

A Location Service Mechanism for Position-Based Multicasting in Wireless Mobile Ad hoc Networks

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Abstract—In this paper we propose a novel location management scheme tailored for multicasting in Mobile Ad-hoc Networks (MANETs). We furthermore propose AMDLM, a location-based multicast algorithm relying on the location management service. Such an approach avoids fragile data structures such as trees or DAGs to manage multicast groups, without reverting to more reliable, yet overhead-prone mesh-based algorithms. AMDLM additionally enables us to derive analytical bounds due to its location-based nature.

I. INTRODUCTION

Mobile ad hoc networks (MANETs) are self-organizing mobile wireless networks that do not rely on a preexisting infrastructure to communicate. Nodes of such networks have limited transmission range, and packets may need to traverse multiple other nodes before reaching their destination. Research in MANETs was initiated 30 years ago by DARPA for packet radio projects [1], but has regained popularity nowadays due to the widespread availability of portable wireless devices such as cell phones, PDAs and WiFi/Bluetooth enabled laptops.

Multicasting provides a means for multipoint communication by enabling applications to seemingly communicate with groups of nodes. Traditionally a well suited tool for collaborative applications, multicasting is especially useful in ad hoc networks where tasks may be carried out by groups of nodes. Due to scarce bandwidth, varying network connectivity and frequent topology changes caused by node mobility and transient availability, routing algorithms tailored for wired networks will not operate well if directly transposed to MANETs. All the more so with multicasting, which adds to the difficulties of unicast routing the complexity of maintaining and handling dynamic multicast group membership changes.

In this paper we present a novel MANET location service for multicasting, which is based on an extension of the DLM scheme [2]. Dedicated servers are distributed throughout the network in order to store the geographic location of multicast group members. Coupled with an underlying geographic forwarding layer (e.g. [3], [4]), the solution offers an alternative

approach for multicast routing. Since no end-to-end routes are maintained, the benefits of location-based multicasting are reduced overhead, increased robustness to mobility and fault-tolerance. There exist several location-based algorithms for *unicast* routing ([5], [6], [2]). In [7] the authors extend unicast position-based routing for multicasting: the paper generalizes routing and assumes that the position of the destination(s) is known in advance through a location service. Because of node mobility and dispersion of multicast node members, we claim that location services designed for unicast routing are not exploitable as such for multicasting. The contribution of this paper is to devise a novel location management scheme adapted for multicasting in MANETs. We furthermore present *AMDLM* (*Adaptive Multicast Distributed Location Management*), a location-based *multicast* algorithm built on top of the location service¹.

The remainder of the paper is organized as follows. The next section provides an overview of other works that address multicasting in MANETs. In Section III we present the DLM [2] location management scheme for unicast routing, which serves as a basis for our multicast algorithm. Section V presents *AMDLM*, a novel location based multicast algorithm. In Section VI we undertake an analytical study of the algorithm, followed in Section VII by a qualitative comparison between *AMDLM* and the other popular approaches for MANET multicasting. We finally conclude and describe future work in Section VIII.

II. RELATED WORK

There have been numerous multicast algorithm proposals for MANETs. In this section we present the most representative of each approach.

As with unicast routing, multicast routing comes in *proactive*, *reactive*, or a combination of the two flavors (*hybrid*). Reactive algorithms [9], [10] present reduced maintenance

The work presented in this paper was supported by the National Competence Center in Research on Mobile Information and Communication Systems (NCCR-MICS), a center supported by the Swiss National Science Foundation under grant 5005-67322.

¹Location-based multicasting may be confused in the MANET community with *geocasting* [8]. Whereas for geocasting nodes join and leave groups by entering and leaving geographic regions, multicasting enables nodes to join and leave groups at any time, regardless of their location. *AMDLM* provides the latter service.

overhead by maintaining state information only when a multicast session is active. The drawback is decreased responsiveness. Proactive algorithms [11], [12], [13] react faster since multicast routing information is readily available, but at the price of introducing high overhead for maintaining multicast group structure even when no multicast session is active. The hybrid approach [14] aims at obtaining a satisfactory balance among the characteristics of both methods by limiting the scope of the proactive procedures to the local neighborhood of nodes and implementing reactive procedures for longer distances.

Various algorithms rely on different data structures to manage multicast group membership. Due to the highly dynamic and everchanging topology of MANETs, solutions that offer multiple routes through more robust data structures perform better. Therefore, mesh-based solutions [10] generally outperform tree-based solutions [9] due to the availability of alternative paths, which in turn tend to perform better than directed acyclic graph (DAG) solutions [13]. In extreme cases of high mobility and frequent multicast group membership changes, basic flooding still remains the best performing multicast algorithm [15]. Performance comparison studies of MANET multicast protocols may be found in [16], [17], [18].

Our (reactive) location-based approach for multicasting, *AMDLM*, differs from previous MANET multicast algorithms by relying on a location service composed of dedicated nodes distributed across the network². Communication between these nodes is provided by an underlying geographic forwarding routing mechanism. Therefore, to the contrary of the tree, DAG or mesh approaches, no multihop data-structure needs to be maintained, reducing the vulnerability to the frequent link-breakages that occur in MANETs.

III. THE DISTRIBUTED LOCATION MANAGEMENT SCHEME (DLM)

DLM [2] is a location management service for MANETs tailored for *unicast* routing, which addresses the shortcomings of GRID [6]. As with GRID, DLM partitions the mobile node deployment region into a hierarchical grid with squares of increasing size, as shown in Figure 1(a). The location service is offered by location servers assigned across the grid, storing node location information. DLM assumes a *uniform* distribution of the location servers. The server density is a parameter that may be adapted to better suit the characteristics of the network. *To the contrary of GRID, location servers in DLM are not directly nodes, but regions in the grid.* Nodes that happen to be located in these region offer the location service. This solution increases DLM's robustness to mobility. The selection mechanism for the predetermined regions is carried out through a hash function, which maps node identifiers to region addresses.

DLM distinguishes between a *full length* address policy and a *partial length* address policy. Under the full length address policy, location servers store the precise position of nodes.

When nodes change regions due to mobility, it is necessary to update all location servers. Under the partial length address policy, the accuracy of node location information stored at the location servers increases along with the proximity of the location servers to the nodes. To the contrary of the full length address policy, several queries are necessary to locate a node. Nevertheless, the partial addressing scheme offers overall increased performance, since it reduces the scope and frequency of location server updates due to node mobility. Indeed, only the location servers affected by the distance travelled by the nodes need to be updated. We therefore consider the partial length address policy whenever we refer to DLM in this paper.

Figure 1 illustrates an example of how a node location query is carried out in DLM. Figure 1(a) depicts the location server hierarchical partitioning, which is an abstract overlay above the full grid in which the nodes evolve (Figure 1(b)). A location server is responsible for its entire region, which may not be within single-hop communication reach. Node *B* desires to find the location of node *A*. Node *B* will first query location server *L10*, which is *A*'s location server in the same region as *B*. *L10* will reply to *B* with information about the quadrant *A* belongs to. *B* will now contact a location server for *A* in that quadrant, e.g. *L4*. *L4* will similarly reply to *B* with the smaller subregion containing *A*. The process continues until *B* eventually contacts a location server that knows *A*'s exact position, *L3* in our example.

IV. DLM AND MULTICAST

In this section we examine the straightforward modifications required for DLM to offer a multicast service.

A. MDLM: Extending DLM for Multicast

DLM scheme relies on a *hash function* for assigning and locating servers responsible for storing node location information. The assignment is essentially based on the identifier of the node we wish to locate. DLM may be extended to offer a multicast service by replacing the node ID parameter by a multicast group ID. Furthermore, location servers will now store a *set* of links to regions that contain multicast group members. The rest of the algorithm remains similar. In the remainder of the paper, we denote by *MDLM* the straightforward extension of DLM for the multicast operation.

Figure 2 illustrates an example of a node *B* multicasting to a group *G* composed of members $G = \{A, A', A''\}$, with the multicast extensions brought to DLM. *B* must first obtain the location of the group members. Node *B* will first query location server *L10*, which is group *G*'s location server in the same region as *B*. *L10* will reply to *B* with a set of quadrants that contain group members. *B* will then contact a location server for *G* in each one of the quadrants returned, i.e. *L4*, *L12* and *L13*. These location servers will similarly reply to *B* with the smaller subregions containing members of *G*. The process continues until *B* eventually contacts the location servers that know the exact position of each group

²See the comment concerning [7] in the introduction.

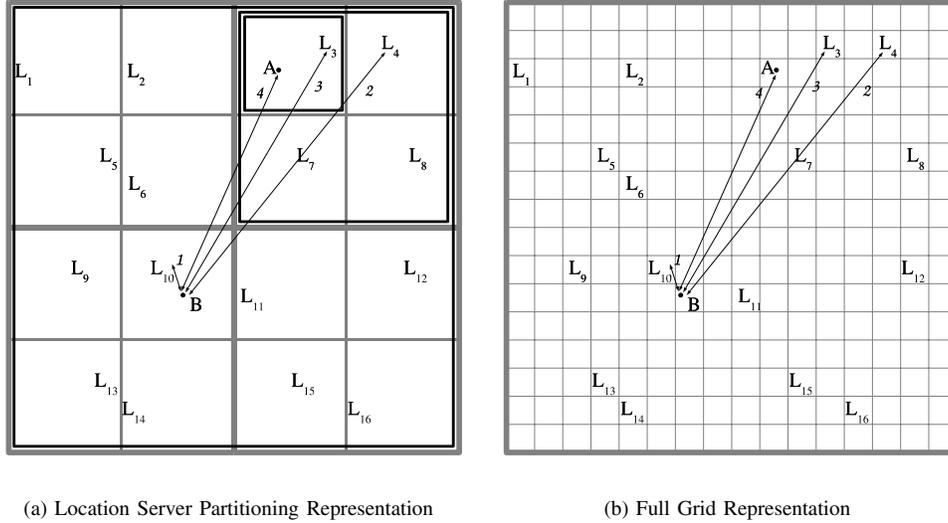


Fig. 1. Node Location Query under DLM's Partial Address Policy

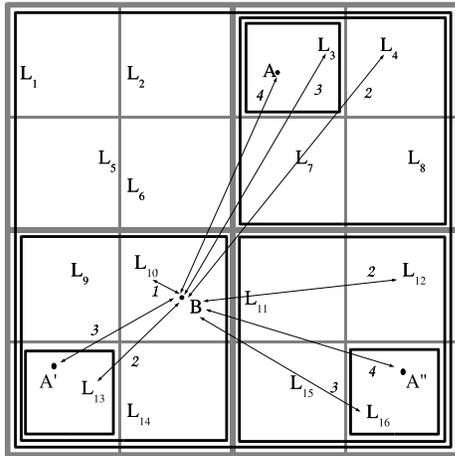


Fig. 2. DLM Multicast Extension

member, L_3 , L_{13} and L_{16} in our example. B may now send a message to A , A' and A'' .

There are also trivial modifications that may be brought to DLM's approach in order to greatly enhance performance. In particular, instead of location queries being sent back and forth between a requesting node and the location servers until location information is gathered, a multicast may be sent and routed through the location servers themselves. Multicast messages will be forwarded along the location servers until they reach their destination. Among the benefits are reduced latency, increased reliability and robustness to mobility, since messages may still reach a moving target.

B. Discussion

The solution presented in Section IV-A to transform DLM into a multicast service (MDLM) is rather straightforward but has nevertheless drawbacks in terms of performance, overhead

and scalability.

In the case of a uniform distribution of *multicast group members*, MDLM may be satisfactory. This is however not the case with a non-uniform geographic distribution of the group members, a situation that may be very frequent. If group members are not uniformly distributed, having a uniformly distributed set of location servers is not optimal in terms of cost to maintain the location information (in regions void of group members) when nodes move, join, or leave the group.

Ideally, the presence or absence of location servers in a region should dynamically adapt to the presence or absence of group members in that region. In the rest of the paper we present a solution that has this property. We also discuss how nodes *join* and *leave* a group and the handling of node mobility.

V. THE ADAPTIVE MULTICAST DISTRIBUTED LOCATION MANAGEMENT ALGORITHM (AMDLM)

A. Design Choices for Efficient Location Management Multicasting

The most desired property for a location-based MANET multicast algorithm is to minimize the number of required location servers without harming overall performance. This may be achieved through maintaining a higher concentration of location servers around multicast group members, which requires a *dynamic* assignment and adaptation of the location servers. Multicast group members and nodes in their proximity will have privileged access to multicast group membership information. Nodes far from group members can still multicast, yet with a higher average cost.

An additional desirable property is the independence of the core multicast algorithm from a particular location server placement scheme. This is achievable by isolating key hash function properties from a specific implementation. The benefit will be a more flexible location-based multicast algorithm,

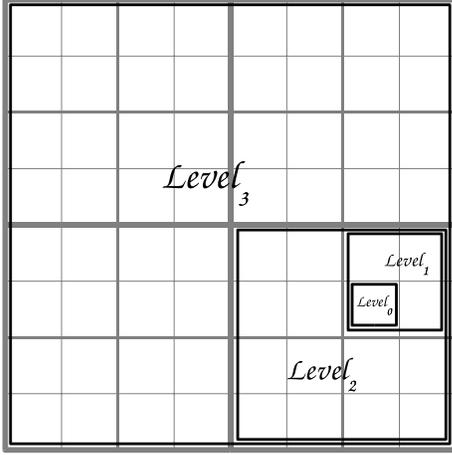


Fig. 3. Grid Partitioning Scheme

since the hash function responsible for placing the location servers may be chosen to better suit a particular MANET topology.

B. Model

The model for *AMDLM* is similar to *GRID* [6] and *DLM* [2]. Wireless nodes evolve in a geographic area partitioned into a hierarchical grid with squares of increasing size. The smallest region contains one square and is referred to as the $level_0$ region. Four $level_0$ regions form a $level_1$ region and so on, as shown in Figure 3. Regions do not overlap, so a $level_k$ region belongs to exactly one $level_{k+1}$ region (and thus nodes belong to exactly one region of each size). We further assume, as with position-based routing algorithms, that nodes are aware of their location through a positioning system such as GPS. Since the grid is static and predetermined, nodes know of their current region within the grid, as well as its boundaries. Nodes sharing the same $level_0$ region are called *neighbors*. All neighbors have knowledge of each other, even though they may not be within a 1-hop communication range (i.e. through flooding or token passing)³. Finally, similarly to *DLM*, we assume node density and distribution such that statistically over time, at least one node will be present per $level_0$ region (the grid dimensions may be chosen accordingly)⁴.

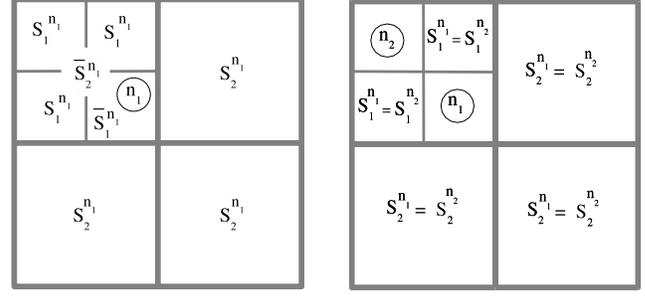
Given two regions reg_1 and reg_2 , we denote by $reg_1 \cup reg_2$ the geographic region that corresponds to the union of reg_1 and reg_2 , by $reg_1 - reg_2$ the geographic region such that reg_2 is removed from reg_1 ; moreover $reg_1 \subset reg_2$ is true if reg_1 is included in reg_2 .

C. Logical Servers and their Placement

Given $k \geq 0$, we define R_k as any $level_k$ region. For a node n_i , $R_k^{n_i}$ is the region R_k such that $n_i \in R_k$. *Logical*

³The size of $level_0$ regions may also be chosen as to be fully covered by the transmission range of the nodes. In this case, the term *neighbors* still refers to two nodes sharing the same $level_0$ region and not to any two nodes within communication range.

⁴This assumption does not mean uniform distribution of group members!



(a) Property 1: Partitioning Rule

(b) Property 2: Sharing Rule

Fig. 4. Hash Function Properties

servers correspond to level₀ regions: nodes happening to be in a given $level_0$ region that correspond to a logical server, participate in the service. Note that, as already explained, not every $level_0$ region is necessarily a logical server.

The logical servers are denoted by S . More precisely, we denote by $S_k^{n_i}(G)$ the logical server(s) in a region R_k for node n_i and group G . We further define $\bar{S}_k^{n_i}$ as being the $level_k$ location server located in n_i 's $level_{k-1}$ region. $S_k^{n_i}(G)$ will simply be denoted $S_k^{n_i}$ in the rest of the presentation. We now present the placement rules of our logical servers for a given group G .

Property 1 (Partitioning Rule, see Figure 4(a)):

$k = 0$: For each node n_i member of G , there exists exactly one logical server of level 0 (denoted by $S_0^{n_i}$), which is region $R_0^{n_i}$.

$k > 0$: For each level $k > 0$ and for each node n_i , there exist exactly four logical servers of level k (denoted by $S_k^{n_i}$). Moreover, there is exactly one of these four servers S_k in each of the four sub-regions region $R_{k-1}^{n_i}$ of region $R_k^{n_i}$ (denoted by $\bar{S}_k^{n_i}$).

Property 2 (Sharing Rule, see Figure 4(b)):

$\forall k > 0$ and for two nodes n_i and n_j member of the same group, if $R_k^{n_i} = R_k^{n_j}$, then n_i and n_j share the same level k server(s), i.e. $S_k^{n_i} = S_k^{n_j}$.

D. Locating Logical Servers

Nodes determine the geographic position of the *logical servers* by means of a *hash function* that implements the placement rules presented in Section V-C. For a given multicast group G and level $k > 0$ (i.e., for group G and region R_k), the hash function returns the four $level_0$ regions corresponding to the four logical servers in R_k for group G . Note that these $level_0$ regions are not necessarily logical servers, since the presence of logical servers depends on the presence or not of members of G in region R_k . So a node n_i — located in the level 0 region of address a ⁵ — wanting to multicast a message to group G first needs to find the smallest $k \geq 0$ such that there is a logical server of level k in the R_k region of n_i .

⁵Each R_0 region can be uniquely identified with an address.

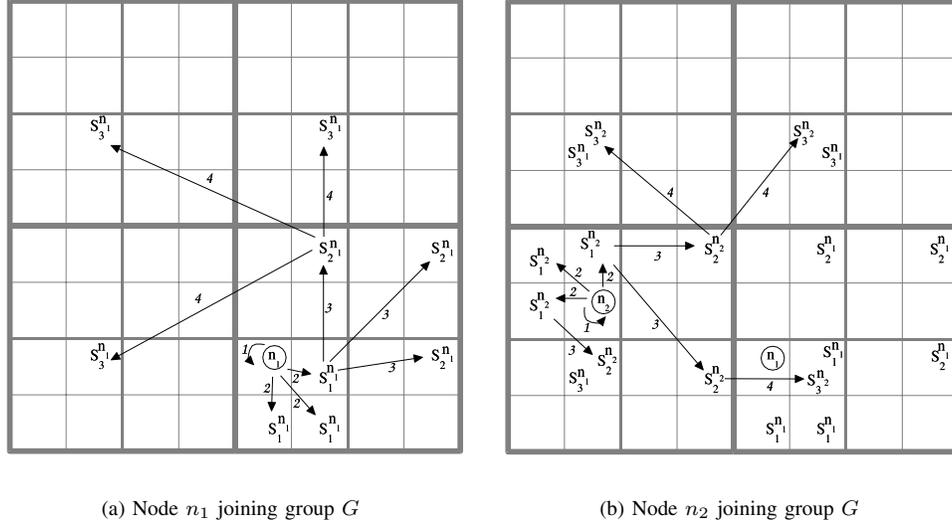


Fig. 6. Join Operation

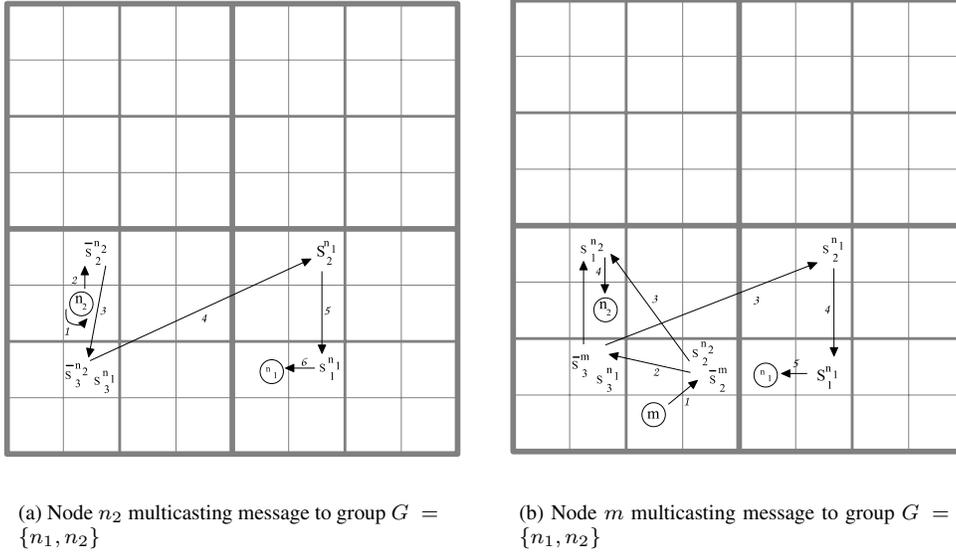


Fig. 7. Multicast Operation

G. Mobility

We consider mobility of multicast group members. Mobility is handled as a *join* operation followed by a *leave* operation, with a *level* parameter (see Algorithm 4 of the Appendix). The *level* represents the highest region level the node has crossed during its journey. Straightforward for the node to compute, it allows to bound the propagation of the *leave* request. Consider a node n_i changing *level*₂ regions. No action is taken when a n_i starts moving⁶. Upon reaching its destination (i.e., node speed passes back below a given threshold), n_i rejoins G

⁶While n_i is moving and before any logical server has been updated, messages may be forwarded to it by following its *trail* — nodes n_i encounters during its move store a forwarding pointer to it, à la [6].

through a *join* request, with *level* = 2 passed as a parameter. In a second stage, n_i must notify its original *level*₀ region that it has left by sending to it a bounded *leave* request. Finally, the original *level*₀ region propagates the *leave* message to remove n_i 's stale entry from the appropriate logical servers. Bounded *join* and *leave* are required since no assumption may be made on their order of reception at the logical servers. Indeed, if the *leave* is received before the *join*, logical servers will confuse mobility with the normal case of a node desiring to leave a group. The *level* parameter solves this problem from preventing the *leave* (and afterward the *join*) from being wrongly propagated higher up in the logical server hierarchy. In our example, the requests are bounded to two levels. All

higher-level logical servers need not be updated.

VI. QUANTITATIVE ANALYSIS: AMDLM VS. MDLM

In this section we study the performance of *AMDLM* compared to MDLM, the straightforward multicast extension of DLM presented in Section IV-A. The nature of *AMDLM* enables us to conduct an analysis not possible with other multicast algorithms such as MAODV [9] and ODMRP [10].

A. Location Servers

1) *Total Number of Location Servers*: The number of required location servers has a direct impact on overhead. Given at least one group member, MDLM assigns 4^m uniformly distributed location servers, where m is the desired density.

The total number of location servers for *AMDLM* dynamically grows and shrinks with respect to the number and distribution of multicast group members. The upper bound at any given time for the total number of location servers is calculated as follows. It is equal to the sum across levels, of the number of $level_k$ regions containing at least one group member and *not* belonging to the same $level_{k+1}$ region, multiplied by four: $4\sum_{k=1}^{k_{max}} | \{R_k \mid \exists n \in R_k, n \in G\} |$, where k_{max} is the highest level. This result is an upper bound since we do not subtract from the result overlapping location servers across different levels, implied by Property 2 of Section V-C.

2) *Join and Leave Operations*: Let n_i be the node desiring to join or leave a group G and n_j any member of G . When n_i joins or leaves G , MDLM requires all 4^m location servers to be updated. *AMDLM* requires $4k$ location servers to be updated, where k is the smallest region containing n_i and another member of the group: $k = \text{smallest } l \text{ such that } R_l^{n_i} = R_l^{n_j}$. Upon the first *join* (and last *leave*) all $4k_{max}$ servers are updated.

3) *Mobility*: Let n_i be the mobile node and k be the largest $level_k$ region traversed by n_i upon moving. Both MDLM and *AMDLM* limit the number of location servers to be notified of n_i 's new position. *AMDLM* requires at most $2 * 4k$ location servers to be updated. Indeed, *AMDLM* handles mobility as combined *join* and *leave* operations (n_i rejoins the group upon arriving to destination and sends a query to its previous $level_0$ region to issue a *leave* query on its behalf).

MDLM requires $4k$ location servers to be updated with n_i 's new position, where k is determined by the density m of location servers. For *AMDLM* k is determined by the total number of $level_0$ regions in the grid. MDLM does not specify how information is removed from the location servers responsible for maintaining n_i 's position before having moved.

B. Cost of Join and Leave Operations

We assume that there is sufficient connectivity in the network in order for any two adjacent $level_0$ regions to communicate. An upper bound on the total distance traveled by the *join* and *leave* operations may now be derived for *AMDLM* based on the number of levels⁷. For sake of simplicity, we consider the Manhattan distance.

⁷Without the assumption about density, we would have been bound by theoretic results obtained for the underlying geographic forwarding layer.

Since a $level_k$ region contains 4^k $level_0$ regions, the upper bound δ on the distance traveled within a $level_k$ region is $\delta(k) = 2\sqrt{4^k} - 2 = 2^{k+1} - 2$ $level_0$ regions (from one corner to the diagonally opposite one). To obtain the upper bound on the distance, we multiply δ by the number of queries required for each relevant operation, per level, for both algorithms (similarly to Section VI-A.1). We therefore obtain a cost of $4\sum_{l=1}^k \delta(l)$ for the join/leave operations and $2(4\sum_{l=1}^k \delta(l)) + \delta(l)$ in case of mobility.

C. Discussion

The recurring dilemma for a location management service in MANETs is the dissemination and maintenance cost of location information versus the accessibility and quality of the information upon retrieval. *AMDLM* addresses this dilemma in the context of multicast by concentrating the effort of maintaining location servers nearby multicast group members, while offering minimal location service in regions with little or no group members.

MDLM's uniform location server distribution, while a reasonable assumption for unicast routing, does not offer the flexibility needed for an efficient access to multicast group information without the overwhelming overhead of maintaining the same quality of service across the entire area of the grid.

VII. QUALITATIVE COMPARISON BETWEEN THE DIFFERENT APPROACHES FOR MANET MULTICASTING

In this section we conduct a qualitative analysis of the performance of *AMDLM*, MAODV and ODMRP under different factors based on the core design of each algorithm.

The main design choices for the underlying group maintenance structures in MANET multicast algorithms are *tree* and *mesh*. We compare *AMDLM* against the main representant of each approach, MAODV [9] and ODMRP [10]. All these protocols are on-demand.

A. No Mobility

We first examine the behavior of the various protocols for static networks — nodes do not move.

1) *Managing concentrated group members*: ODMRP does not maintain multicast group membership when no node is interested in multicasting, generating no network activity whatsoever. Both MAODV and *AMDLM* are expected to exhibit similar behavior in terms of multicast group management. Nevertheless, *AMDLM* generates additional overhead, since it forwards group member location information (to a bounded number of designated location servers).

2) *Managing scattered group members*: In absence of multicast senders, network activity for ODMRP is non-existent. MAODV actively maintains a multihop tree connecting multicast group member nodes. For few nodes scattered over a large geographic area, the number of non-member nodes required to maintain the multicast tree greatly outnumbers the number of member nodes. In case of numerous group members, MAODV generates important overhead, since it constantly maintains a

multicast tree connecting all members and periodically generates *group hello* packets. AMDLM assigns a bounded number of location servers responsible for managing multicast group membership (See Section VI). A judicious grid decomposition adapted to the number of nodes is required to achieve optimal overhead.

3) *Multicasting*: Since ODMRP does not actively manage group membership, mesh construction is required whenever nodes wish to multicast. Sender nodes create a mesh reaching multicast group members through periodic flooding. ODMRP does not scale well with respect to numerous senders or receivers (multicast group members) [18]. The characteristic behind its robustness (mesh structure offering alternative paths) is that of its high overhead. Indeed, ODMRP generates nearly as much overhead as pure flooding by disseminating data across the forwarding group (*scoped flooding*). With group members scattered over large regions, ODMRP will ultimately lead to network performance degradation similar to the broadcast storm problem discussed in [20].

In MAODV and AMDLM, multicast group members wishing to multicast have immediate access to routing information. For non-member nodes, MAODV requires flooding in order to reach a node on the multicast tree to obtain routing information. AMDLM induces the least overhead among the protocols, since flooding is not required at any stage. Routing information may at any time be retrieved from the logical servers referenced by the hash function.

B. Mobile Nodes

We now introduce mobility to the analysis. The main factor on performance is the frequent link breakages caused by mobility (node crashes may therefore be considered as a particular form of mobility).

1) *MAODV*: Group members are reachable through a bidirectional multicast tree, providing a single path composed of critical links to reach multicast group members. Node mobility increases the occurrence of link breakages, damaging MAODV's tree structure and leading to reduced multicast efficiency. Furthermore, the tree-based approach may even generate great overhead by incessantly reacting to broken links and initiating repairs. The more scattered the group members, the greater the chance for link breakages to occur. Even a single link breakage may obstruct the path to group members and force MAODV to repair the tree. The physical tree structure therefore proves highly fragile.

2) *ODMRP*: It has been shown in [16], [18] that an increase in mobility has little impact on the efficiency of the algorithm. These results may be explained by two key characteristics of ODMRP. Firstly, ODMRP periodically recreates routes to destination nodes while sender nodes have packets to multicast, maintaining route freshness (although at the expense of increased overhead). Secondly, the underlying mesh structure is more robust than the tree approach by offering alternative paths to reach the multicast group members.

3) *AMDLM*: A location-based scheme offers relative independence from node mobility. Indeed, the logical tree is

formed by nodes in geographic regions (logical servers) designated by the hash function. These geographic regions are fixed. Nevertheless, the time required for the relevant logical servers to be updated through geographic forwarding increases the latency of the multicast algorithm, i.e. the overall time required to locate and reach multicast group members. Furthermore, packet loss may occur if the location information in the logical servers is stale.

C. Additional Factors

AMDLM uses the logical servers not only for storing group membership but also for forwarding packets to group members. The decision to use logical servers for routing reduces the overall latency. The greater number of packets transiting through the geographic regions responsible for managing group membership may however cause possible bottlenecks under high network traffic.

MAODV and ODMRP are independent from geographic concerns and may seamlessly function under reasonable arbitrary node distribution. AMDLM on the other hand expects to find one or more nodes in the regions designated by the hash function to manage multicast group membership. AMDLM therefore benefits from a hash function tailored to the node topology, by favoring densely populated areas for the placement of the logical servers.

D. Summary

By adopting a significantly different approach for multicast group management, *AMDLM* can offer greater robustness and reliability than the tree-based approach of MAODV without the associated overhead induced by the mesh-based approach of ODMRP.

VIII. SUMMARY AND FUTURE WORK

We have presented a location service specifically tailored for multicasting in MANETs. We have additionally specified *AMDLM*, a multicast algorithm built on top of the location service. The advantages of such an approach over multicast algorithms relying on a tree, DAG or mesh approach is the absence of a multihop data-structure connecting the source and members of the multicast groups. Such data-structures are indeed less robust to frequent link breakages that occur in the highly dynamic environment of mobile ad hoc networks.

Designing an efficient location service in the context of multicast within MANETs is a difficult task. To the contrary of unicast routing, the location service must efficiently maintain information regarding a *set* of scattered nodes associated with each group. Maintaining accessible multicast group membership across the network may quickly lead to high communication overhead, reducing performance and wasting limited resources. *AMDLM* addresses the dilemma of the location service overhead versus multicast group information accessibility by dynamically adjusting the density of the location servers.

For future work, we intend to compare *AMDLM* through simulation to MAODV [9] and ODMRP [10] in order to fully comprehend the performance of each approach in various

situations and validate the qualitative analysis presented in Section VII.

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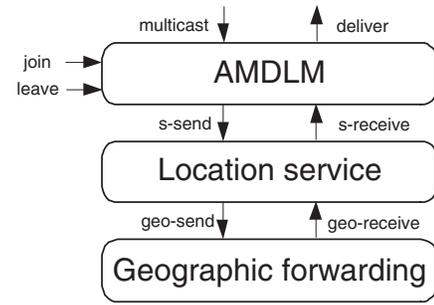


Fig. 8. AMDLM Architecture

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APPENDIX

AMDLM Algorithm Pseudo-Code

Figure 8 represents the layers that together provide the AMDLM multicast service. At the lowest level, the service relies on a geographic forwarding layer ([21], [4]), providing a geographic-based point-to-point unicast by means of a *geo-send* and corresponding *geo-receive* procedures. Above the geographic forwarding layer resides the *logical servers* abstraction. Its interface provides the *s-send* and *s-receive* communication primitives.

Algorithms 1, 2 and 3 describe the *join*, *leave* and *multicast* operations. Algorithm 4 shows how the mobility is handled when a node moves from one R_0 region to another. Finally, Algorithm 5 describes the interaction between the logical server and underlying geographic forwarding layers. Every logical server maintains two data structures: (1) *members* for storing the multicast group membership and (2) *links*, for storing references to active logical servers. Both *members* and *links* are initially empty.

Algorithm 1 : AMDLM - Join

```

1: {Upon join(G) by a node  $n_i \in S_0$  :}
2:
3: s-send(join,  $k_{max}$ , G,  $S_0^{n_i}$ ) to  $S_0^{n_i}$ ;
4:
5: {Upon s-receive(join, level, G,  $S_i^{n_j}$ ) by a node  $n_i \in S_k$ }
6:
7: if k==0 and  $(G, n_j) \notin members_i$  then
8:    $members_i = members_i \cup \{(G, n_j)\}$ ;
9:   if |  $members_i$  | == 1 then
10:    s-send(join, level, G,  $S_0^{n_i}$ ) to  $S_1^{n_i}$ ;
11:   end if
12: else if  $(G, S_{n_j}^l) \notin links_i$  then
13:    $links_i = links_i \cup \{(G, S_i^{n_j})\}$ ;
14:   if  $k < level \leq k_{max}$  and |  $links_i$  | == 1 then
15:    s-send(join, level, G,  $S_k^{n_i}$ ) to  $S_{k+1}^{n_i}$ ;
16:   end if
17: end if

```

Algorithm 2 : AMDLM - Leave

```
1: {Upon leave (G) by a node  $n_i \in S_0$  :}
2:
3: s-send(leave,  $k_{max}$ , G,  $S_0^{n_i}$ ) to  $S_0^{n_i}$ ;
4:
5: {Upon s-receive(leave, level, G,  $S_l^{n_j}$ ) by a node  $n_i \in S_k$  }
6:
7: if  $k == 0$  and  $(G, n_j) \in members_i$  then
8:    $members_i = members_i \setminus \{(G, n_j)\}$ ;
9:   if  $members_i == \emptyset$  then
10:    s-send(leave, level, G,  $S_0^{n_i}$ ) to  $S_1^{n_i}$ ;
11:   end if
12: else if  $(G, S_l^{n_j}) \in links_i$  then
13:    $links_i = links_i \setminus \{(G, S_l^{n_j})\}$ ;
14:   if  $links_i == \emptyset$  and  $k < level \leq k_{max}$  then
15:    s-send(leave, level, G,  $S_k^{n_i}$ ) to  $S_{k+1}^{n_i}$ ;
16:   end if
17: end if
```

Algorithm 3 : AMDLM - Multicast

```
1: {Upon multicast (m, G) by a node  $n_i \in S_0$  :}
2:
3: for all  $(G, n_j) \in members_i$  do
4:   deliver m to  $n_j$ ;
5: end for
6: for all  $(G, S_k^{n_j}) \in links_i$  do
7:   s-send(m, G,  $S_0^{n_i}$ ) to  $S_k^{n_j}$ ;
8: end for
9: if  $k_{max} \geq 2$  then
10:  s-send(m, G,  $S_0^{n_i}$ ) to server  $\overline{S}_2^{n_i}$ ;
11: end if
12:
13: {Upon s-receive(m, G,  $S_l^{n_j}$ ) by a node  $n_i \in S_k$  }
14:
15: if  $k == 0$  then
16:   for all  $(G, n_h) \in members_i$  do
17:     deliver m to  $n_h$ ;
18:   end for
19: else if  $links_i \cap \{(G, S_{k-1}^{n_h})\} \neq \emptyset$  then
20:   s-send(m, G,  $S_k^{n_i}$ ) to server  $S_{k-1}^{n_h}$ ;
21: end if
22: if  $l \leq k < k_{max}$  then
23:   s-send(m, G,  $S_k^{n_i}$ ) to  $\overline{S}_{k+1}^{n_i}$ ;
24: end if
```

Algorithm 4 : Mobility management

```
1: {Upon node  $n_i$  has moved from  $S_0^{old}$  to  $S_0^{n_i}$  :}
2:
3: { $n_i$  must update  $members_i$  and  $links_i$  sets according to its new position}
4: if  $members_i \cap \{(G, n_i)\} \neq \emptyset$  then
5:   level = minimum k such that  $R_k^{R_0} = R_k^{R_0'}$ ;
6:   s-send(join, level, G,  $S_0^{n_i}$ ) to  $S_0^{n_i}$ ;
7:   s-send(leave, level, G,  $S_0^{old}$ );
8: end if
```

Algorithm 5 : Logical server algorithm

```
1:
2: {Upon s-send(content, G,  $S_k^{n_i}$ ) to a server  $S_l^{n_j}$  by a node  $n_i \in S_k$  :}
3:
4: Obtain  $S_l$  through the hash function;
5: Obtain  $S_k$  through the hash function;
6: for all  $R_0 \in S_l$  do
7:   if  $dist(R_0^{n_i}, R_0) < dist(R_0', R_0), \forall R_0' \neq R_0^{n_i} \in S_k$  then
8:     geo-send(content) to  $R_0$ ;
9:   end if
10: end for
11:
12: {Upon geo-receive(content) by a node  $n_i \in S_k$  from a server  $S_j$  :}
13:
14: s-receive(content,  $S_j$ );
```
