Performance Evaluation of MANET and DTN Routing Protocols

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***Abstract*—Unstructured mobile networks (UMNs) are mobile networks in which there is little or no pre-installed infrastructure (access points, antennas), and as such message forwarding is performed among the mobile nodes or within the wireless infrastructure. Routing in those networks occurs either using MANET approaches, where nodes build and end-to-end path among source and destination, or DTN routing, where nodes exchange cached messages whenever they enter in radio range with one another. One open question in the field, however, is when to use each of the approaches. Most UMN deployments lie on a gray zone, where it is hard to determine the most suitable protocol. This paper presents a performance evaluation of both approaches, in an attempt to identify when to employ each protocol.**

I. Introduction

Unstructured mobile networks (UMNs) are mobile networks in which there is little or no pre-installed infrastructure (access points, antennas), and as such message forwarding is performed among the mobile nodes or within the wireless infrastructure. UMNs are suitable to a wide range of applications, from environmental monitoring to vehicular networks, mesh networks, among others [1–3].

Routing in UMNs can be divided into two classes: *MANET* [4] and *DTN* [5] routing. In Mobile Ad Hoc Networks (MANETs), it is assumed that the graph of the network topology forms a single connected component, and as such it is always possible to identify an end-to-end path on which data can be forwarded. Disruption and Delay-Tolerant Networking (DTN), on the other hand, assumes that an instantaneous end-to-end path may never exist, either due to high mobility of the nodes or due to their frequent disconnections. Thus, both networks employ very different forwarding strategies [6]. In MANETs, routing algorithms employ control packets to build efficient unicast routes, where a single copy of each packet is sent. In DTNs, several copies of the packet are replicated to a set of nodes, which store them on secondary memory and forward the data whenever a new node comes within radio range. Thus, MANET and DTN routing strategies have significant differences in their operation and assumptions [6].

Previous studies attempted to characterize the topology formed in real deployments, in an attempt to identify which routing strategy would be more suitable [6–8]. Most studies show that real-life UMNs are formed by partitions of nodes having fairly stable connections, due to the nature of human interactions. They occur in groups based on friendship, work relations and personal habits, and changes in those groups occur in large time granularities. Further, these groups may change in regular time intervals, i.e. during business hours people tend to interact with their coworkers, while on the rest of the day they interact more with friends or relatives.

Thus, one must identify if DTN or MANET routing is more appropriate for a given partition of the mobile network or a given communication request. Hybrid forwarding algorithms would pick the best forwarding alternative on each scenario, or adaptive algorithms would parameterize the protocol properly in order to forward the message in the most efficient way. Current characterization efforts are based on a global knowledge of the network topology. Those works employ complex network metrics in order to identify which paradigm best fits a certain network topology [6]. It has been identified, though, that a significant part of the spectrum of configurations lies on a “grey zone”, where it is not clear which paradigm is best. This situation is depicted in Figure 1: dense and mostly static networks should employ MANET routing, while dynamic sparse networks should employ DTN routing. Almost static and sparse networks (A-DTNs) will not be discussed in this paper, since they are rare in mobile networks. The other configurations lie on a zone where a combination of MANET and DTN approaches is the ideal solution.

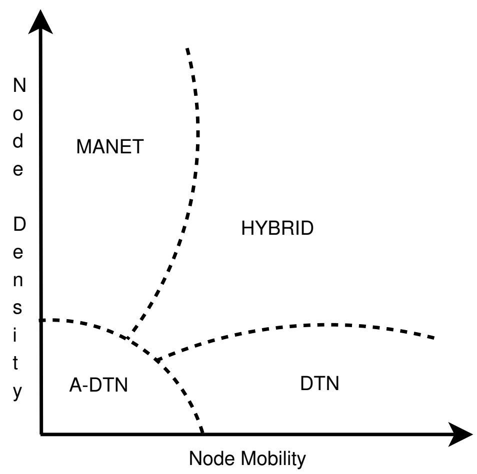

Fig. 1. Graphical representation of the DTN × MANET dilemma.

This paper presents a performance characterization of MANET and DTN forwarding strategies. Our objective is to

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increase the understanding of the trade-offs of such protocols, in order to propose better adaptive or hybrid protocols. We employed a realistic simulation model, in order to account for factors that are usually left out on most DTN simulations.

The remaining of this paper is organized as follows. Section II presents the related works. Section III describes the evaluated protocols, followed by their evaluation in Section IV. The conclusions and future work are presented in Section V.

II. Related Works

Node mobility studies in unstructured mobile networks have shown that most networks are a mix of MANET and DTN regions. Nelson et al. proposed a mobility model for emergency networks based on the actions of the rescue workers [8]. They found regions with an elevated number of nodes having a high clustering coefficient, while others presented sparse topologies.

Chantreau et al. analyzed the inter-contact times of mobility traces to identify the impact of human mobility on the forwarding algorithms [7]. They evaluate flooding and wait-and-forward (similar to Spray and Wait [9]), and propose ways to configure both protocols based on the inter-contact times.

Manfredi et al. presented a trace-based evaluation of when to use MANET or DTN protocols [6]. Their study, based on complex network analysis and simplistic simulations, showed that some popular DTN traces have periods of "DTN-like" behavior and moments of "MANET-like" behavior, highlighting the need for adaptive and hybrid protocols.

Several hybrid algorithms attempt to exploit the benefits of each strategy. HYMAD is a hybrid protocol that routes data between disjoint groups of nodes using DTN strategies, while MANET routing is used within the groups [10]. In [11], the end-to-end semantics is maintained whenever possible. When the path is broken, a DTN-based approach is used. In this approach, the application can choose to use MANET or DTN forwarding. Another hybrid scheme that combines AODV and DTN routing is presented in [12]. The sending node chooses, in the application level, when to use DTN or AODV.

The protocols above employ simple decisions, and as such present a high overhead. Most run two routing protocols at the same time, instead of running only the most suitable protocol. Their delay is also high in networks with low connectivity, since DTN is mostly used as a failover mechanism. To produce better hybrid or adaptive protocols, first we need to improve our understating of the performance of DTN and MANET routing. This study characterizes the scenarios in which DTN or MANET routing perform best, in an effort to provide quantitative data for the development of more efficient hybrid and adaptive protocols.

III. Evaluated algorithms

This section describes the evaluated algorithms. We selected one algorithm of each of the main types of DTN and MANET routing techniques. Although there are other more efficient protocols on each of the classes, this is irrelevant to our study since we focus on the advantages and disadvantages of one class of protocol over another.

A. MANET Protocols

MANET routing can be grouped by different criteria [13], however in this work we separate them as reactive and proactive. Proactive protocols create routes for all nodes beforehand, while reactive protocols create routes only on demand.

Reactive routing: AODV – AODV is an on-demand distance-vector protocol [14]. Whenever a node initiates a communication, AODV broadcasts route request (RREQ) messages. All nodes forward this message until the destination is found. The destination, sends in unicast a Route Reply (RREP) message through the shortest path from source to destination, calculated using the RREQ packets that it received. If a routing failure occurs, nodes use a localized approach to restore it, sending Route Error (RERR) messages to its neighbors.

Proactive routing: OLSR – The optimized Link State Routing (OLSR) protocol is a proactive link state routing protocol [15]. It employs multipoint relays (MPRs) to reduce the overhead of route construction. OLSR minimizes the overhead by carefully selecting which nodes will forward routing data, the MPRs. MPRs are chosen so that a node must be able to reach all of its two-hop neighbors through a MPR.

B. DTN Protocols

Since we focus our work on UMNs, we evaluated only stochastic DTN approaches, which are applicable when very little can be inferred from the positions of nodes. Stochastic protocols can be divided into three categories [7]: *flooding*, where the messages are disseminated to all nodes upon a contact; *wait-and-forward*, where a limited number of messages are disseminated; and *informed forwarding*, where the choice of nodes is based on previously acquired knowledge.

Flooding: Epidemic – is a stochastic routing algorithm for DTNs where the source node sends the message to all its neighbors, which then send the message to all their neighbors [16]. This cycle is repeated up to a maximum number of hops, determined by the Time-to-live (TTL) field of the message. Using node mobility, the message can be delivered to regions of the network that are not reachable through and instantaneous end-to-end path. Epidemic routing is very efficient in terms of its delivery ratio, however the number of messages sent increases proportionally to the number of nodes [16].

Wait-and-forward: Spray and Wait – Spray and Wait uses two forwarding strategies [9]. In the first strategy, called Spray, L message copies are disseminated. The source node forwards the message to all its neighbors, which store the message in their cache, and then forward the message. Each neighbor is allocated a fraction of L. This process is repeated several times, and at each time the value of L is reduced. When a node receives the message having L set to zero, the process stops. The destination may not be reached using the Spray strategy. Hence, nodes may use the Wait strategy: the message is forwarded directly to the destination if one of the nodes having the message in its cache contacts the destination.

Informed forwarding: PRoPHET – Probabilistic Routing Protocol using History of Encounters and Transitivity forwards messages according to an expected delivery probability, based on connectivity analysis [17]. PRoPHET assumes that node movements are not entirely random, thus the protocol forwards messages to nodes that make more frequent contacts with others, which are more likely to contact the destination.

IV. Evaluation

This section presents the performance evaluation, performed via simulations. We chose simulations due to the high complexity and cost of large scale experiments. The simulation scenarios were chosen in order to better characterize the more suitable approach for each situation.

A. Simulation environment

The simulation employs NS-2, a discrete event simulator that provides very realistic MAC and PHY models. Unlike DTN simulators, NS-2 models the energy consumption, the effects of signal propagation on the environment, fading due to movement and sources of interference, and simulates the entire MAC and PHY layers.

The simulator has been adapted for DTN protocols. First, each node has a message buffer that stores both received and sent messages. We also implemented our own contact mechanism, since the performance of the DTN protocols depends on an efficient contact. Our implementation has 3 steps. Periodic announcements identify neighbors and announce which messages are stored on the buffer. If a node wishes to receive messages owned by another node, it replies to the announcement, listing the requested messages. Finally, the request is followed by the transmission of the messages. We use the Most Forwarded First Out (MOFO) packet discard policy for full buffers [18], since it presented the best performance.

Each node starts the simulation with 1000J of energy. We only consider the energy consumption of the wireless card. We model an IEEE 802.11b Cisco Aironet 250 [19] card, as defined in Table I. We simulate a scenario of rescue worker communication, where one message is generated every 5s. Those messages could contain maps, small texts or alerts. All messages have a fixed size of 10 KB in our simulations.

TABLE I
SIMULATION PARAMETERS

Message load	
Interval among messages	5s
Start of message load	1400s
End of message load	2900s
Simulation time	3600s
Radio model	
Communication range	240m fixed
Propagation model	Two Ray Ground
Data rate	11Mb
Energy consumption on transmission	1.6887W
Energy consumption on reception	1.0791W
Energy consumption on idle listening	0.6699W
Signal output power	10dBm

The protocols were configured as follows. We employed the default parameters for OLSR, AODV and PRoPHET. For Spray and Wait, the maximum number of copies was set to 6, and we employed its binary mode. We employ the following name in the curves: *Flood* for the flooding-based approach (Epidemic), *WF* for wait-and-forward (Spray and Wait), *IF* for informed forwarding (PRoPHET), *Reactive* MANET routing (AODV), and *Proactive* MANET routing (OLSR).

The following metrics have been considered: (i) end-to-end delay; (ii) delivery rate – the percentage of messages that arrived at their destination; and (iii) number of hops required to reach the destination. The presented results are the mean of thirty independent runs of the simulator, having a confidence interval of 95%. We vary the random seed on every run.

B. Simulated Scenarios

Three simulation scenarios were defined in order to evaluate the performance of the protocols under different conditions. We simulate different mobility models because previous studies showed that the performance of DTN protocols is dependent on the mobility pattern [10]. The following mobility models were evaluated.

1) Random unrestricted movement: In the Random Way Point (RWP) model, each node chooses with uniform probability a destination point in the simulation area, as well as its speed. Upon arriving at the destination, the node pauses for an uniformly distributed time, and then selects another destination. We employed the RWP implementation of [20], which ensures the existence of a stationary state. We deploy forty nodes distributed on a 1000x1000 area, moving at an maximum speed of 1 m/s and pause time of 8s.

2) Movement on an emergency: The Mobility Model for Emergency Networks (MME) is presented in [21]. It is a model where nodes move in groups, visiting pre-defined regions (the *points of interest*) with a higher probability. For each group, a destination is selected according to the assigned probabilities. Next, the model selects the speed of the group. The group moves to that position, pauses for a certain time, and then selects another destination.

In this scenario we chose a 3000x3000 area representing a nuclear power plant. We defined five points of interest, having 10%, 10%, 20%, 20% and 40% as their visit probabilities. Nodes move with a speed of 1 m/s, and the pause time of 8s. We simulate forty nodes separated into 4, 5, 10 or 20 groups.

3) Restricted RWP on a City Section: We employed the implementation of [20], in which node movement is restricted to paths, representing the streets of a city. In each street segment, the nodes move respecting the maximum speed limit. In this scenario we varied the number of nodes from 20 up to 80 nodes. Nodes move with a max speed of 50km/h, and the pause time is 8s. This scenario emulates the varying conditions of traffic, from low to heavy.

C. Results

This section analyses the simulation results. Instead of analyzing the performance of each particular protocol, we focus our discussion on the properties of each class of protocols. Those conclusions, as such, can be generalized to other protocols within the same class.

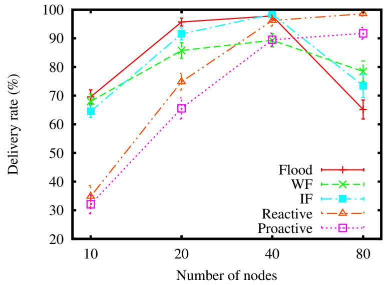

Fig. 2. Delivery rate (%) - Random waypoint

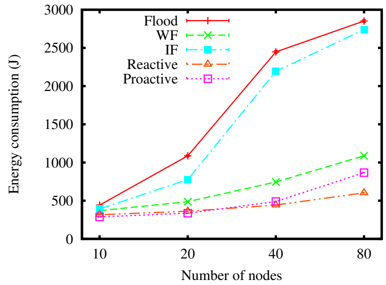

Fig. 3. Energy consumption - Random waypoint

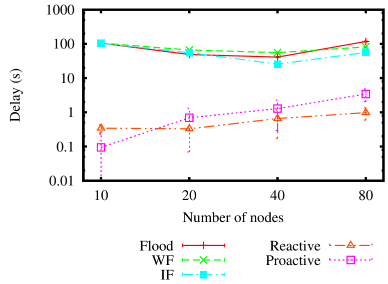

Fig. 4. Delay (s) - Random waypoint

1) Random Unrestricted Movement: Figure 2 presents the delivery rate. When node density is low, the DTN protocols outperform the MANET protocols. With the increase in density, the delivery rate of the DTN protocols decrease. This reduction is more pronounced on informed forwarding and flooding, since the messages are discarded due to insufficient queues. Those protocols send much more messages than wait and forward, hence more messages are discarded and more collisions occur. The reduction in performance of wait and forward is due to its limitation on the number of forwards. As a consequence, nodes only deliver messages to nearby destinations. Thus, the performance of wait and forward protocols depends strongly on the amount of contacts and mobility patterns. For MANET protocols, the delivery rate increases with node density. This increase is more pronounced on reactive protocols, because routes become more stable, and more alternatives are found in case of a route change.

The energy consumption is presented in Figure 3. Both MANET and DTN approaches increase their energy consumption with higher node densities. Flooding has the highest increase, since flooding is highly prone to collisions and insufficient space in the queues, which generate more packet transmissions. Informed forwarding performs better due to its reduced number of messages being sent, and as such less buffer space is used, generating less drops. Wait and forward, in turn, has the smoothest increment, since it has a constant amount of message replicas in the Forward phase. The increment occurs because more contacts occur for denser networks, and as such more packet forwards may occur during the Wait phase. For the MANET approaches, the main reason for energy consumption is routing maintenance. In the case of proactive routing, this cost increases with node density since all routes are updated periodically.

Figure 4 presents the end-to-end delay. The DTN approaches presented the highest delay. Flooding's poor performance is due to the occurrence of collisions and packet discards on full buffers. Informed forwarding sends less messages than flooding, thus it has much less packets discards due to buffers and collisions, hence improving the delay. A similar trend occurs with wait and forward. For the MANET approaches, we observed an increased end-to-end delay. The increment is higher for the proactive approach, since it must update the routes to all nodes, while reactive approaches only update the active routes.

Wait and forward and informed forwarding behaved similarly. This occurs because the movement pattern is almost random, and informed forwarding has no opportunities to optimize the forwarding decisions. The main tool for DTN delivery in this scenario was the amount of message replicas. For MANET protocols, random movement was not a problem. Instead, node density dictated the performance.

2) Movement on an Emergency: Figure 5 shows that the all DTN approaches performed similarly, due to the characteristics of the mobility pattern. All nodes tend to meet in specific points of the simulated area, thus all protocols have the same contact opportunities. The slight performance decrease is due to the increment in the number of nodes in the group (simulations with less groups), which causes more packet collisions in the MAC layer and because the buffers are more occupied since those nodes exchange more messages among themselves. In MANET protocols, on the other hand, the performance improves with less groups, since routing is more efficient within the groups. Larger groups, thus, generate shorter routes. The delivery rate of DTN approaches was not statistically different from that of MANET approaches.

The variation in energy consumption is more significant among the DTN approaches, as shown in Figure 6. The increment in flooding occurs due to the collisions and messages discards on full buffers. Discards due to full buffers are particularly important in flooding because a message may be removed several times, since it enters the buffer upon a contact, is removed, and then is received again upon a subsequent contact. In wait-and-forward, the increase in the energy consumption is due to more contacts, and as such more nodes are able to participate in both the wait and forward phases. Informed forwarding, on the other hand, reduces the energy consumption for larger groups, since larger groups will allow a much larger differentiation of contact probabilities. Meanwhile, the consumption of MANET protocols varied less significantly. This occurs because most packets were discarded due to the lack of routes. Proative protocols consume less since they are less tolerant to node movement, and as such less messages are discarded and less route updates are needed.

The end-to-end delay is shown in Figure 7. The DTN

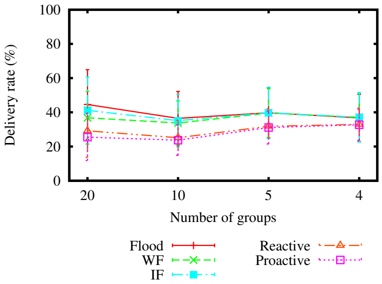

Fig. 5. Delivery rate (%) - Emergency scenario

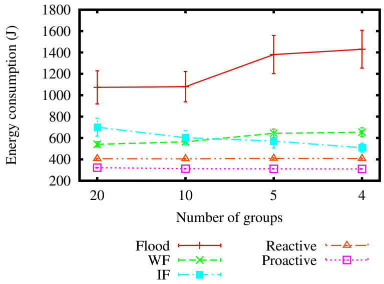

Fig. 6. Energy consumption - Emergency scenario

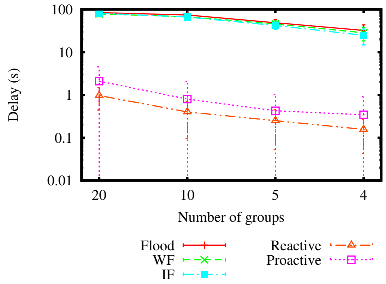

Fig. 7. Delay (s) - Emergency scenario

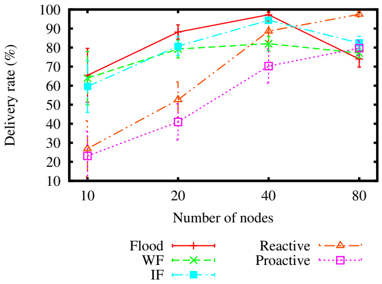

Fig. 8. Delivery rate (%) - Restricted RWP

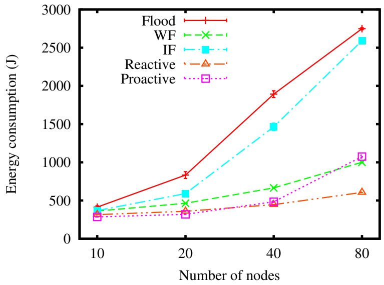

Fig. 9. Energy consumption - Restricted RWP

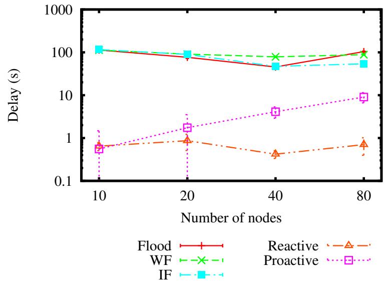

Fig. 10. Delay (s) - Restricted RWP

protocols presented the highest delay. As in previous scenarios, the performance of flooding is mostly dictated by packet collisions and drops. Unlike the previous scenario, this scenario presents a more consistent mobility pattern. As a consequence, informed forwarding is able to optimize the forwarding process, reducing the end-to-end delay with regards to wait and forward. The delay for MANET approaches is lower because most message deliveries occurred within groups, not from one group to another. Thus, since source and destination are very close from one another, the delay was reduced.

This scenario showed the importance of choosing the right routing paradigm depending the destination. In our simulations, only DTN approaches delivered messages when the destination was outside the group of the sender. However, for inter-group communication, MANET approaches outperformed the DTN approaches. This corroborates the findings of [10]. Finally, this scenario outlined the importance of collisions in DTNs, which usually are left out on simulations.

3) Restricted RWP on a City Section: Figure 8 presents the delivery rate. The DTN protocols presented the highest performance for sparse networks, while they were outperformed by MANET protocols on dense networks. The main culprit for the performance degradation in the DTN approaches is packet collisions, which increase with more contacts. Both wait and forward and informed forwarding performed better than flooding due to less collisions. MANET protocols did not reach 100% delivery rates for dense networks due to route failures caused by node movement.

Both MANET and DTN protocols presented a larger energy consumption for denser networks, as shown in Figure 9. For informed forwarding, the increase is partly due to more nodes, and as such the forwarding probabilities are more homogeneous, causing more packet forwards. The consumption of wait and forward increases due to more contacts, causing more message exchanges. For MANETs, the consumption increased for higher densities since more packets were received, and longer routes could be created and maintained. Since messages reach more distant nodes, the consumption increased due to the need for more packet forwards. Besides, more nodes on the network require more bandwidth for route updates.

Figure 10 presents the end-to-end delay. All the DTN protocols performed similarly, due to the characteristics of the movement patterns. Wait and forward presented an almost constant delay, caused by its fixed number of message forwards. With regards to the MANET approaches, the reactive paradigm outperformed the proactive paradigm, since it sends less route update messages, reducing the contention on the network.

The results in this scenario are similar to the results using the RWP model. The restricted movement creates more contact opportunities, and contact patterns arise, allowing informed forwarding decisions to improve the forwarding. However, patterns are not as pronounced as in the emergency scenario. For MANET protocols, the performance was better than the emergency scenario, since the network did not form groups.

V. Conclusions and Future Work

Depending on the characteristics of the deployment, unstructured mobile networks may employ either MANET or DTN routing. However, for certain deployments it is quite hard to pick the best approach. This paper presented a performance evaluation of both MANET and DTN routing, in order to characterize their advantages and drawbacks. Our simulation is more complete than previous works, since we considered a more complex model for PHY and MAC layers. We simulated packet drops, contention among stations, and the discard and forwarding policies employed in contacts in the DTN approaches.

The simulation results showed that the performance of the protocols depends on the mobility pattern. When the nodes tend to move in groups, MANET protocols perform better for intra-group message exchanges, while DTN protocols are better for inter-group communications. MANET protocols are better for dense networks, since they build stable routes, reducing the end-to-end delay. Further, the contact mechanism is expensive, generating packet collisions and contentions in dense networks. This effect had been overlooked so far in the literature. Finally, sparse networks generate frequent routing failures, degrading the performance of MANET protocols.

As future work, we intend to propose hybrid or adaptive protocols based on our findings. We will investigate ways to estimate network metrics such as average node degree, amount of changes per second, route stability, among others, and decide which strategy (DTN or MANET) fits best under the instantaneous conditions.

VI. ACKNOWLEDGEMENTS

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