On Throughput Performance and its Enhancement in Mobile Ad Hoc Networks (MANETs)

Mouna Abdelmoumen, Mariem Ayedi
and Mounir Frikha

Sup’com
Ariana, Tunisia
Email: {mouna.abdelmoumen, ayedi.mariem, m.frikha}@supcom.rnu.tn

Tijani Chahed

Institut Mines-Telecom; Telecom SudParis
Paris, France
Email: tijani.chahed@telecocm-sudparis.eu

***Abstract*—In this work, we investigate the performance of Mobile Ad Hoc networks (MANETs) in terms of the throughput achieved in transferring packets from source to destination. First, we study the relationship between mobility and routing and define metrics that enable us to derive an analytical expression for the throughput. Secondly, we validate this expression, via simulations, as a function of several mobility patterns, as well as routing protocols, for various nodes speeds. Eventually, we propose the use of additional fixed relays so as to enhance the throughput performance in case of ill-behaved mobility schemes.**

***Keywords*—MANETs; mobility models; routing protocols; throughput model; additional relay proposal.**

I. INTRODUCTION

Data traffic transfer in Mobile Ad Hoc Networks (MANETs) requires the existence of a path between source and destination. This path is established based on the use of intermediate nodes which act as relays. As these nodes are mobile, network connectivity can change at any time. And so, the performance of the network, in terms of throughput for instance, is largely dependent on the varying topology of the network, which itself depends on the nodes mobility pattern, as well as the used routing protocol.

Several works studied the impact of mobility on MANET performance. For instance, Grossglauser and Tse [1] showed that the mobility of nodes increases the throughput between source and destination. N. Sadagopan, F. Bai, B. Krishnamachari and A. Helmy [2] defined a connectivity-oriented metric, namely path duration, to analyse the effect of mobility on the connectivity graph between the mobile nodes. They developed a simple first-order model that showed that the throughput is in a strong linear relationship with the reciprocal of the average path duration. As of its relationship to routing, the same study showed how mobility impacts the performance of reactive routing protocols in MANETs.

Despite the fact that these works focused on the relationship between mobility and MANETs performance, they did not give explicit details on the relationship between mobility and routing in this context. In the present work, we focus on this relationship between mobility and routing, and define mobility and routing oriented metrics, namely mobility and routing path durations and path absence durations, which would enable us to model the throughput achieved in transferring packets between source and destination. This model will be next validated through simulations by considering different mobility patterns and routing protocols. Eventually, and in the case of poor throughput performance due to network fragmentation, we propose a new solution based on the deployment of additional fixed relay nodes that would maintain mobility and routing paths for longer and hence enhance the overall network performance.

The remainder of this work is organized as follows. In Section II, we focus on the relationship between mobility and routing and derive an expression for the throughput based on mobility and routing oriented metrics. In Section III, we evaluate these metrics and validate our throughput model by means of comparison between analytical and simulation results. In Section IV, we present our proposal for additional fixed relay nodes deployment and quantify its impact on the network performance. Section V concludes the paper.

II. MODEL

In order to study the network performance, in terms of throughput, one needs to characterise the paths established between the source and destination. In order to do so, we first focus on the relationship between mobility and routing.

A. Mobility-Routing Relationship

When two nodes i and j come within each other communication range, a so-called *mobility* link, denoted by $L_m(i,j)$, is established. The path between the source and destination is a succession of such links, whose creation/destruction is function of nodes encounters/dis-encounters, and hence mobility.

Once this mobility-based path is established between the source and destination, and before the effective transfer of information between them, the routing protocol exchanges some information, such as routing table update, route request/response, etc, so as to enable the source and destination nodes to learn about the existence of a path between them. A *routing* link between nodes i and j, denoted by $L_r(i,j)$, will

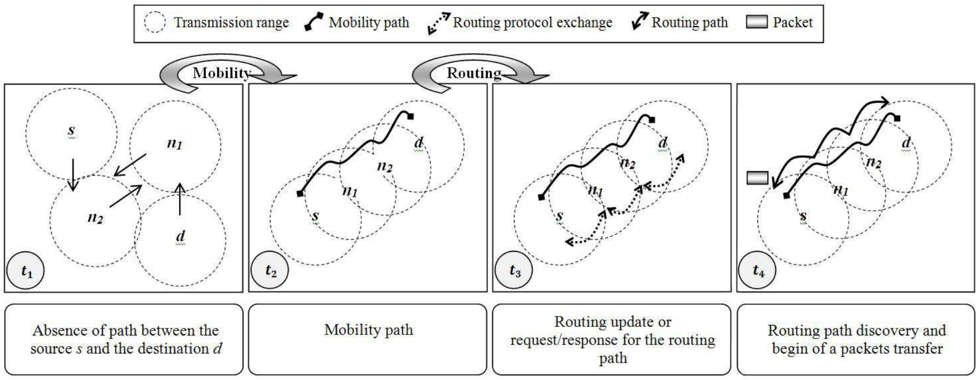


Fig. 1. Mobility-Routing relationship.

thus be created on top of the mobility link, $L_m(i,j)$. Figure 1 illustrates this situation.

Both mobility and routing paths are composed of time-varying sub-, or unitary, paths relating successive nodes between source s and destination d pairs.

The mobility and routing unitary paths, denoted by up_m and up_r, respectively, between nodes s and d, are composed of $k-1$ consecutive mobility or routing links, respectively, and are defined in a similar fashion as $up_a(s,d,t_c,t_v) = \{L_a(s,n_1),...,L_a(n_{k-2},d)\}$, where index a can be replaced by m for mobility and r for routing. t_c is the establishment or discovery time of the mobility or routing unitary path, respectively, and t_v is the corresponding break or interruption time. Also, we define $\forall q$, $up_{a_q}(s,d) = up_{a_q}(s,d,t_{c_q},t_{v_q})$. Then, the mobility and routing paths, denoted by P_m and P_r, respectively, between nodes s and d, are composed of successive unitary paths: $P_a(s,d,t_c,t_v) = \{up_{a_g}(s,d),...,up_{a_l}(s,d)\}$. $P_a(s,d,t_c,t_v)$ is the mobility or routing path between s and d established at time $t_c = t_{c_g}$ and interrupted at time $t_v = t_{v_l}$ with $\forall q \in [|g+1,l|]; t_{c_q} \simeq t_{v_{q-1}}$ or $t_{c_q} - t_{v_{q-1}} \leq \varepsilon$.

The absence of mobility, as well as routing paths AP_m and AP_r, respectively, between s and d corresponds to the absence of successive mobility and routing links between s and d for a period of time larger than ε. So, we have, $AP_a(s,d,t_i,t_f) = (up_{a_i}(s,d), up_{a_f}(s,d))$ where $t_{c_f} \gg t_{v_i}$.

B. Metrics

To quantify the mobility and routing paths, we define, first, the link duration, $LD_a(i,j,t)$, observed at time t, as the longest time interval, $[t,t']$, during which $L_a(i,j)$ exists. Based on the work of N. Sadagopan et al. [2], we define the mobility and routing path duration, $PD_a(s,d,t_1,t_2)$, which is equal to:

$$\sum_{up_{a_q}(s,d) \in P_a(s,d,t_c,t_v)} \min_{1 \leq h \leq k_q} LD_a(n_h, n_{h+1}, t_{c_q}) \quad (1)$$

where $\forall\ up_{a_q}(s,d)$; $n_1 = s$, $n_{k_q} = d$ and k_q is the number of nodes of the unitary path.

The duration of the path absence is simply given by:

$$APD_a(s,d,t_i,t_f) = t_f - t_i \quad (2)$$

For an observation duration denoted by $T = [t_{begin}, t_{end}]$, we define three sets. The first set, denoted by $P_a(s,d,T)$, contains all of the paths between s and d observed during T; $\{P_{a_z}(s,d) = P_a(s,d,t_{c_z},t_{v_z}); t_{c_z}, t_{v_z} \in T, t_{c_z} \leq t_{c_{z+1}} \forall z \gg 0\}$. The second set, denoted by $AP_a(s,d,T)$, contains all the absences of paths between s and d observed during T; $\{AP_{a_z}(s,d) = AP_a(s,d,t_{i_z},t_{f_z}); t_{i_z}, t_{f_z} \in T, t_{i_z} \leq t_{i_{z+1}} \forall z \gg 0\}$. The third set, denoted by MP_{SD}, contains all source-destination pairs between which a mobility path will be investigated.

For the observation duration T and for the MP_{SD} set, we derive the following average metrics. The average path duration, $\overline{PD_a}$, is equal to :

$$\frac{\sum_{(s,d) \in MP_{SD}} \overline{PD_a(s,d)}}{Card(MP_{SD})} \quad (3)$$

where $\overline{PD_a(s,d)} = \frac{\sum_{P_{a_z}(s,d) \in P_a(s,d,T)} PD_{a_z}(s,d)}{Card(P_a(s,d,T))}$ having $PD_{a_z}(s,d) = PD_a(s,d,t_{c_z},t_{v_z})$ and where Card is the number of elements in the set.

The average path absence duration, $\overline{APD_a}$, is equal to:

$$\frac{\sum_{(s,d) \in MP_{SD}} \overline{APD_a(s,d)}}{Card(MP_{SD})} \quad (4)$$

where $\overline{APD_a(s,d)} = \frac{\sum_{AP_{a_z}(s,d) \in AP_a(s,d,T)} APD_{a_z}(s,d)}{Card(AP_a(s,d,T))}$ having $APD_{a_z}(s,d) = APD_a(s,d,t_{i_z},t_{f_z})$.

C. Throughput Model

We assume a full buffer case wherein source s has continuously data to transfer to destination d during observation duration T at transmitting rate (traffic rate) $r_{traffic}$. When the mobility path between s and d is established, the routing path can be set on top of it and hence data transfer can take place. As the routing path constitutes the effective opportunity to exchange data between source and destination nodes, the transfer of data is performed only during the routing path period represented by $\overline{PD_r(s,d)}$ and is interrupted during the path absence duration accounted for by $\overline{APD_r(s,d)}$. Figure 2 illustrates this situation.

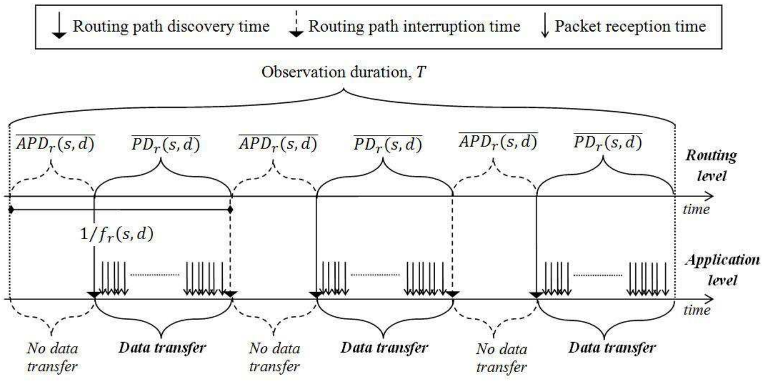


Fig. 2. Relationship between the routing level and the packet transfer.

Hence, for the source-destination pair (s, d), the observation duration T is divided as follows:

$$T = T_{Transfer} + T_{No\,Transfer} \tag{5}$$

where $T_{Transfer}$ and $T_{No\,Transfer}$ are the total durations during which a data transfer takes place and is interrupted, respectively.

Following Figure 2, we have:

$$T_{No\,Transfer} = \overline{APD_r(s,d)} * f_r(s,d) * T \tag{6}$$

where $f_r(s,d)$ is the routing path discovery frequency which is equal to $\frac{1}{\overline{PD_r(s,d)}+\overline{APD_r(s,d)}}$. Hence, (6) becomes:

$$T_{No\,Transfer} = \frac{\overline{APD_r(s,d)}}{\overline{PD_r(s,d)} + \overline{APD_r(s,d)}} * T \tag{7}$$

Based on (5) and (7), we obtain:

$$T_{Transfer} = (1 - \frac{\overline{APD_r(s,d)}}{\overline{PD_r(s,d)} + \overline{APD_r(s,d)}}) * T \tag{8}$$

Now, we suppose that the total quantity of information transfered between nodes s and d during T is $D(s,d)$. The connection throughput, denoted by $Th(s,d)$, is equal to $\frac{D(s,d)}{T}$. And so,

$$Th(s,d) = (1 - \frac{\overline{APD_r(s,d)}}{\overline{PD_r(s,d)} + \overline{APD_r(s,d)}}) * \frac{D(s,d)}{T_{Transfer}} \tag{9}$$

In addition, we assume that the packet reception rate, denoted by $r_{recp}(s,d)$, is different from the packet generation rate, denoted by $r_{gen}(s,d)$. This difference is due to many factors such as the number of links of the routing path, the transmission conditions, the inter-frame waiting times, as well as the routing path repair duration. Hence, we have:

$$\frac{D(s,d)}{T_{Transfer}} = \frac{r_{gen}(s,d)}{r_{recp}(s,d)} * r_{traffic} \tag{10}$$

The connection throughput is thus equal to:

$$(1 - \frac{\overline{APD_r(s,d)}}{\overline{PD_r(s,d)} + \overline{APD_r(s,d)}}) * \frac{r_{gen}(s,d)}{r_{recp}(s,d)} * r_{traffic} \tag{11}$$

III. MODEL VALIDATION AND PERFORMANCE EVALUATION

In this section, we evaluate our metrics and throughput model using simulations.

A. Simulation Settings

In order to evaluate the mobility and routing metrics and to validate our connection, throughput model, we consider the following mobility models, routing protocols and network settings. For the mobility models, we have chosen the following widely-used mobility patterns:

- Random Way Point (RWP), as described by D.B. Johnson and D. A. Maltz [3], is the most widely used mobility model for which the node movement is free of restrictions, both temporal and spatial;
- Smooth Random Mobility Model (SRMM), defined by C. Bettstetter [4], enhances RWP by adding a temporal dependency where speed is changed incrementally in a smooth fashion;
- Graph Based Mobility Model (GBMM) which was presented by J. Tian, J. Hahner, C. Becker, I. Stepanov and K. Rothermel [5] performs as RWP, but it constrains the node movement to a connected graph;
- Manhattan Mobility Model (MMM), evoked by F. Bai, N. Sadagopan and A. Helmy [6], includes all dependencies. It makes use of a map to confine movement to lanes. Moreover, nodes move according to a temporal correlation. The nodes speed is constrained by the speed of the front node in the same lane.

For RWP and SRMM mobility models, the value of the pause time is randomly chosen between $10s$ and $60s$. In addition, we use the maps shown in Figures 3 (a) and (b) for GBMM and MMM, respectively.

In addition, we consider the following widely referenced routing protocols:

- Dynamic Source Routing (DSR) [7] is a reactive routing protocol, where routes are created on demand using two mechanisms: route discovery to find routes and route maintenance to preserve them. It is based on source

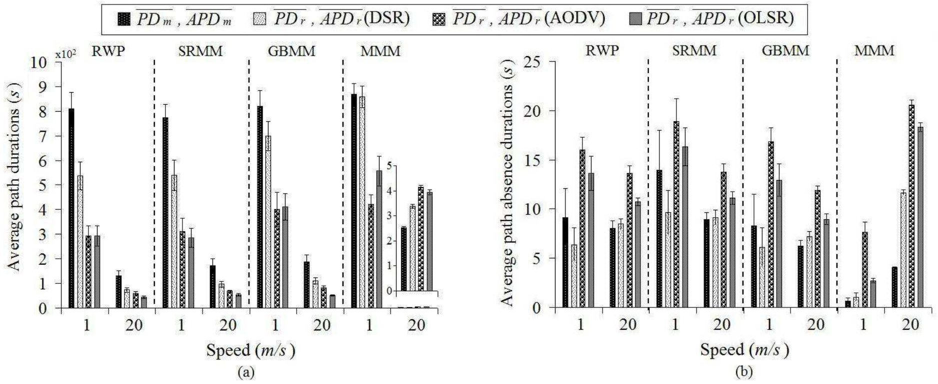


Fig. 4. Average path durations (a) and average path absence durations (b) function of mobility models, nodes speed and routing protocols.

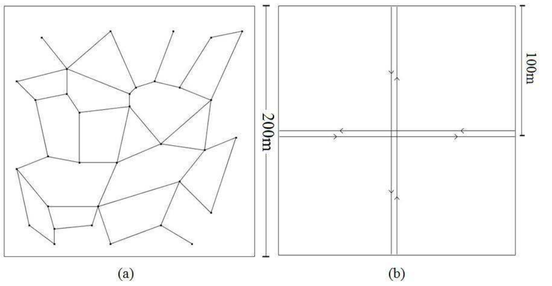


Fig. 3. Maps used for GBMM (a) and MMM (b)

routing whereby all the routing information is maintained and continually updated at mobile nodes;

- Ad-hoc On-demand Distance Vector (AODV) [8] works similarly to DSR using route discovery and maintenance mechanisms. It, however, uses hop by hop routing;
- Optimized Link State Routing (OLSR) [9] is a proactive routing protocol, where the information about the network topology is exchanged by control packets (Hello messages). OLSR makes use of Multi-Point Relays (MPR) nodes to retransmit broadcast messages and hence reduce control packets.

We run simulations over NS-2 (Network Simulator version 2). Simulation duration is taken to be $1000s$. Speeds of 1m/s and 20m/s (equal to 3,6km/h and 72km/h, respectively) are used to mimic the mobility of both pedestrians (low speed) and cars (high speed). Transmission ranges are equal to $100m$.

The traffic rate is 32kbits/s and the data packets size is 96Bytes. Traffic is generated during all simulation duration. So, let the set of the source-destination pairs, MP_{SD}, be $\{(i, i+20)\ \forall i \in [1, N]\}$ where N is the number of nodes.

We use the number of nodes and the simulation area of 10 and 200m×200m, respectively to simulate a high nodes connectivity.

Finally, we generate 20 mobility scenarios for RWP, SRMM, GBMM and MMM based on [10], [11] and [12] tools, respectively.

B. Mobility and Routing Metrics Results

Figure 4 shows the average path durations and the average path absence durations as a function of nodes speed for the different mobility models and routing protocols stated above.

First, we observe that both metrics decrease as speed increases for all mobility models and routing protocols. In effect, when the nodes speed increases, paths are established and broken more frequently and hence the path and absence of path durations decrease. In addition, Figure 4 shows that for high nodes speed, the best values for the metrics are obtained for MMM followed by GBMM, RWP and finally SRMM. When the nodes speed increases, the mobility models performance order changes and becomes GBMM, RWP, SRMM and MMM. The reasons for these results are the following. First, the performance of MMM is due to the map shown in Figure 3(b) where links are only formed if nodes move close to each other in the same or opposite lanes or at intersections which are less probable situation when the nodes speed is high. As a consequence, the network fragmentation occurs which means that some nodes become not reachable by other nodes of the network which leads to large absence of path duration and small path duration. In addition, the performance of random mobility models RWP and SRMM are similar as they allow nodes to move in all directions, and so, links can be formed more frequently than for the MMM model. The good performance of GBMM is due to the fact that it is a mix between restricted and random mobility models. In effect, nodes positions are fixed on the graph as shown in Figure 3(a) and the nodes destination positions are randomly chosen. As a consequence, the probability of link and path establishment is high whatever the network parameters are.

Moreover, we observe that the mobility path durations are larger than the routing ones and, on the contrary, the absence of routing path durations are larger than the mobility ones for all mobility models and nodes speed. The reason is that mobility paths persist more and are less sensitive to interruptions than the routing ones.

Finally, we observe that AODV is the worst routing protocol as it has the lowest values of path durations and largest absence of path durations. The best routing protocol for such

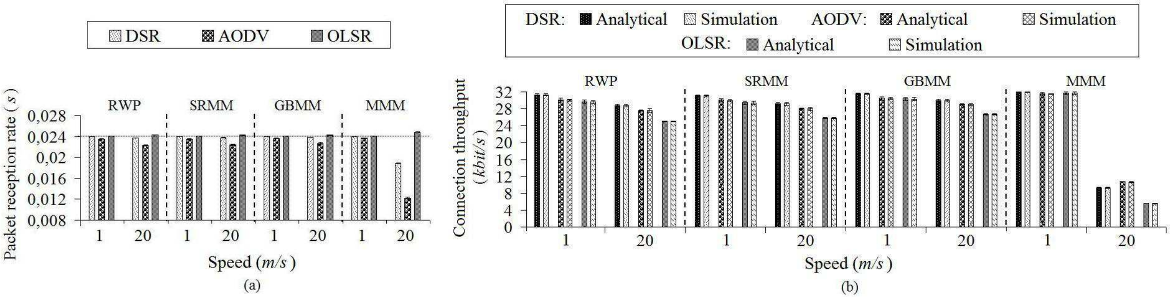


Fig. 5. Packet reception rate (a) and connection throughput (b) function of mobility models, nodes speed and routing protocols.

configuration is DSR. As OLSR is a proactive protocol, at each topology modification and/or periodically, messages are broadcasted to update network information. This fact increases the knowledge about the validity of paths. However, as our network has a high nodes connectivity, less updates are made which allows OLSR to be more efficient. DSR and AODV are reactive, and so, latencies characterize the routes discovery mechanism. Due to the maintenance mechanism however, path interruptions can be quickly detected. In particular, DSR uses MAC notification to detect link failure and AODV uses periodic Hello messages which are broadcasted each $2s$. And hence, DSR failure detection mechanism is more efficient than AODV's. As a result, DSR performs better.

C. Throughput Results

Figure 5 shows the average packet reception rate and connection throughput as a function of nodes speed for the different mobility models and routing protocols obtained from the analytical model (see 11) and from the simulations.

First, we observe that, in almost all cases, packet reception rate is close to packet generation rate. The reason is that as shown for the routing metrics, discovered paths last a longer period of time before breaking. This allows a constant reception rate of packets at the destination. In addition, we observe from Figure 5(b) that the throughput performance follows the mobility and routing metrics as explained above. Moreover, as can be seen from Figure 5(b) throughput under GBMM is the largest among all routing protocols. AODV and DSR work better than OLSR. Those observations are due to the results obtained for mobility and routing metrics discussed above. Furthermore, we observe that throughput reaches 32kbit/s peak and it is low for MMM at high speed. These performances follow, again, the routing metrics: when the routing path duration is high compared to the absence path duration, the network performance is at its best. When the nodes speed decreases, the MMM mobility model works bad as the network fragmentation occurs.

Last, but not least, we observe that our analytical connection throughput model follows closely the values obtained by simulations, as shown in Figure 5(b).

IV. PROPOSAL FOR ENHANCING THROUGHPUT PERFORMANCE

As shown in the previous section, for MMM at high speed, when network fragmentation is frequent, paths cannot be available for a large duration and the network performs poorly. On the contrary, when mobility enables more path establishment opportunities, as in the case of GBMM, throughput achieves a better performance. M. Abdelmoumen, I. Arfaoui, M. Frikha and T. Chahed [13] proposed the use of additional fixed relay nodes so as to improve the network performance by increasing the opportunities of establishing paths and preserving them. We next reproduce its architecture and its impact on enhancing throughput performance for the case of MMM mobility model.

A. Number and Position of Additional Relays

The number of these additional relay nodes must be large enough so as to improve the network performance, but must not exceed a certain limit so as not to overload the network. By trial and error, we fix this number to around 20% of the total number of nodes in the network.

As of their positions, they depend on the (instantaneous) topology of the network. For the special case of MMM model at high speed, as the transmission range of the nodes is sufficiently large compared to the simulation area (100m and 200m×200m, respectively) and with reference to the MMM map (see Figure 3(b)), we choose to fix relay nodes at the positions shown in Figure 6, so as to cover all possible nodes positions and to have a continuous transmission link during the simulation duration.

B. Performance of Proposal

Figures 7 and 8 show the mobility and routing metrics and the average connection throughput, respectively, before and after the use of the additional relay nodes. For comparison, we also show the old values of the studied metrics.

As shown in Figure 7, the mobility path duration increases and the absence of mobility path duration decreases a little with the use of the additional relay nodes. In effect, at high nodes speed, the mobility and routing metrics do not yield a large improvement because nodes move fast enough to have a high connection/disconnection frequency despite of the use of the fixed relay nodes.

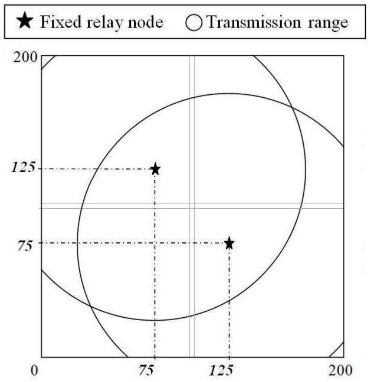
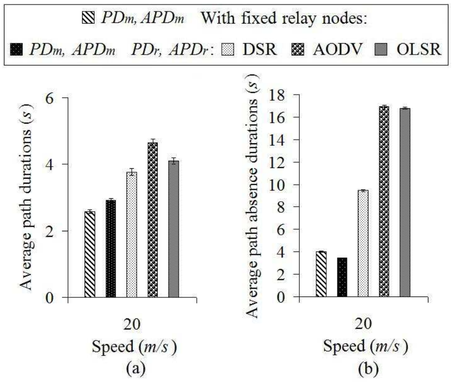


Fig. 6. Relay nodes position for MMM at high speed.



(a) (b)

Fig. 7. Average path durations (a) and average of the path absence durations (b) for MMM at high speed without and with fixed relay nodes.

As of throughput, Figure 8 shows that throughput increases with the use of the fixed relay nodes for all mobility models, routing protocols and nodes connectivity. The reason is that packets are lost in smaller number because the absence routing path duration is lower than without the use of the fixed relay nodes. In addition, as explained in the previous section, DSR and AODV work better than OLSR.

V. CONCLUSION AND FUTURE WORK

In this work, we studied the relationship between mobility, routing and MANETs network performance, notably in terms of throughput. We specifically proposed a new model for throughput based on metrics for mobility and routing and validated it in comparison to simulations for various network settings, mobility patterns and routing protocols.

In the case of poor performance, mainly due to network fragmentation, we proposed, and optimized, the use of additional fixed relay nodes which would maintain the overall network connectivity and hence improve the overall throughput performance.

As a future work, we intend to make our study more practical by applying it to a real network.

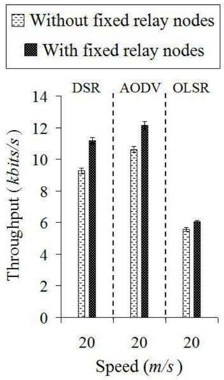


Fig. 8. Network throughput for MMM at high nodes speed without and with fixed relay nodes.

REFERENCES

[1] M. Grossglauser and D. Tse, ”Mobility increases the capacity of ad hoc wireless networks”, IEEE/ACM Trans. Netw., Aug. 2002, vol. 10, no. 4, pp. 477-486 .

[2] N. Sadagopan, F. Bai, B. Krishnamachari and A. Helmy, ”PATHS: analysis of path duration statistics and their impact on reactive MANET routing protocols”, Proc. ACM MobiHoc, Jun. 2003, pp. 245-256.

[3] D.B. Johnson and D. A. Maltz, ”Dynamic source routing in ad hoc wireless networks”, In Mobile Computing, The Kluwer International Series in Engineering and Computer Science Volume 353, 1996, pp. 153-181

[4] C. Bettstetter, ”Mobility modeling in wireless networks: categorization, smooth movement and border effects”, SIGMOBILE Mob. Comput. Commun. Rev., Jul. 2001, pp. 55-66.

[5] J. Tian, J. Hahner, C. Becker, I. Stepanov and K. Rothermel, ”Graph-based mobility model for mobile ad hoc network simulation”, SS’02, San Diego, Apr. 2002, pp. 337-344.

[6] F. Bai, N. Sadagopan and A. Helmy, ”IMPORTANT: a framework to systematically analyze the impact of mobility on performance of routing protocols for adhoc networks”, INFOCOM ’03, San Francisco, Mar.-Apr. 2003, pp. 825-835 .

[7] D. Johnson, Y. Hu and D. Maltz, ”The Dynamic Source Routing Protocol (DSR) for Mobile Ad Hoc Networks for IPv4”, RFC 4728 Experimental, Feb. 2007.

[8] C. Perkins, E. Belding-Royer and S. Das, ”Ad hoc On-Demand Distance Vector (AODV) Routing”, RFC 3561 Experimental, Jul. 2003.

[9] T. Clauser and P. Jacquet, ”Optimized link State Routing Protocol (OLSR)”, RFC 3626 Experimental, Oct. 2003.

[10] R. Baumann, F. Legendre and P.Sommer, ”Generic mobility simulation framework (GMSF)” , Mobility Model,08 : Proceeding of the 1st ACM SIGMOBILE workshop on Mobility models, Hongkong, China, May. 2008, pp. 49-56.

[11] The CANU Mobility Simulation Environment (CanuMobiSim) [http://canu.informatik.uni-stuttgart.de/mobisim/: Aug. 2014]

[12] The mobility tool generators [http://nile.cise.ufl.edu/important/software.htm: Jun. 2013]

[13] M. Abdelmoumen, I. Arfaoui, M. Frikha and T. Chahed, ”On the performance of MANETs under different mobility patterns and routing protocols and its improvement based on fixed relay nodes”, NTMS, Istanbul, May. 2012, pp. 1-5.