forwarding techniques of MANET-DTN needs to handle those situations. The main problem is the selection of reliable and secure nodes that are responsible for transportation of messages between isolated islands with limited connectivity [1]. By using real human mobility models, movement and disconnections are not only more realistic but also the selection of the reliable and secure nodes is more effective. Therefore, it is critical to choose proper mobility model. Today there are a lot of social [9] and non-social mobility models that are used to simulate the behaviour of nodes in MANET-DTN networks. In order to choose proper one with social or non-social movement, a good and reliable evaluation tool that evaluates the social aspect of mobility models is needed. Therefore, we propose Tools for Evaluation of Social Relations in Mobility Models (TESRMM) as a new evaluation method that is able to reveal the social aspect of considered mobility model.

Another problem is, that some researchers use many different mobility models with different parameters without analysis of movement. In authors' simulations with social movement is important to know, how strong relation ties among nodes are, how the nodes behaviour influence functionality of mobile network and how evaluations of mobility model and results of routing protocols interrelate between each other. Successful message transfer through the mobile network and other routing parameters could be misrepresented and misinterpreted without that information. With proposed evaluation method is possible to analyse mobility models based on grouping of nodes into communities and social relationships among communities and nodes in each

community. This new evaluation method was created based on existing Louvain method and network parameters. We adapted those algorithms and parameters in an effort to evaluated social behaviour and relation ties among nodes from the movement of mobile nodes. Evaluation method uses the multiplicity of contacts among nodes directly from mobility models.

The innovation of the concept comes from reason, that some authors and researchers using protocol dependent and independent methods such as transmission probability, inter-contacts time, contact duration and more as evaluation methods. Those analytical and probabilistic methods do not directly exhibit the social aspect of mobility models. Our research was focused more on social aspect in order to reveal whether the mobility model is showing signs of sociality. By using adopted methods such as Louvain method for community detection, is possible to analyse grouping of nodes, how strong are relationships among nodes and also if the mobility of nodes is random or based on social or grouping patterns. Parameters of proposed method along with graphical interpretation can provide a better understanding of movement in mobility models and help with the selection of proper mobility model for considered simulations.

The article is organised as follows. Section 2 briefly described the existing evaluation methods. In Sect. 3 we propose TESRMM and Sect. 4 describes the simulation of proposed evaluation method along with other methods. Main results that are analysed and compared with random mobility models such as Random Walk mobility model and Matis model. At the end, we conclude this paper in Sect. 5.

2 Social based mobility models evaluation methods

This section briefly describes most commonly used evaluation methods for mobility models and social mobility models. Authors of mobility models use many evaluation methods. In [10] authors proposed two different types of metrics for a mobility models:

1. protocol-dependent metrics,
2. protocol-independent metrics.

Protocol-dependent metrics

Protocol-dependent metrics are usually the object of performance evaluation. Some examples of these metrics are as follows:

- **Packet Delivery Fraction (PaDF)** is the metric that evaluate the ratio of data packets delivered to the destination to those generated by the sources and is calculated as

follows:

$$PaDF = \frac{\text{Number of Packet Received}}{\text{Number of Packet Sent}} * 100[\%] \quad (1)$$

- **Average Throughput** (TP) [11] is the number of bytes received successfully (NBR) and is calculated by:

$$TP = \frac{NBR * 8}{\text{Simulation Time} * 1000} [kbps] \quad (2)$$

- **Routing overhead** (ROH) is the total number of control packets or routing packets generated by routing protocol during simulation and is obtained by:

$$\text{Routing Overhead} = \text{Number of RTR Peckets} \quad (3)$$

- **Average End-to-End** (E2E delay) [12] delay is the average time of the data packet to be successfully transmitted across a MANET from source to destination. The average E2E delay is computed in milliseconds by:

$$D = \frac{\sum_{i=j}^n (R_i - S_i)}{n} [ms] \quad (4)$$

where D is the average end-to-end delay, n is the number of data packets successfully transmitted over the MANET, i is the unique packet identifier, R_i is the time at which a packet with unique identifier i is received and S_i is the time at which a packet with unique identifier i is sent.

- **Packet Loss** is the difference between the number of data packets sent (NDPS) and the number of data packets received (NDPR). It is calculated as follows:

$$\text{Packet Loss} = NDPS - NDPR \quad (5)$$

Protocol-independent metrics

Protocol-independent metrics, as the name suggests, are independent of the protocols that are running on the network. This types of information can be extracted directly from the resulting mobility traces of nodes after simulation. In [10] authors presented several metrics:

- **Degree of Spatial Dependence** describing the similarity of the velocities of nearby nodes. In the case of a car or military column models, this value will be very high.

- **Degree of Temporal Dependence** describing the velocity of a node at two nearby time instances.
- **Relative Speed** of two nodes.
- **Geographic Restrictions** describing constraints on the degrees of freedom of the nodes (when models with obstacles are used).
- **Number of Link Changes** for a pair of nodes, is the number of time slots a link makes and breaks between these two nodes.
- **Link Duration** for a pair of nodes is the average time the link remains active once it becomes available.
- **Path Availability** is the time a path is available between a pair of nodes.
- **Number of Neighbours** is metric that can used as indicator of hotspots or group existence in mobility models.

Authors of some social mobility models also use other approaches that better describes a social context of mobility models. Some of them use cumulative distribution function (CDF). CDF can be used on many different types of data. For example, in [13] authors use CDF of inter-contact time and contact duration. Contact duration is defined as the time interval in which two devices are in radio range. Inter-contacts time is defined as the time interval between two contacts. Another type of evaluation method is probability distribution function (PDF). Authors in [14] used a PDF of the node degree, i.e. the number of neighbours.

Evaluation methods, such as CDF of inter-contact time and contact duration or PDF of node degree, can be used to exhibit some social aspect, but results of this methods must be interpreted well. For thus reasons we presented in Sect. 3 our evaluation method, that focus more on the social aspect of mobility models.

3 Proposal of simple tools for evaluation of social relations in mobility models

In this section the evaluation method for mobility models is described. This method reveals if the mobility of model that we investigated, shows signs of social behaviour. Authors in [15] observe that clustering level in models with social behaviour is usually far greater than in models with non-social behaviour. The authors suggest that this is related to the fact that humans usually organise themselves into communities. Therefore, we are trying to find out how many communities was created by the movement of nodes in particular mobility model. In the following sections, output format that is needed to be properly formatted in order to be used for evaluation are described. Then the description of the Louvain method algorithm and calculation of its parameters and also Average Weighted Degree as network parameter are provided.

Time slot t	Node 1		Node 2	Node m	
	x	y		x	y
t_1	550	630	102	128	648
t_2	740	752	⋮	789	652
⋮	⋮	⋮	⋮	34	742
t_n	455	360	756	⋮	⋮

Fig. 1 Example of 3 dimensional output matrix

3.1 Output format of the model

To use evaluation method, output format from mobility model needs to be described. During the simulation of the model, x and y positions are stored for every node. To do so, simulation time needs to divide into same time slots. Every time slot store positions of every node in simulation area. The output of the model is then the 3-dimensional matrix of positions in every time slot for every node shown in Fig. 1.

It is possible to see, that the first matrix (in front) is the matrix of positions in all time slots of node 1. The same matrix for node 2 is behind the matrix of node 1. Behind this matrices are all other matrices of all other nodes.

From this 3-dimensional matrix is calculated the Meetings matrix by the following mechanism:

1. For every time slot are calculated distances between nodes by using positions of nodes by the following formula:

$$d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \quad (6)$$

2. To represent a radio range between nodes (for example 10 m for Wi-Fi), the threshold needs to be set.
3. For every time slot is created a Boolean matrix where every distance between nodes in particular time slot less than defined threshold will be considered as 1 in Boolean matrix for the particular time slot, 0 otherwise.
4. Calculate a sum of all Boolean matrices from all timeslots together.

After step 4, Meetings matrix is created, where values in this matrix represent how many times each node met each other or how long they have been together. For example, node 1 met node 3 500 times in 1000 time slot simulation.

3.2 Communities detection based on Louvain method

The process of discovering communities is provided by Louvain method [16]. Because Louvain method is the main algorithm of the evaluation method, the description of the method and its parameters are provided. The adaptation of the method is based on the fact that proper input is needed to be used. Usage of the method in order to reveal communities and relationships among nodes from mobility models is possible if Meetings matrix from the previous section is used as input. Meetings matrix is, in fact, a weighted graph. This weighted graph will be used as a social network where nodes are vertices of this graph and edges represents contact among nodes. The edge between nodes will exist if and only if nodes that are taken into consideration met each other at least once. Authors of this method use a modularity quality for communities discovering. Modularity quality measures how well a given partition of a network compartmentalises its communities. The modularity of a partition is a scalar value between -1 and 1 that measures the density of links inside communities as compared to links between communities. The modularity can be either positive or negative. Positive values indicating that there is some community structure. To look for the best divisions of a network, it is good to have positive, and preferably large, values of the modularity. In the case of weighted graphs it is defined as [16]:

$$Q = \frac{1}{2m} \sum_{i,j} \left[A_{i,j} \frac{k_j k_i}{2m} \right] \delta(c_i, c_j) \quad (7)$$

where $A_{i,j}$ represents the weight of the edge between i and j , $k_i = \sum_j A_{i,j}$ is the sum of the weights of the edges attached to vertex i , c_i is the community to which vertex i is assigned, the δ -function $\delta(c_i, c_j)$ is 1 if $c_i = c_j$ and 0 otherwise and $m = \frac{1}{2} \sum_{i,j} A_{i,j}$. The gain in modularity Q is obtained by moving an isolated node i into a community C is computed as:

$$\Delta Q = \left[\frac{\sum_{in} + k_i}{2m} - \left(\frac{\sum_{tot} + k_i}{2m} \right)^2 \right] - \left[\frac{\sum_{in}}{2m} - \left(\frac{\sum_{tot}}{2m} \right)^2 + \left(\frac{k_i}{2m} \right)^2 \right] \quad (8)$$

where \sum_{in} is the sum of the weights of the links inside C , \sum_{tot} is the sum of the weights of the links incident to nodes in C , k_i is the sum of the weights of the links incident to node i , $k_{i,in}$ is the sum of the weights of the links from i to nodes

in C and m is the sum of the weights of all the links in the network.

The method algorithm is divided into two phases that are repeated iteratively. The input of the method is the social network as a weighted graph of N nodes. First, every node is assigned to the different community of the network. So, in the initial partition, there are as many communities as nodes. Then, for each node i is considered the neighbours j of i and the gain of modularity is evaluated in case of removing i from its community and by placing it in the community of j . The node i is then placed in the community for which this gain is maximum, but only in the case that this gain is positive. If no positive gain than i stays in its original community. This process is applied repeatedly and sequentially for all nodes until no further improvement can be achieved. Then the first phase is complete. The second phase of the algorithm is based on building a new network, which nodes are now the communities found during the first phase. The weights of the links between the new nodes are given by the sum of the weight of the links between nodes in the corresponding two communities. When the second phase is completed, resulting weighted network is reapply to the first phase for another iteration. These phases are iterated until there are no more changes and a maximum of modularity is attained. The output of the method is a number of communities, the number of nodes in each community and also modularity value. More about this method is in [16].

Mentioned Louvain method for community detection doesn't directly reflect the social behaviour of nodes in mobility models. For example, the method was previously used on the Twitter social network to explore the problem of partitioning Online Social Networks onto different machines. This method worked with static networks. So we adapt Louvain method for detection of social communities from resulting movement of mobility models in mobile networks, not just static network.

3.3 Average weighted degree

Another parameter that could be used as metric to describe social aspect is the average weighted degree. The weighted degree of a node is like a degree. It's based on the number of edge for a node but pondered by the weight of each edge. It's doing the sum of the weight of the edges. In our situation, where we need to observe the whole movement of nodes from Meetings matrix, which is basically weighted graph, the average weighted degree is the better parameter than classic node degree. When Meetings matrix is used, node degree just expresses how many nodes particular node met during simulation, while average node degree express not only how many nodes particular node met, but also how often. The average weighted degree wd_i for node i is computed by formula 9.

$$wd_i = \sum_{j \in \prod(i)} w_{i,j} \quad (9)$$

where $w_{i,j}$ (in case of symmetric positive matrix without loops $w_{i,j} = w_{j,i}$) is weight between node i and j . $\prod(i)$ is neighbourhood of node i .

4 Simulations and results

Not only the proposal evaluation method but also some other existing evaluation methods were simulated and verified in software Matlab. There were used one social based mobility model SSBMM [17] and two random mobility models: Matis model [18], and Random Walk [19].

4.1 Simulation scenarios

Simulations are oriented on the comparison of our proposed evaluation method with some protocol independent and dependent methods. The main idea of the simulations was to analyze how the mobility models with social and non-social mobility models can affect the network performance and point out differences between them. Simulations were also designed as a comparison of proposed evaluation and other protocol dependent and independent methods.

The first set of simulations is oriented on our proposed evaluation method. Results are focused on number of communities, modularity quality and average weighted degree (see Sect. 4.5). Contacts in Meeting matrix was calculated based on nodes' movement in Matlab software and processed by external Gephi software [20]. Gephi software provides many analyses of social networks and it also implements Louvain method with modularity quality. Obtained communities from Louvain method is also possible to render and divide by colours.

The second set of simulations is oriented on some of the protocol independent methods for mobility model evaluation. CDF and PDF were chosen for statistical evaluation of nodes' contact multiplicity.

The third set of simulations is oriented on some of the protocol dependent methods. Average E2E delay, Message delivery ratio, average time of delivery and average number of used nodes were used as evaluation methods. Those methods were performed for four routing protocols Dynamic Source Routing (DSR), Unlimited-Dynamic Source Routing (U-DSR), Social Based Opportunistic Routing (SBOR) and Social Based Opportunistic Routing-social aspect (SBOR-sa).

4.2 Simulation setup

First set of simulations was running based on variables, which are defined in the Table 1. Simulated area was 1500×1500 m

Table 1 Set values of variables for first set of simulations

Variable	Value
Area (m)	1500 × 1500
Number of nodes	50, 100, 200
Radio range (m)	20, 50, 100, 300
Time slots per day	48
Simulation duration (days)	28

Table 2 Set values of variables for second set of simulations

Variable	Value
Area (m)	1500 × 1500
Number of nodes	200
Radio range (m)	20, 50, 100
Time slots per day	48
Simulation duration (timeslots)	10,000

Table 3 Set values of variables for third set of simulations

Variable	Value
Area (m)	1500 × 1500
Number of nodes	200
Radio range (m)	20, 50, 75, 100, 150, 200, 250, 300
Time slots per day	48
Simulation duration (days)	28

wide. Simulations were performed with a different number of nodes and radio ranges. The time of simulations was divided into time slots. In order to reveal human mobility patterns, we choose 4 weeks of 28 days. Every day was divided into 48 (half hour) time slots.

A collection of results for second set of simulations was based on variables defined on Table 2. In this setup, we excluded scenario with 300 nodes due to the similarity of results. We also change the number of time slots in order to obtain the higher multiplicity of contact for PDF and CDF.

The third set was running based on variables, which are defined in the Table 3 and it is similar to the first set. The only difference is the higher number of radio ranges because the performance of routing protocols and disconnections in MANET-DTN networks is depended on radio ranges.

4.3 Simulated routing protocols

Used routing protocols were chosen based on their properties. Since simulations were designed to compare social and non-social random mobility models, DSR and UDSR were chosen because of their independence from social relationships. On the other hand, SBOR with SBOR-sa were chosen because

they use social aspect. Used routing protocols are briefly described in the following sections.

DSR with limited number of path finding for message

A first routing protocol is standard DSR routing protocol based on RFC 4728 [23], which is simple and efficient, on-demand routing protocol designed for usage in multi-hop wireless ad-hoc networks. DSR allows the network to be completely self-organise and self-configurable. The protocol is composed of two main mechanisms of “Route Discovery” and “Route Maintenance”, which allow discovering path from S (source) to D (destination). During Route Discovery mechanism was a path find by RREQ (Route Request) packet. After receiving RREP (Route Replay) packet was a path established [23]. Path finding was limited on two attempts for one message, first time at the start of communication and the second time during the maintenance process.

DSR with unlimited number of pathfinding for message

Second routing protocol U-DSR is like previous routing protocol DSR [23] with same mechanisms and process but with one change. U-DSR was different in a number of path finding, where the attempts to find a path between S and D wasn't limited.

SBOR with history based probability

Another type of routing in MANET environment is based on opportunistic transfers with or without social relations among nodes. For our comparison was used SBOR (Social based Opportunistic Routing). This method can assume a flooding-based routing [24] for sending “extended RREQ packet (E-RREQ)” and direct transfer of single-copy forwarding based scheme for sending of data with social determining. The selection of the next hop neighbour from potential nodes is provided by the probability of delivery. This probability was calculated from contact history among nodes. SBOR is the good solution, in situations, where is impossible to establish E2E path [18].

SBOR-sa with history based probability influenced by social aspect

SBOR-sa is the same routing solution like SBOR, but with one change. The main differences between them are in the probability of delivery. Standard probability of delivery calculated from contact history is recalculated by social aspect given from knowledge about nodes origin and division to the study groups. This kind of information can be extracted from Nodeinfo matrix [18].

4.4 Simulation result assumptions

We decided to use random models as a comparison with SSBMM. Our SSBMM mobility model as the social model should provide better results than random models in terms of modularity quality and number of communities. In social models, it is expected that the number of communities should grow with the growing number of nodes while in random models should a number of communities remains same or a similar with the growing number of nodes. A growing number of communities is caused by the behaviour of nodes in social models. With the growing number of nodes in social model, new friendships are created so the new groups and communities are also created. In random models, nodes are moving randomly. In an ideal or pure random models, nodes should statistically cover all simulation grid the same by their mobility. In this case, it is expected that the number of communities should be 1 because statistically, every node met each other's the same time. In real random models, nodes usually move across the same field of simulation grid and sometimes moves from one field of the simulation grid to another. A number of these fields are low so it is expected that the number of discovered communities should be also low and should remain the same with growing numbers of nodes. Only things that change is growing number of nodes in these discovered communities.

Another aspect of assumption is modularity quality. In social based mobility models it is expected that modularity quality should be higher than in random models. This is caused by stronger relationships inside communities than in outside of those communities. In graph theory, the weights of edges inside of communities are higher than in outside of those communities. In random models or ideal random models, it is expected that these weights of edges should be statistically the same inside or outside of communities.

Generally, from the assumption mentioned above, we can expect from mobility models that produced a low and almost constant number of communities with low values of modularity quality that mobility of those models are random. On the other side, models that produce bigger numbers of communities that grow with the growing number of nodes and also produce bigger numbers of modularity quality should be mobility models with a social aspect.

From average weighted degree parameter can be expected, that bigger values should represent more frequent contacts among nodes. In random mobility models, contacts among nodes are distributed almost equally, which mean that the average value of a weighted node degree remains almost same because of small standard deviation value. In social mobility models, some contacts between nodes are more often, which means that it is expected that the average number of weighted degree should be bigger due higher standard deviation value. It means that more often contacts among nodes

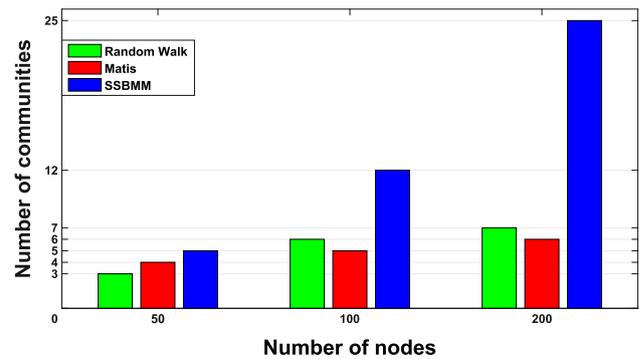


Fig. 2 Number of communities in 20m radio range

in social models push average weighted degree into higher value.

4.5 Number of communities, modularity quality and average weighted degree results

The first set of simulation, we to know how many communities is possible to get from the mobility of each used models along with modularity quality and average weighted degree results.

Number of communities

In radio range of 20 m (Fig. 2) is possible to see, that SSBMM has way more communities with 200 and 100 nodes simulation. In the simulation with 50 nodes, the SSBMM has one more community than Matis model and two more than Random Walk mobility model. While SSBMM has significantly growing number of communities with growing numbers of nodes, in random models number of communities grows just slightly. Also, 20 m radio range create the sparse network in simulation area. Therefore, not many nodes are in their radio range, so in the case of SSBMM, much smaller, but stronger communities are created. The number of communities created by random models results from moving across the same field phenomena mentioned in Sect. 4.4.

On Fig. 3 we can see the graphic division of nodes into communities on 20 m radio range by Gephi software.

The SSBMM has thicker edges inside than among communities. This means, that there are stronger relationships among nodes. In the random models, edge thickness inside and among communities is comparable, thus weaker relationships among nodes are created.

The same behaviour was observed for radio range of 50 m (Fig. 4). SSBMM has bigger numbers of communities, while random models have almost same numbers of communities that grow just slightly.

The graphic division of 200 nodes into communities on 50m radio range by Gephi software is shown on Fig. 5. It

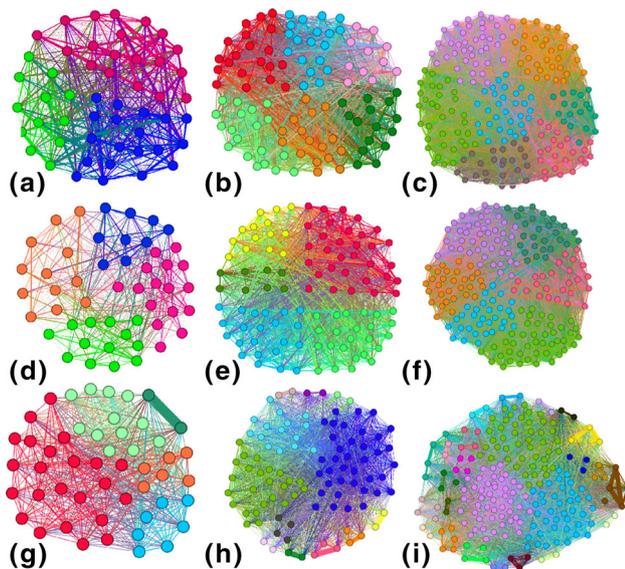


Fig. 3 Division of nodes into communities in radio range of 20 m by Gephi. **a** Random Walk 50 nodes. **b** Random Walk 100 nodes. **c** Random Walk 100 nodes. **d** Matis 50 nodes. **e** Matis 100 nodes. **f** Matis 200 nodes. **g** SSBMM 50 nodes. **h** SSBMM 100 nodes. **i** SSBMM 200 nodes

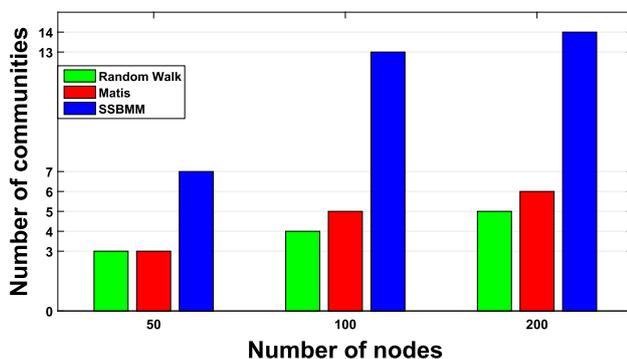


Fig. 4 Number of communities in 50 m radio range

is possible to see the same behaviour of nodes than in 20 m radio range.

In radio range of 100 m on Fig. 6 is possible to see, that SSBMM still has bigger numbers of communities, but these numbers are smaller than in radio ranges of 20 and 50 m. This is because of the dense network in radio range of 100 m. Thus, Louvain algorithm must consider more edges among nodes, so fewer but stronger communities are created. On Fig. 7 is depicted the graphic division of 200 nodes into communities on 100 m radio range by Gephi software.

Different behaviour was observed in simulations of 300 m radio range on (Fig. 8). In simulations of 50 and 100 nodes, SSBMM has 2 communities. Those two communities were actually nodes divided by their origin (Dormitory, City settlement from SSBMM model [17]) that is possible to see on Fig. 9h, j, the odd nodes are from Dormitory and even

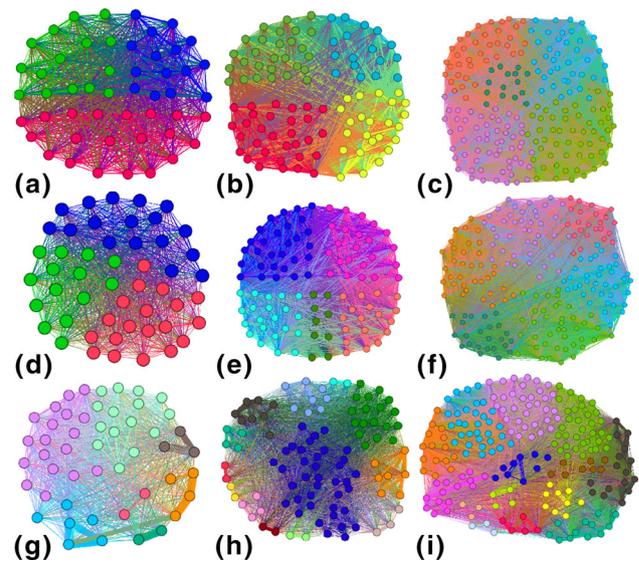


Fig. 5 Division of nodes into communities in radio range of 50 m by Gephi. **a** Random Walk 50 nodes. **b** Random Walk 100 nodes. **c** Random Walk 100 nodes. **d** Matis 50 nodes. **e** Matis 100 nodes. **f** Matis 200 nodes. **g** SSBMM 50 nodes. **h** SSBMM 100 nodes. **i** SSBMM 200 nodes

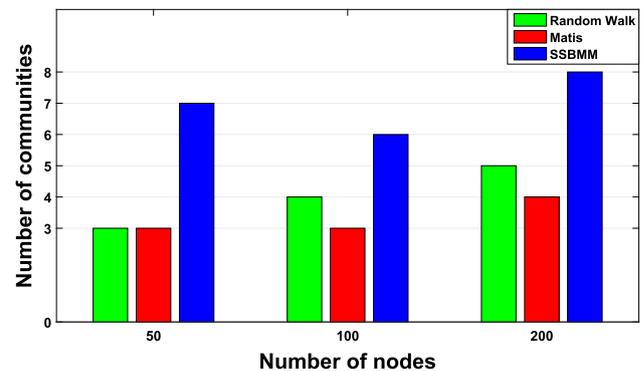


Fig. 6 Number of communities in 100 m radio range

nodes are from City settlement. On radio range of 300 m, the network is very dense, so it is possible to say, that only meetings in origin areas were strong enough to form communities. Therefore, many more edges among nodes in radio range of 100 m is considered by Louvain algorithm, so the even smaller number of communities were discovered.

Modularity quality

On Fig. 10 are depicted a modularity quality results. It is possible to see that modularity quality of SSBMM was always better than in random models. Authors in [21] declared, that nonzero values represent deviations from randomness, and in practice, it is found that a value above about 0.3 is a good indicator of significant community structure in a network. Even in radio range of 300 m, where numbers of communities

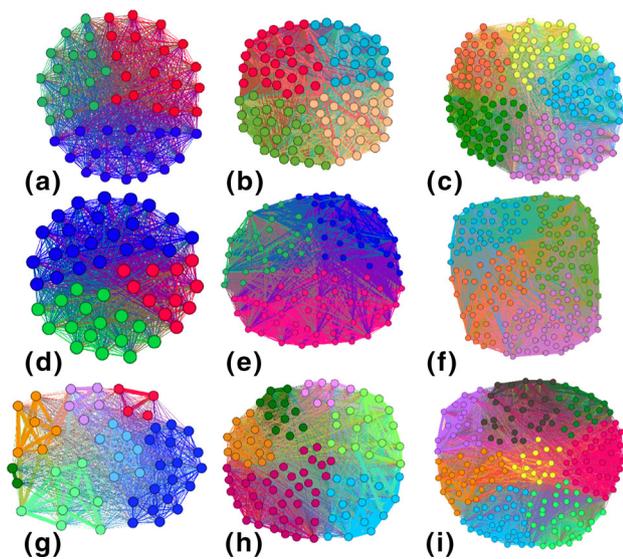


Fig. 7 Division of nodes into communities in radio range of 100m by Gephi. **a** Random Walk 50 nodes. **b** Random Walk 100 nodes. **c** Random Walk 200 nodes. **d** Matis 50 nodes. **e** Matis 100 nodes. **f** Matis 200 nodes. **g** SSBMM 50 nodes. **h** SSBMM 100 nodes. **i** SSBMM 200 nodes

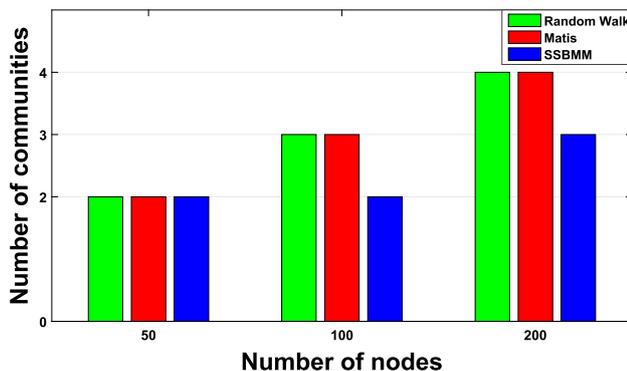


Fig. 8 Number of communities in 300m radio range

were lower in the case of SSBMM in very dense network scenario, modularity quality was still better and above 0.3, which proves SSBMM deviation from randomness. We noticed that modularity with increasing radio range decreases. This is caused by increasing the density of the network, where more edges among nodes are considered by Louvain algorithm, so the decision about division nodes into communities is more difficult. In SSBMM simulation scenario of 50 nodes in radio range of 20m is possible to see the lower value of modularity quality than expected, compared to other simulation scenarios. This is due to the other side of extreme, where 50 nodes in this small radio range are in large simulation area. Such a network is very sparse, so meetings among nodes that form the community are not so often, that means relation ties are weak. It is also possible to see that modularity quality of random models is very low. From our investigation, we observed

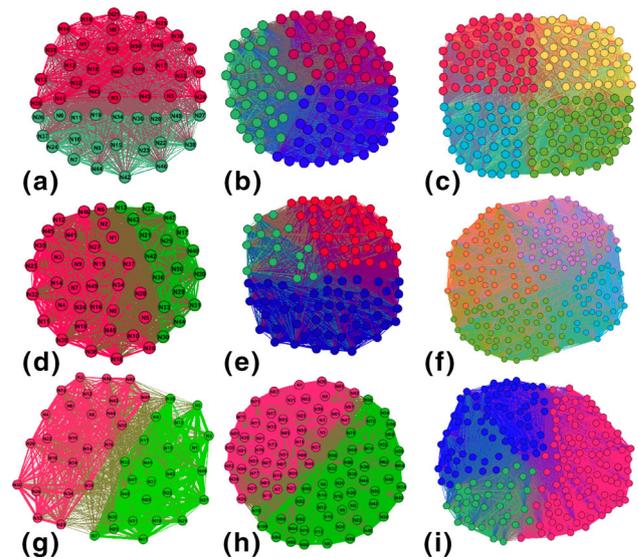


Fig. 9 Division of nodes into communities in radio range of 300m by Gephi. **a** Random Walk 50 nodes. **b** Random Walk 100 nodes. **c** Random Walk 200 nodes. **d** Matis 50 nodes. **e** Matis 100 nodes. **f** Matis 200 nodes. **g** SSBMM 50 nodes. **h** SSBMM 100 nodes. **i** SSBMM 200 nodes

that movement of one node in Matis model almost cover all simulation area and all grids same times. Some nodes cover just certain parts of simulation area. This problem we mentioned as moving across the same field phenomena (see Sect. 4.4) In this case, a small number of communities were produced by the mobility of Matis model, but because of random movement, small values of modularity quality were produced. Also, authors in [22] observed, that nodes move in the Random Walk mobility model are short, then the movement pattern is a random roaming pattern restricted to a small portion of the simulation area and then node does not roam far from its initial position. From this reason, nodes tend to move in their parts of simulation area, so their mobility almost looks like movement in communities. Therefore, Random Walk mobility model tends to produce the higher value of communities than the pure random model, but also smaller values of modularity quality.

Average weighted degree

Results of average weighted degree for 50 nodes are depicted on Fig. 11. The SSBMM outperform random models in all radio ranges. The frequency of contacts among some nodes in SSBMM was higher than in random models, which also push average weighted degree values higher. Therefore, it is possible to say, that social ties among nodes cause more often contacts among nodes and this behaviour affects average weighted degree values. The same behaviour is possible to see in Figs. 12 and 13 for 100 and 200 nodes.

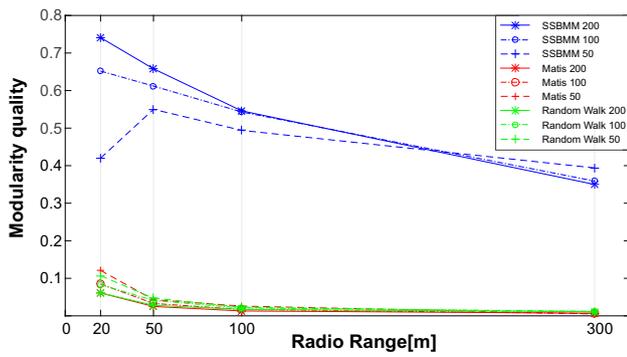


Fig. 10 Modularity quality results

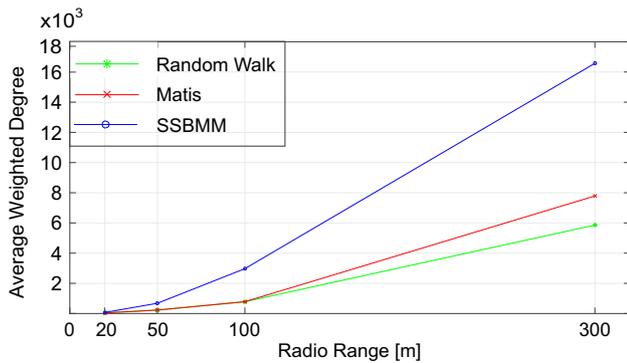


Fig. 11 Average weighted degree of 50 nodes

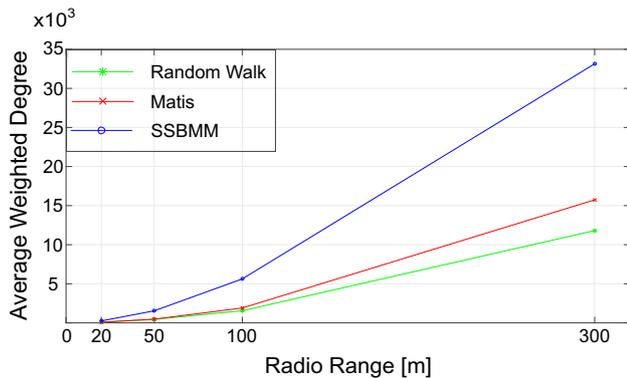


Fig. 12 Average weighted degree of 100 nodes

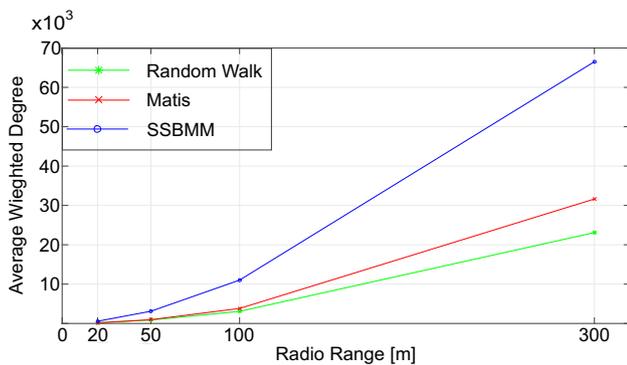


Fig. 13 Average weighted degree of 200 nodes

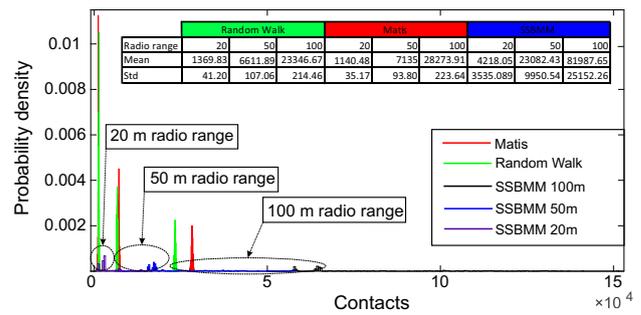


Fig. 14 Probability density of contacts multiplicity

4.6 Statistical evaluation results

Some statistical evaluation of mentioned mobility models was also performed. Probability density function (PDF) and cumulative probability function (CDF) of contacts were used for the second set of simulations among nodes. Contact values from Meetings matrix were used for this evaluation. Longer simulation duration (10,000 time slots) and 200 nodes were used for more accurate result. Multiple simulation runs of each mobility model were performed to obtain multiplicity of meetings of every node in radio ranges from Table 1 except 300 m.

Figure 14 describes probability density of contacts between nodes in the simulation of SSBMM, Matis model and Random Walk mobility model. In this figure is also the table with mean and standard deviation (Std) values. In all radio ranges, the mean value of SSBMM is almost four times higher than mean values of random models. This means, that SSBMM model has way more contacts and longer contacts duration between nodes in simulation duration than random models. The SSBMM also has a much higher value of Std than random models. This means, that SSBMM has the greater dispersion of contacts between nodes. Generally, we can expect, that SSBMM model will have more contacts resulting from longer duration of contacts between nodes with stronger relation ties. From our investigation, we find out, that PDF of contacts of Matis model and Random Walk mobility model closely follow the normal distribution of these contacts which is typical for randomly generated values, while SSBMM does not follow any known distribution.

CDF of contacts for all mentioned models was also evaluated and is shown on Fig. 15. It is possible to see a significant difference between random models and SSBMM. In all radio ranges, SSBMM cover much more contacts than random models. This means that SSBMM produces much more contacts that result from longer contacts time between nodes. It also means that nodes with strong relation ties tend to be together for the longer time than nodes with weak or no relation ties. Therefore, longer times that nodes spend together produce more contacts between them.

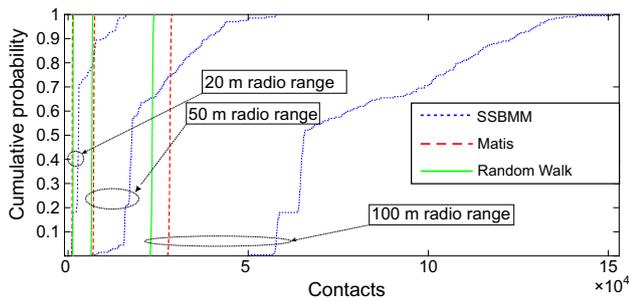


Fig. 15 Cumulative probability of contacts multiplicity

4.7 Routing evaluation results

Not only statistical evaluation results but also routing evaluation results are performed because of social mobility model verification as the third set of simulations. Described mobility models (Random Walk, Matis model and SSBMM) was used for running four routing methods (DSR, U-DSR, SBOR and SBOR-sa), which are possible to use in MANET environment. Two of them (DSR and U-DSR) was based on standard MANET routing solutions and the next two of them (SBOR and SBOR-sa) was based on social opportunistic routing solutions.

In this paper are described two main simulation results for three mobility models, where was running four mentioned routing protocols.

The first results from the set of results are displayed in Table 4, which represents message delivery ratio among three types of delivery results, Full, Partial and Null. Every message was consist of packets. Results of Full received message means, that all of the sent packets of the message was received. The result, when only some packets of sent message

were received, is represented by the result of Partial received message. The third result, which represents types of received message is the Null transfer of message. It means, that zero number of packets was received by the destination node.

DSR couldn't find some path, when the networks is sparse because the nodes at the start o simulation were divided to two different subnetworks. In the case of the denser network, DSR found some paths, but they maintenance wasn't possible.

Therefore DSR reached only Null and Partial message transfer.

U-DSR reached better results than DSR for sparse network and for the denser network was U-DSR totally successful.

Opportunistic routing SBOR and SBOR-sa got the best results from all routing protocol, especially for social mobility model SSBMM.

The second main result from routing evaluation results show combined graph for an average time of delivery and an average number of used nodes with Std for an average number of used nodes (Fig. 16). Displayed results are only for successful attempts, three mobility models and four routing protocols. DSR routing protocol newer reached full message transfer in every simulation because the nodes were divided into two separate areas without radio connection and standard DSR routing protocol couldn't find and maintenance the path between S and D for successful transfer of the message. From this reason, the average time was infinity and number of used nods with Std was zero. This result isn't graphically represented.

On the other hand, U-DSR routing protocol was more successful than DSR. For the lowest radio range got U-DSR infinity time of delivery, because zero attempts from all simulations were totally successful. With the increasing radio range got the decreasing average time of delivery for success-

Table 4 Message delivery ratio (full/partial/null)

		Message delivery ratio—full/partial/null (%)							
Protocol	Mobility model	Radio range (m)							
		20	50	75	100	150	200	250	300
DSR	Random Walk	0/0/100	0/0/100	0/0/100	0/10/90	0/50/50	0/100/0	0/100/0	0/100/0
	Matis	0/0/100	0/0/100	0/0/100	0/0/100	0/40/60	0/100/0	0/100/0	0/100/0
	SSBMM	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100	0/100/0	0/100/0	0/100/0
U-DSR	Random Walk	0/60/40	40/60/0	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0
	Matis	0/60/40	90/10/0	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0
	SSBMM	20/70/10	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0
SBOR	Random Walk	70/0/30	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0
	Matis	80/0/20	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0
	SSBMM	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0
SBOR-sa	Random Walk	70/0/30	90/0/10	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0
	Matis	40/0/60	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0
	SSBMM	90/10/0	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0

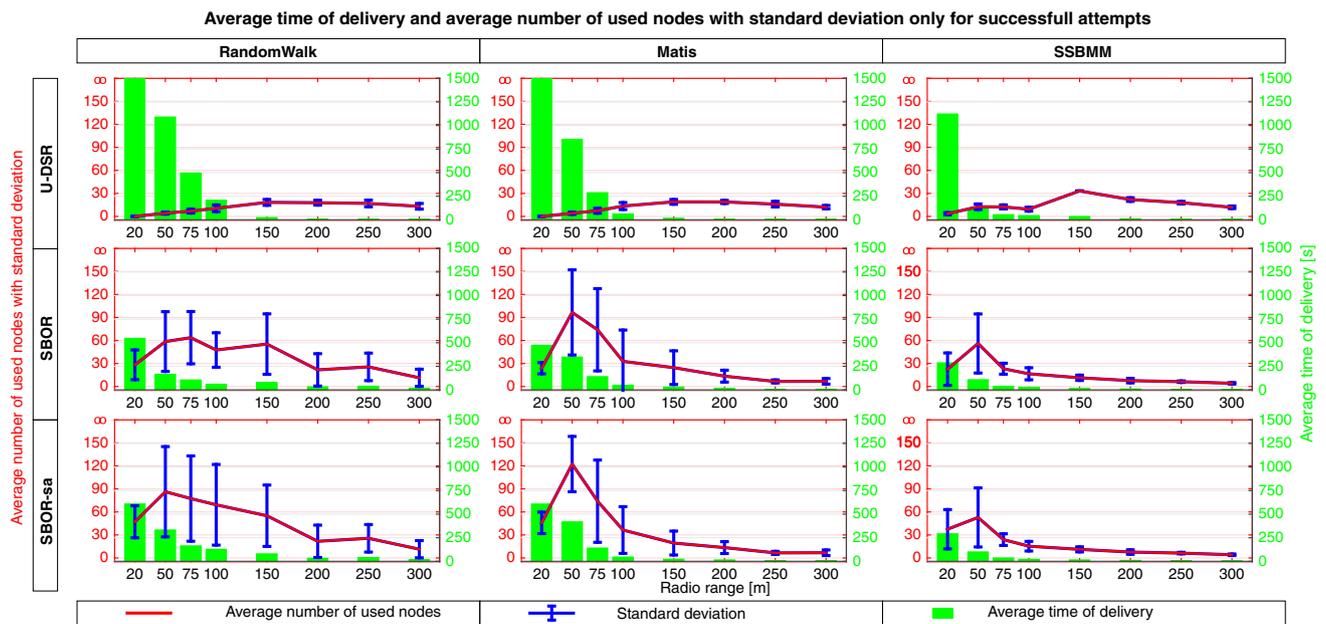


Fig. 16 Average time of delivery and average number of used nodes with standard deviation only for successful attempts for three mobility models (Random Walk, Matis model and SSBMM) and for four routing protocols

ful attempts. By changing of mobility model from Random Walk mobility model through Matis model to SSBMM is possible to see, that the time has to decrease characteristic. An average number of used nodes is almost the same for all mobility models.

SBOR routing protocol reached lower average times of delivery by comparison with U-DSR for every mobility model. This time had the decreasing tendency from Random Walk mobility model through Matis model to SSBMM. Based on statistical and average weighted degree results are possible to say, that Random Walk mobility model got the lower multiplicity of contacts than Matis model. Thus Std of an average number of used nodes are bigger in the case of Matis model, because of Matis model got more contact during simulation and it had opportunities to meet more and always different nodes due to random mobility pattern and use them to transfer messages. Std of SSBMM is much lower because of this social model has the similar mobility pattern through all simulations. From this reason, almost the same nodes were used to transfer messages in all simulations.

SBOR-sa routing protocol got the worse average time of delivery for random mobility models (Random Walk and Matis model) because there was applied social aspect which changes some relations among nodes. This change causes degradation of an average number of used nodes and Std results for random models, but improve results of SSBMM a little bit.

The third result is focusing on the average time of successful delivery especially on time's Standard deviation (Fig. 17).

On the graphs are displayed results for all four routing methods, which are compared by three mobility models.

DSR wasn't successful for all mobility models and therefore the average time is infinity with zero Std. Therefore the graphical result isn't displayed on the graph.

U-DSR wasn't successful by sparse network and random mobility model, where reached infinity time of delivery. With the same radio range, U-DSR was successful by using SSBMM. Random Walk mobility model covered with the almost the same probability like Matis model, but with the lower number of contacts. Which means, that in Matis model are more contact among nodes during transfer of the message, stable paths between source and destination, what has the direct impact on average time of delivery and Std in positive meaning. In the environment, where SSBMM was used, the average time was the lowest from all model and the Std got low value because every movement in simulations was similar.

SBOR routing protocol got higher values of average time of delivery and Std for Matis model then Random Walk mobility model because in cases of the sparse network Matis model had more opportunities to meet other nodes, which can bring message closer to the destination. From this reason was average time higher. Because of random movement, which was different in all simulations, Matis model got higher values of Std. SSBMM had the similar pattern of movement, therefore Std values were lower and due to social behaviour of nodes, an average time of delivery is lower in cases of using the social routing protocol.

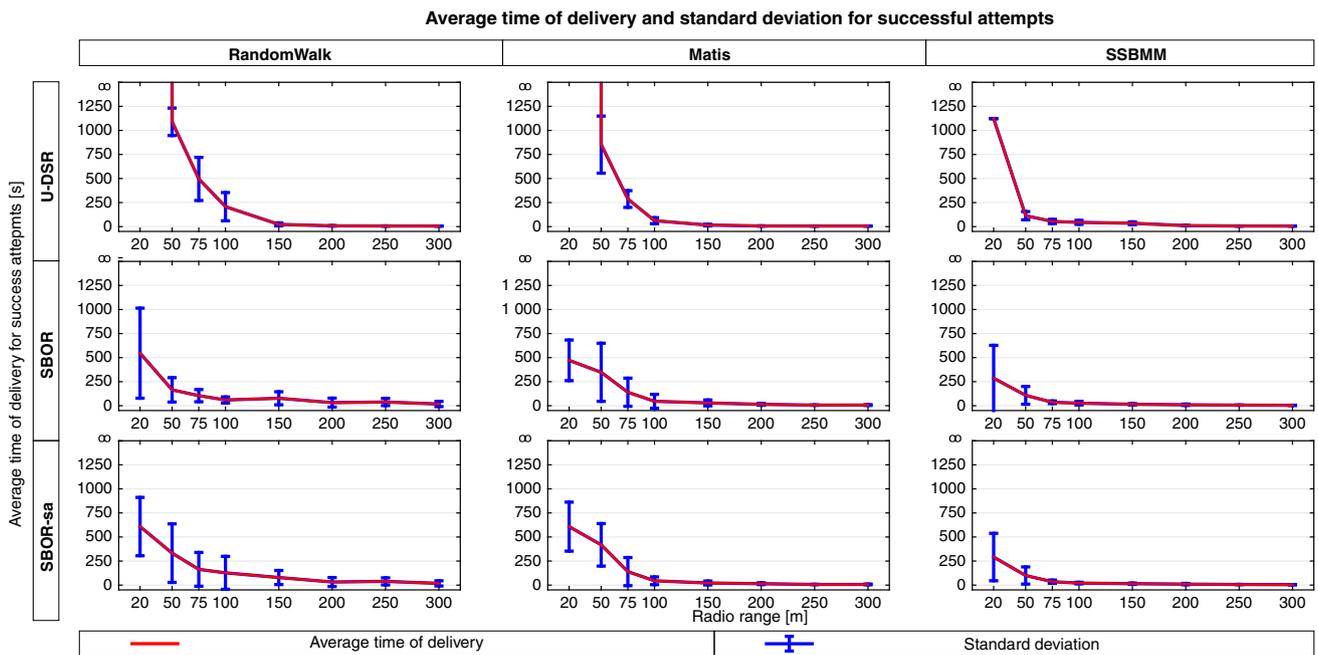


Fig. 17 Average time of delivery and standard deviation for successful attempts

In general, an average time of delivery and Std for SBOR-sa was degraded for random mobility models, while SSBMM perform better results for the sparse network, where differences among simulations were lower than without social aspect.

5 Conclusion and discussion

In this paper, we propose tools for evaluation of social relations in mobility models as new evaluation method. This method is based on Louvain method and average weighted degree parameter. With the proper mobility model output format, this method is able to reveal social aspect in mobility models based on the evaluation of modularity quality, the number of communities and average weighted degree parameter from resulting movement of mobility of models. Mentioned method was simulated against other commonly used evaluation methods such as protocol dependent methods and protocol independent methods. Simulation of particular methods was evaluated using two random based mobility models (Matis [18], Random walk [19]) and social based mobility model (SSBMM [17]). From performed simulations, we made following conclusions.

Simulations using a number of communities parameter shows, that this parameter is useful in sparse networks or small radio ranges. In dense networks with big radio ranges, there are a lot of nodes in contact through all simulation time. Therefore, even nodes that are not in the social relationship with other nodes may be considered by the method as the

social group. In small radio ranges, not that many nodes are in contact. Thus, only nodes that are in contact with other nodes for sufficient simulation time, can be considered as the social group. Results shows, that social model has a lot more social groups in small radio ranges than random based mobility models. In big radio ranges, a number of social groups are almost same for all mobility models.

When using modularity quality parameter alongside with a number of communities parameters, results can be interpreted better. Because of modularity quality parameters express, how well nodes are divided into their communities, bigger values of modularity quality are expected when using social based mobility models. Nonzero values represent deviations from randomness, and in practice, it is found that a value above about 0,3 is a good indicator of significant community structure. Our results also show, that if random mobility models were used, small values of modularity quality were obtained. These values are nonzero which means deviation from randomness but are also very close to zero, which means that this deviation is not that significant. Using pure random mobility is possible to obtain zero values of modularity quality, with only one community detected. When social based mobility model was used, obtained values of modularity were above 0,3 significant community structure boundary in all used radio ranges. In very sparse networks with small numbers of nodes, the value of modularity quality could decrease, but when using social based mobility model it should stay above significant community structure boundary. On the other hand, in simulations with very sparse network and a lot of nodes, values of modularity quality were still

above the boundary, while values of modularity quality of random based mobility models were almost zero.

Results of the average weighted degree show another significant deviation of social based mobility model from random based mobility models. The average weighted degree can be interpreted as how many times nodes in mobility models were in contact and also how often in a single parameter. Results show that social mobility model has at least twice as bigger values of average weighted degree as random mobility models in all used radio ranges. That means, that nodes in social based mobility models communicate more often. Also, some contacts between nodes are even more often with longer duration due to the social attraction, which means that an average number of weighted degree should be bigger.

In this paper were also performed simulations using protocol independent methods and protocol dependent methods. PDF and CDF statistical metrics were used as protocol independent method. PDF results shows differences between social and random mobility based models. In random mobility based models PDF of contacts multiplicity shows that with almost same probability in both models were obtained smaller values of contact multiplicity than in social based mobility model. This means, that social based mobility model has way more contacts and longer contacts duration among nodes in whole simulation duration. In the case of CDF results, in all radio ranges, social based mobility model cover much more contacts multiplicity than random models. This means that social based mobility model produce much more contacts that result from longer contacts time between nodes that has stronger social ties.

Four routing protocols (DSR, U-DSR, SBOR and SBORsa) were simulated as protocol depended methods for evaluation of mobility models (Random Walk, Matis model and SSBMM). The results show advantages of using social mobility model for transfer data between source and destination node. In general, when social SBOR routing methods were used for social movement, the results were much different compared to non-social movement. Because of social routing methods rely on the social behaviour of nodes, the results of successful delivery and other qualitative parameters of routing will be better. Better results could be achieved if the mobility of nodes in social models was even closer to the real movement of humans. The usage of non-social DSR routing methods shows no significant influence of social movement on routing results. Some results were better in the case of using the social movement of nodes in mobility models. But they were not significant enough to claim, that social movement has some impact on quality of results when using non-social routing methods.

Modeling of human movement is a challenging task and is very difficult to simulate all kinds of human behaviour and movement. Since there are a lot of social mobility models, proper tool for evaluation of social behaviour in these mod-

els is needed. In MANET-DTN networks, social behaviour of nodes is important because wireless mobile devices are carried by humans. Incorporate social behaviour of nodes into mobility models could achieve better routing result with the usage of social routing methods. Also, other researches that rely on the social behaviour of nodes and calculate the probability of its parameters based on nodes movement could achieve better results. In case of MANET-DTN, the social movement could help select a reliable and secure node as message carrier in the case of network disconnection. All this could help to achieve a better result not only in simulator's environments but also in real life since MANET-DTN networks are used in disaster situations when whole telecommunication systems are destroyed. But before all this, proper simulation tool is needed to inspect network performance. TESRMM could help to select proper mobility model.

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