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On the Classification of Routing Protocols in Mobile Ad-Hoc Networks

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Abstract

We present an overview of existing classifications of ad hoc routing and topology control protocols. Originally created to clarify protocols behaviors, separate classifications can be found for routing, topology control, broadcasting and location management protocols. In recent years, the term "hybrid" began to be broadly used for algorithms that should be classified in more than one class. Therefore, those classifications became difficult to understand, and new protocols hard to classify. In this paper, we are proposing an original classification of broadcasting techniques, location management, topology control, and routing protocols for mobile ad hoc networks. The proposed classification does not consider which classes a protocol belongs to but instead, from a node level point of view, in which order it applies different classes it belongs to. Finally, we discuss the benefits of our approach and provide examples of our classification applied to well known routing and topology control protocols.

Index Terms

Mobile Ad Hoc Networks, Classification, Routing, Topology Control, Topology Management, Forwarding, Position-based Routing, Broadcasting Location Management, Flooding.

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1   Introduction

Routing and topology control protocols have gone through many improvements since the early works in mobile ad hoc networking. Getting inspired from the IP world, first routing protocols have been **topology-based** designed. A hope-wise route was created from a source to a destination. However, the movement of the nodes contained in the path were making such approach instable, triggering route repairs and route errors. In recent years, it became popular to try to use geolocalization to improve ad hoc protocols' performances. The first implication has been the outbreak of *forward-based* protocols. Instead of creating a route to the destination, those protocols simply forward one or more packets in the network and let intermediate nodes choose to relay them or not by following some heuristics. Different methods have been developed to improve these forward-based algorithms (see [17]). Some of them were named *greedy*, since they tried to allow only nodes that lie toward the destination to forward packets. No prior knowledge was needed, except the availability of a location service for the location of the destination node and the nodes' capacity to obtain their own position. The heuristic used by these greedy algorithms could be greatly improved by a node's knowledge of its neighborhood. This unfortunately would come at the cost of periodic beacons, or periodic transmissions of small messages, whose main purpose are to broadcast the neighborhood with position information and to update a location service terminal. Since such approach needed periodic updates of position information, it was called **time-based**, or **position-based** protocols. When coupled with a location service, which main purpose is to make a specific node's location information available to any node in the network, position-based protocols eliminate some of the limitations of topology-based protocols. A number of such algorithms have been developed and are compared in [30]. Later, position-based protocols have been extended to include the velocity with the objective to optimize the role of periodic beacons. By knowing nodes' position and velocity, protocols could avoid to periodically flood the network with position updates. Thus, it can either fix a distance threshold above which an update is required or extend node's coverage region such that a buffer zone is able to cover a predefined region where a node is supposed to have moved to. These properties gave the name to this approach : **distance-based**, or **velocity-based**. It added the ability a source node had to know in which region a destination node could be found. In [1], a topology control protocol is introduced which is able to adapt the frequency of its topology updates. Authors in [3] and [4] attempt to address mobility issues both in topology management and in broadcasting techniques by extending nodes' transmission range to cover regions where neighboring nodes should have moved to, therefore insuring constant connectivity. DREAM [6], in other hand, triggers the sending of location updates based on nodes' distance and *mobility rate*. Similarly, in order to accurately route packets, LAR [5] uses a geometrical construction, named *expected zone*, representing an area where a node is supposed to have moved to, . Finally, TMPO [7] computes a node's *mobility rate* in order to adapt and maintain a connected dominating set (CDS). However, all these

protocols are still dependent to pro-actively maintained neighborhood knowledge, or location services, which are degrading their performances. For example, some studies have shown the impact of periodic beacons, which can be compared to increasing the probability of transmission in 802.11 performances [8], or the effects of beaconing on the battery life [9]. Therefore, these approaches have major drawbacks in terms of reliability, scalability and energy consumptions. The next step to their evolution will therefore be designed to improve the channel occupation and the energy consumption. The new generation of position-based routing protocols, called **prediction-based**, is able to provide a node with the actual position of a destination node, should it keeps its actual trajectory. This new family of protocols has been first defined in [10], and mainly implemented for sensor networks (see [11], and [12]), for mobile networks and location management (see [14, 15]), and later for topology management in mobile ad-hoc networks (see [13]). This approach can be found as well under the term **dead-reckoning**, borrowing the term from an ancient navigation technique. By obtaining its position and velocity, a node can model its movement or those of its neighbors. This model can be deterministic or stochastic depending on the predictive ability of the mobile node. Therefore, by using this kind of technique, a node can obtain a relatively accurate prediction of its neighborhood, and thereafter can take better routing decisions.

Routing protocols have long been classified through many exclusive criteria such as proactive vs reactive, position-based vs non-position-based, or power-controlled vs hierarchical-based. Any protocol which could not fit in such classes were considered as *hybrid*. However, in recent months, almost every protocols whatsoever had to be treated as *hybrid* in almost any part of their intrinsic behaviors. They form a hierarchy but still are power controlled, they are locally proactive and globally reactive, or they could fulfill all these criteria at the same time. Therefore, since those criteria were creating more confusion than they were clarifying the subject, in our point of view, a new classification needs to be created.

In this paper, we are introducing a new kind of classification for routing protocols that is able to classify topology control, location management and broadcasting techniques, further pointing out the overlapping of regular classification classes. Since more or less all new protocols are using almost all classes in their behavior, we are proposing a new approach which do not class protocols given the classes they belong to, but given in which order they apply different classes they belong to. We believe that this method is easier to understand and, by getting rid of that *hybrid* term, it helps to extract protocols' intrinsic behaviors.

The rest of the paper is organized as follows. In Section 2 related works are presented. Section 3 presents the proposed routing protocols' classification. In Section 4, we discuss the benefits of our classification and identify some research opportunities extracted from it. Finally, Section 5 draws some concluding remarks and future works.

2 Related Work

There is a growing body of literature on taxonomy of topology control, broadcasting, and routing protocols. Since the relative large amount of proposed protocols in these areas, it became necessary to structure them. Those protocols need efficient broadcasting techniques to route request packets or create structures and the availability of GPS made possible the outbreak of position-based protocols. [16], to our knowledge, wrote the first survey on position-based routing protocols. While classifying location services in four classes: *Distance-routing effect, Quorum, Grid location service and Homezone*, the author groups forwarding techniques into three categories: *Greedy packet forwarding, Restricted directional flooding, and Hierarchical routing*. Even being early in position-based protocols' development, this survey manages to extract their essence and will be the core to future broadcasting classifications. Each protocol lets intermediate nodes decide whether they have to forward a packet given their relative positions toward the destination, restricts intermediate nodes to forward a packet only if they are in the global direction to the destination, or uses a build-in hierarchy to correctly route packets to the destination. In all three cases, the idea is to limit the broadcasting overhead created by packets' flooding in ad hoc networks. In [17], the authors propose another designation for broadcasting techniques. They ordered them in four classes *Simple flooding; Probability-based; Area-based and Neighbor knowledge*. Even if words are different, the main idea is the same. Neighbor knowledge includes *greedy packet forwarding* and *hierarchical routing*, while area-based is similar to *restricted directional flooding*. This approach has later been adopted by [20] in the author's survey of broadcasting and topology control protocols. This paper presents these protocols mainly into two classes: *centralized*, and *localized*; the latter being further differentiated into *Distributed CDS, Low weighted structures and Forwarding approach*. Though non scalable, global methods are helpful since localized protocols can be an adaptation from protocols developed for the centralized class. For example, [1] creates a distributed version of the well known minimum spanning tree (MST) obtained in centralized protocols. Even if being a comprehensive approach to broadcasting and topology control, we think that their classification does not put enough extend to the position-based approach. A separate paper from the same authors (see [19]) specifically considers the latter approach. To our opinion, broadcasting and position-based routing should be grouped into a same classification since all three sub-classes can benefit from position informations in a way or another. Hence, two different surveys prevents readers from understanding their intrinsic overlapping properties. Therefore, we will introduce a modified classification that will better reflect them.

In other hand, [18] proposes a classification of topology control protocols. Topology control finds its justification either in proactive protocols by reducing the periodic updates of their routing tables, or in broadcasting protocols by using hierarchical routing methods. In both cases, the aim of topology control is both to reduce the broadcasting overhead and the power to reach all nodes in the net-

work. The authors of [18] draws a base line to topology control classifications by ordering them in two main categories *Centralized or Distributed*, the latter getting refined into two sub-categories *Connectivity based and Capacity based*. Even if being, to our knowledge, the first classification of topology control protocols, this paper suffers from a lack of accuracy in the classes defined in it. For example, we think it should be important to refine the connectivity-based class. Indeed, we should distinguish a flat hierarchy from a cluster-based or a zone-based hierarchy, since their properties and overhead complexity are different. Moreover, following the globally admitted approach to topology control, the authors propose to separate power control protocols from hierarchical ones, while to our opinion, a topology control protocol can be both of them. Finally, since this classification does not take into account position-based topology control algorithms, we add them in this paper.

Finally, [21] wrote an interesting paper that reviews almost all known routing protocols for mobile ad hoc networks. Even if they still used the commonly admitted *proactive-reactive-hybrid*([37]) approach, the authors are very exhaustive in their classification. However, as explained before, to our opinion the proactive-reactive-hybrid approach is not able to fairly describe routing protocols and should not be separated from topology control and broadcasting. For example, in their paper, DDR [22] is classified as hybrid, since it is locally proactive and globally reactive. But what the classification does not reflect is the zone-based topology created by this protocol. The proactive approach is completely tied to the topology management since intra-zone routing can be extracted from it at no extra cost.

In this paper, our objective is to draw a global classification, which includes broadcasting, topology control and routing protocols. And in order to fulfill this objective, we use a novel taxonomy of routing protocols by considering choices and decisions a protocol takes at node level.

3   Classification

We are introducing in this section a global classification of routing protocols. The main idea is not to try to classify protocols by using their global behaviors as a criterion, but instead to consider a protocol at a node level. We therefore look at a packet arriving at a node and use the decisions the node takes as a criterion in our classification. We are therefore proposing to classify routing protocols as indicated in Fig 1. In order to ease the reading of this tree, we put detailed blocks composing it in separate figures yet to be considered as a whole (see Fig. 2, Fig. 3, Fig. 4, and Fig. 5).

The main idea of this classification is the use of a flow chart-like method reflecting the protocol behavior from specific aspects at the node level to global properties at the network level. It first considers protocols at a node level with issues like topology or position information. Then it takes a step back and deal with higher aspects such as routing tables and route discoveries. Finally, if necessary,
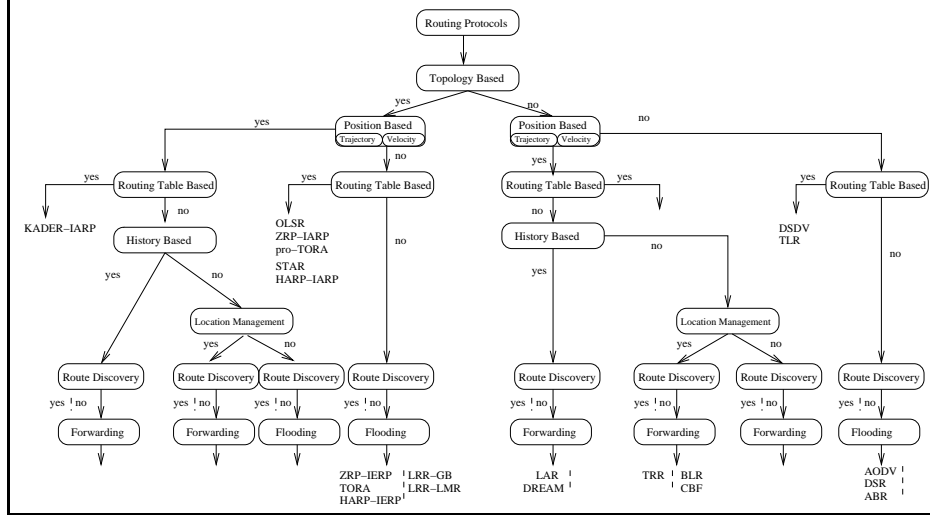
Figure 1: Classification of routing protocols.

it can request an external help from a location service to obtain a specific node's location information.

We first draw in Section 3.1 a global description of our classification depicted in Fig. 1, then discuss the specific elements in the following sections (Sections 3.2, 3.3, 3.4).

3.1 Routing Protocols

3.1.1 Topology Based

This represents a bigger classification of topology based protocols depicted in Fig 2. For the sake of simplicity, we decided to represent it in a different tree. However, before being able to jump to the next stage, a packet must come and go through this entire class. Upon completion, we will be able to know whether a routing protocol uses a topology control algorithm or not, and in the former case, which one it will use. To make things short, the purpose of this stage could be rephrase with a question : *will a packet use any existing underlying structure or will it be free to follow its own way to the destination?*

3.1.2 Position Based

This class reflects a node's ability to obtain its own position in a way or another. There are several ways for a node to obtain this information. Two main classes are described in [23] : *GPS and GPS-free* positioning. It is conceivable that GPS positioning is to be used for that purpose. However, there are situations where GPS is not available. This occurs notably in indoor situations where the GPS signal

is too low. For that matter, some GPS-free positioning algorithms have been developed ([24], [25] and [26]) with a degree of accuracy depending of the physical layer used. It is therefore rational to consider a node able to get its position as long as one accepts a certain degree of positioning error, or lack of accuracy. A extension of the position-based class to a mobility-based class or a trajectory-based class can also be studied, where node have access to their velocities and trajectories respectively. These improvements generalize the classification and incorporate new protocols that would not only have access to position information but to velocities and trajectories as well. However, since velocities are usually extracted by successive position samples and trajectories obtained by considering positions, velocities and time, the crucial part is to obtain position information. Therefore, the question at this stage could be : *Does a node knows its position ?*

3.1.3 Routing Table Based

This class simply reflects the availability of a valid route to the destination when a packet has to be forwarded to a destination node and if a relaying node knows a valid route to it. However, there are situations where a packet is initially forwarded using a routing table but then falls again to a non routing table strategy on its way to its destination. This could be the case either when a relaying node looses the path to the destination or if a better information is found. Besides, this often happens in hybrid routing protocols. Therefore, this issue here would be: *Is there at this node a valid route to the destination ?*

3.1.4 History Based

History based routing is a strategy that occurs when a protocol chooses not to use routing tables, but instead keeps track of nodes passing by or eavesdrops neighboring communications to help it find a destination node. In both cases, nodes are able to obtain a certain knowledge of the network topology at no extra cost since it only listens to the events occurring in its neighborhood. That matter could be put into words as follow : *Does a node have a prior knowledge of the destination's position information ?*

3.1.5 Location Management

In the case where a node does not have a prior knowledge of a destination's position, it needs to get it by using a location service. As for the topology control class, this represents again a bigger class depicted in Fig 3 which is mainly inspired from [28]. It is obvious that since location queries are propagated in a similar way that broadcast packets are, location queries and location services performances can be improved the same way broadcasting protocols can. The question in this stage can be formulated as follow: *Is a node able to get the position of the destination ?*

3.1.6 Route Discovery

This class simply includes protocols that, prior to packet sending, requests a valid route by broadcasting a *route request* message in the network. As for the previous class, it can mainly be improved by refining broadcasting techniques. Since packets fall into this class when no valid routes already exist and no topology histories are available, the reason for this class could be: *In the lack of valid routes, does nodes request a route to a destination before forwarding a packet ?*

3.1.7 Forwarding

This represents the class of forward-based or broadcasting-based protocols. When nodes need to broadcast packets while avoiding the broadcasting storm problem, these protocols try to reduce the broadcast burden by forwarding packets to only necessary nodes. The authors of [17] and [20] propose an original classification of this approach. However, to our opinion, since the behavior of the sender and the receiver is different, we have to address this situation in two categories: the sender's subclass (Fig. 4) and the receiver's subclass (Fig. 5).

3.1.8 Flooding

When nodes do not get any help from existing structure and do not benefit from location services but still need to send a packet to a destination node, they simply flood the entire network and wait for the target response. Several improvements have been developed in order to limit the broadcasting storm, still this class remains the worse case scenario for any routing, topology or broadcasting protocols. For example, nodes can limit the broadcast range to only reach close-by neighbors, then in the lack of response gradually increasing the broadcast range. This feature is used in most reactive routing protocols such as DSR or AODV and is called *expanding ring search*.

3.2 Topology Based

The objective of topology control protocols lies in *two aspects*:

1. Keeping a minimum number of links between nodes, yet insuring the network connectivity.

2. Reducing the power needed to reach nodes when using the constructed topology.

Thus, packet collisions can be reduced and the overall network capacity may be improved.
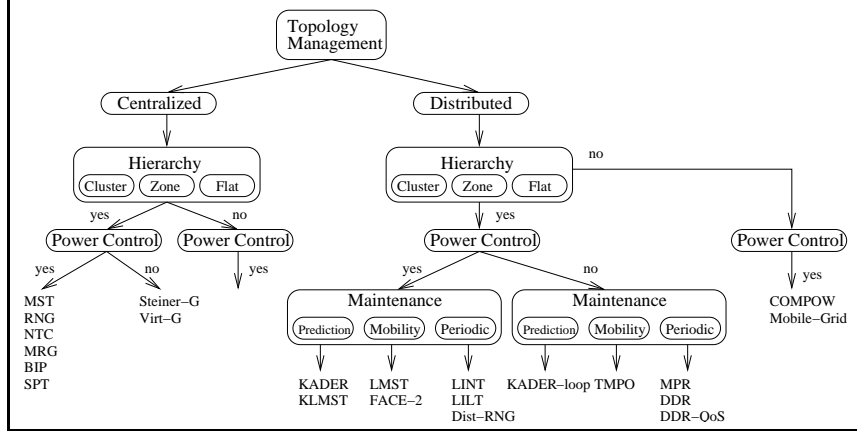
Figure 2: The Topology Management class.

3.2.1 Centralized Topology Control

According to algorithms belonging to this class, a node or a subset of nodes has the responsibility of creating and maintaining the topology. When a subset of nodes and not a single node has this responsibility, protocols are called *decentralized*. These algorithms are usually a direct adaptation of graph theory algorithms. It has however been recognized that such approaches are not scalable, since scalability cannot be achieved by relying on solutions where each node requires global knowledge about the network.

3.2.2 Distributed Topology Control

In that class, each node is responsible for the maintenance of the state of its local neighbors. There is no global knowledge of the network. If an algorithm needs a piece of information more than few hops away, it will be considered *distributed*. Otherwise, it will be classified as *localized*. Distributed algorithms and architectures have been commonly used for long time in computer science. However, due to the limited capabilities of processing power, storage and energy supply, many conventional distributed algorithms are too complicated to be implemented in wireless ad hoc networks. Thus, wireless ad hoc networks require efficient distributed algorithms with low computation complexity and low communication complexity. Therefore, in order to obtain efficient distributed protocols, such protocols should be localized. Yet, localized algorithms are hard to design, and in some cases even impossible. For example, it is impossible to locally construct a *Minimum Spanning Tree*. Yet, Li *et al.* ([1, 2]) gives efficient localized algorithms and, in the latter paper, they create a *Low Weight Local Minimum Spanning Tree* where the total edge length of the structure is no more than a constant factor of that of the minimum spanning tree.

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3.2.3 Hierarchy

A hierarchy in mobile ad hoc networks is created when one gives a subset of nodes more responsibilities than other nodes in the network. Therefore, while some nodes only have a passive role and simply listen to traffic, others play active roles either in neighborhood management or in traffic relaying. Since one objective of topology control protocols is to reduce the number of links connecting nodes, thus the number of relaying nodes, we can create a hierarchy that fulfills the first requirement of topology control protocols by giving to some nodes a relaying responsibilities. However, efficient organization is a key aspect of ad hoc network-layer protocols. Then, in order to reduce the organization complexity overhead which is proportional to the number of nodes in the network, we can extend nodes' responsibilities to neighborhood management. Accordingly, topology control protocols can fall in one of those four cases:

- *No Hierarchy*—In this case, the only way topology control protocols can reduce the number of relaying nodes while keeping uniform responsibilities among nodes, is to adapt the transmission range to only reach critical nodes yet insuring full connectivity. We consequently fall in the power control class (see 3.2.4).

- *Flat Hierarchy*— This scheme represents the major part of hierarchy-based topology control protocols. All nodes have identical capabilities but have different responsibilities. A subset of nodes has a traffic relaying responsibility while others only listen to traffic. By reducing the number of relaying nodes, irrelevant links are removed from the network topology while the network is kept fully connected. Therefore, we can meet the first requirement of topology control protocols.

- *Cluster-based Hierarchy*— In cluster schemes, the physical network is transformed into a virtual network of interconnected clusters. Each cluster has one or more controllers acting on their behalf to make control decisions for cluster members and, on special cases, to construct and distribute representations of cluster state for use outside of the cluster. The main drawback of cluster-based protocols is the cluster-head itself. The node designated as controller of the cluster becomes a critical node and its loss may partition the network. In some schemes, it even creates a communication bottle-neck, since all communications have to pass through it. Yet, a fair cluster-heads dispatching scheme may improve nodes battery life since cluster-heads' larger role in the cluster induces an bigger energy consumption. In cluster-based scheme, transmission ranges may differ, battery life at different nodes may differ, and processing capabilities may differ as well.

- *Zone-based Hierarchy*— Finally, that scheme is an extension of the flat scheme where we want to limit the topology reorganization scope without the described drawbacks of cluster-based protocols. Actually, nodes movements are pushing tree schemes to their limits. Therefore, by shrinking the topology reorganization scope, we can increase their scalability. Moreover, this is distributively performed within each zone hence getting rid of global controllers. Some protocols are able to create

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non overlapping zones while others not. The main idea here is the reduced reorganization complexity inferred by nodes' movement and the ability to fulfill the first topology control criterion, both of them performed in a complete distributed manner.

3.2.4 Power Control

We are defining power control as the process of adapting the transmission range in order to only reach desired nodes, or to limit the collision induced by multiple packet transmission. In [18], this feature is formulated as capacity-based. In previous classifications, an oppositions has been introduced between the hierarchical class and the power control class. Protocols were either power controlled or hierarchy based. Even if it is clearly possible for a protocol to try to find a best global transmission range without any hierarchy (see [31]), it is however conceivable to use it to adapt the transmission range or to only send packets in predefined directions ([32, 13]). For example, cluster-heads could adapt their transmission range to create a connected cluster-head backbone. Then, they can re-adapt it when desiring to reach nodes contained in their clusters such that transmissions are kept local. Therefore, for all these reasons, it occurred to us that this class should be situated after the hierarchy's. A node indeed tries to see if a preferred link exists, and if so, adapts its transmission range to only reach it. Accordingly, the power class represents all schemes that use a non uniform transmission range whether using a hierarchy or not.

3.2.5 Maintenance

Now that a topology is created, we are analyzing the maintenance that needs to be done in order to keep its coherence. Broadly adopted, topology maintenance is usually periodically performed. In other words, the topology is periodically re-created which, of course, induces a large communication overhead. By using position-based protocols adapted to topology control, it is then possible to improve their maintenance (see [13, 7]). We are proposing here to distinguish three categories of topology maintenance :

- *Non periodic maintenance*— Maintenance is only triggered from an alert message punctually received from either the physical layer or the network layer. We therefore limit communication overheads to strict necessary updates. However, link losses happening unexpectedly, a link existence cannot be guarantied and makes this approach unsuitable for fault tolerance networks.

- *Periodic maintenance*— This class is the most used class in topology control protocols. Periodically, with the help of beacons, a node updates its local state related to its neighbors. In other words, messages are periodically exchanged between nodes in oder to update their preferred links while insuring a full connectivity. This method

creates a large communication overhead but is necessary to keep the coherence of the topology.

- *Aperiodic maintenance—* In this class, the frequency to update the topology is not fixed but suited to topology changes. Two different aperiodic maintenances are possible:

  - *Mobility based maintenance–* By the help of nodes position and velocity, it appears to be possible to calculate nodes' movements and therefore only update links between nodes when their respective distances have reached a predefined threshold. In [7], given nodes mobility, the cluster-head role is assigned following a round-robin process, therefore always keeping the best node as cluster-head.

  - *Prediction based maintenance–* By using nodes trajectory models, it is possible to further improve the mobility based scheme. By the knowledge of nodes position at every single time instant, a node can consequently predict when its links are overwhelmed by other ones. It can therefore directly adapt its local topology to these modifications. Different from the periodic and the mobility based scheme, this maintenance is predicted without the need for any messages. Hence, the global network capacity is significantly increased.

3.3   Location Management

As mentioned in Section 3.1, this location management classification in Fig 3 is inspired from [28]. It is yet extended to include location update strategies defined in [10].

The core behavior of location management protocols is the location updates to location servers. The following schemes are proposed in [10]. In the *timer-based location* update scheme, each node periodically sends a location update to a location server. In *distance-based* update scheme, each node tracks the distance it has moved since its last update and sends its location update whenever the distance exceeds a certain threshold. In the *predictive distance-based*, also called *dead-reckoning*, the node reports to the location server both its position and velocity. Based on this information and a mobility pattern, the location of the node can be predicted. The node checks its location periodically and sends a location update to its location server whenever the distance between the predicted location and its exact location exceeds a certain threshold. Major actual location management protocols are *timer-based*. DREAM Location Service (DLS [27]) is *distance-based*, while *predictive distance-based* location managements are only emerging (see [15]). We however include all possible configurations in order to have a general location management classification and to help finding new research opportunities in that particular field. In the rest of this section, we illustrate particular classes of location management protocols.

3.3.1 Centralized Location Management

Similarly to topology control, when a single node has the responsibility to obtain and maintain the position of all nodes in the network, the location service is called *centralized*. When a subset of nodes have such responsibilities, location services are named *decentralized*. Their behaviors are yet similar. All nodes in the network must register to them with their actual position. Then, when a node needs to obtain a destination node's position, it sends a *location query* to the location server. According to the *Mauve Classification* [29], this would be considered as a *some-for-some* or *some-for-all* approach. This solution is yet not suitable for mobile ad hoc networks since a small number of location servers creates a single point of failure in the network and traffic bottlenecks which affects the network's performances.

3.3.2 Distributed Location Management

In order to suppress the single point of failure obtained from the centralized approach, the role of location server can be distributed among all nodes in the network. According to the *Mauve Classification*, distributed location management protocols can be considered as an *all-for-some* or *all-for-all* approach. The author in [28] distinguishes three different classes:

- *Proactive Database*— In location database system, specific nodes in the network serve as location databases for other specific nodes in the network. When a node moves to a new location, the node updates its location database servers with its new location; when location information for a node are needed, the node's location database servers are queried. The author surveys two different proactive location database systems: *Home Region Location Services* and *Quorum-based location services* (see [28]).

- *Proactive Dissemination*— In a location dissemination system, all nodes in the network periodically receive updates on a given node's location. Thus, when a given node requires location information on another node, the information can be found in the node's location table.

- *Reactive Location Systems*— Reactive location services query location information on an as needed basis. When a specific node requires location information on another node, it queries the location server, which itself tries to obtain it. Finally, upon completion, it transmits the obtained location to the requesting node.

3.4 Forwarding

Forwarding protocols have been developed under two assumptions. Firstly, nodes are able to obtain their positions. Secondly, nodes must be able to obtain
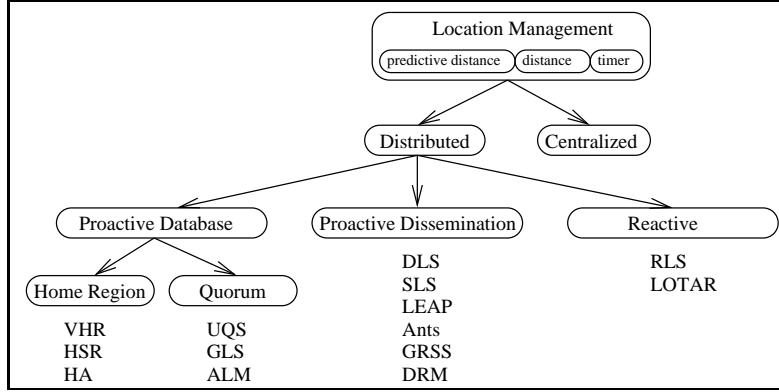
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Figure 3: The Location Management class.

destination nodes's positions. We therefore assume in this section that nodes know their position and those of destination nodes.

As mentioned in 3.1, we separate forwarding protocols in two different categories which are the two active modes a node may have: *sender and receiver*. A node enters the receiver mode upon reception of a packet, then moves to the sender mode to forward it to its neighbors. Therefore, forwarding protocols enter both categories one after the other. The name *greedy forwarding* is used when a node forwards a packet to a single neighbor, while *restricted directional flooding* can be found when forwarding to more than one node ([29]).

3.4.1 Sender

It is composed of two sub-classes : *next-hop and decision*:

- *Next-hop*— This sub-class chooses the next-hop node the sender sends packets to. A packet can be sent to a single node, a group of nodes (in a particular area for instance) or to all nodes in the neighborhood.

- *Decision* — It is the core algorithm that helps reducing the broadcasting overhead of this technique and directly depends on the above sub-class. If a packet needs to be sent to all nodes, then no decision on targeted nodes is required. When a packet needs to be sent to a single node, the only possible decision is to use the Neighbor Knowledge method.

    - *Area Based Decision*— Area based decision methods for sender nodes evaluate the transmission area where packets will be forwarded given the position of the destination node. The sender could use directional antenna for instance in order to radiate to a particular direction, or sends packets to nodes in a particular area; Dream [6] is typically an area-based position-based routing protocol.

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– *Neighbor Knowledge Decision*— Neighbor Knowledge decision methods maintain the state of nodes' neighborhood, via "Hello" packets, which is used in the decision whom to sent a packet to[1]. This kind of protocols are also called *Position based Routing* in [30]. The neighbor knowledge approach uses different strategies to determine the greedy behavior of a packet on its way to the destination node. We list here the most popular ones:

* *Most Forward with radius (MFR)*— Takagi and Kleinrock [33] propose this schema where the packet is forwarded to a neighbor whose progress is maximal.

* *Nearest forward progress (NFP)*— In that schema, discussed by Hou and Li [34], the packet is forwarded to the closest node that can make the packet progress to the destination. By doing so, the protocol wants to save power and to increase the transmission success by reducing interferences.

* *Compass method (DIR)*— In this method, proposed by Kranakis, Singh and Urrutia [35], a message is forwarded to a neighbor such that the angle between the source and the relay node is minimized.

* *Geographic distance routing (GEDIR)*— This is a greedy scheme based on geographic distance. The sender selects the neighbor node that is closest to the destination among other neighbors (see [36]).

If a packet needs to be sent to a single node using a MFR strategy for instance, the decision will be to pick up the neighbor node whose progress to the destination is maximal among all other neighbor nodes and to send the packet directly to it.
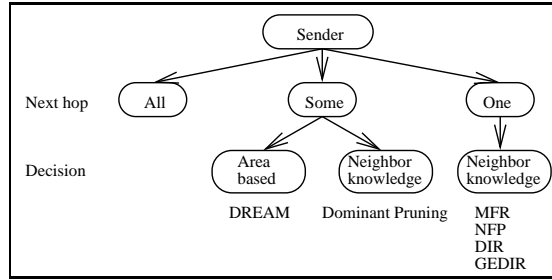

Figure 4: Behavior of a sender node in the Broadcasting class.

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[1]In the absence of GPS signals, a node can obtain the distance to its neighbors on the basis of incoming signal strengths or time delay in direct communications

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3.4.2 Receiver

While the sender simply chooses which node to sent a packet to, the receiver's role is to decide whether it is a forwarder or not. This is where forwarding protocols effectively perform neighbors suppression in order to avoid packet duplications. The receiver handles packets in different ways whether they have been unicast or broadcast transmitted. For example, if a packet has been unicast transmitted, no further work is needed and the protocol simply moves to the sending process. If a packet was intended to a sub-group of nodes, the protocol has to consider the probable reception of the same packet by other nodes and its influence on the packet's future transmissions. Three main categories are to be drawn:

- *Probability based*— This category contains all forwarding techniques that use probability distributions to decide which nodes forward packets. The probability distribution can either be uniform or a function of an given input. If nodes are able to obtain their position information, similar strategies than those proposed in the sender class can be used (i.e. MFR,NFP,DIR,GEDIR). Then a node forwards a packet with a certain probability. When this probability is 100%, this schema is then similar to flooding.

- *Timer based*— This category regroups all techniques that sets a timer, the expiration of which will decide which node forwards the packet. Again, if position information is available to nodes, similar strategies from those proposed in the sender class can be used to set a timer (i.e. MFR,NFP,DIR,GEDIR). Timer-based protocols can be further subdivided into three subclasses similar to the ones described in [17].

    - *Counter Based Decision*— Upon reception of a previously unseen packet, a node initiates a counter to 0. During a predefined timer, the node increases the counter by one for every redundant packet. If the counter is less than a threshold when the timer expires, the node broadcasts the packet. Otherwise, the packet is dropped.

    - *Area Based Decision*— Area-based decisions for receiver nodes assume nodes have a common transmission range; upon expiration of a timer, a node is a forwarder if forwarding the packet makes it reach an additional area not yet covered by neighbors redundant broadcasts.

    - *Neighbor Knowledge Decision*— Timers are set given the knowledge of the neighborhood. Upon reception of a packet and depending on the strategy, a node sets a timer either proportional to a given input which can be the distance from the sender, or proportional to the angular deviation between the sender and itself. A node which timer expires first rebroadcasts, while other nodes that are able to hear the transmission drop the packet.

- *Coverage based Decision*— A node in this category does not use timers to restrict the broadcast but instead either bases its contention on the computed

set of nodes that would not be covered if it does not forward, or uses a pre-defined trajectory or regions to choose relaying nodes from.

– *Neighbor Knowledge Decision—* Nodes decide whether to rebroadcast on the knowledge of which of its one hop or two hops are expected to receive a same packet. If the set of all one hop neighbors are covered, then it drops the packet.

– *Trajectory based Decision—* Nodes decide on their forwarding capabilities given their proximity to a predefined trajectory. The optimal configuration would be to assign forwarding responsibilities to nodes that are closest to to the trajectory that reaches a destination node.

– *Area based Decision—* Nodes decide to be forwarders if they are contained in a predefined forwarding area. Nodes can usually compute such area using position information contained in packets' heading. LAR [5] is a typical receiver-based area-based protocol.

As a summary, upon reception of a packet, a node handles it following the receiver process and decides whether it is a forwarder. If so, it enters the sender's process and chooses which neighbor nodes to forward the packet. This process is performed at every node and for every packet sent.
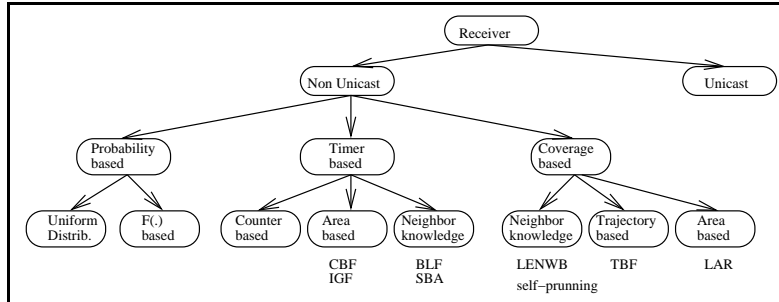

Figure 5: Behavior of a receiver node in the Broadcasting class.

4 Discussion

In this section we apply our classification to well known routing protocols and show that our approach effectively helps classifying protocols. Then, we discuss the improvements this new classification can do, notably in extracting new directions of research not yet covered.

4.1 Benefits from the Proposed Classification

The motivation behind this classification is to clarify protocols that have dual behavior depending on whether they are locally or globally used. Another mo-

tivation is to regroup denominations that are used in many approaches, yet with different objectives or results. We therefore describe how the classification could help extracting those protocols behaviors. For all proposed protocols, we consider their behavior at a specific node and for a particular destination. As examples, we classified several protocols for each classes (see Fig 1, Fig. 2, Fig 3, Fig 4 and Fig 5).

Since our approach considers protocols behavior at a specific node for a particular destination, and since a protocol cannot have different behaviors at a same node for an identical destination, this classification extracts hybrid protocols' intrinsic properties. For example, in Fig 1, the *terminodes routing protocol* [23] can be found in two leaves (TLR and TRR). The first or the second leave will be preferred given the specific node and destination. For instance, when a packet is sent using this protocol and if the destination is not locally located, the sender follows the branch leading to the TRR (Terminode Remote Routing). But as the packet reaches the first node in the destination's vicinity, the node then follows the second branch leading to the TLR (Terminode Local Routing). Consequently, the classification differently classifies local protocols from remote ones.

Moreover, what differentiates this approach from simply classifying TLR as "link state proactive" and TRR as "position-based broadcasting" is that this classification is able to extract all particular behaviors implicitly included in the global class "proactive". For example, proactive protocols use routing tables. They can yet use a topology control protocol, or not or be position-based or not. This classification adds a smaller granularity to regular routing protocols classifications while considering all typical classes of routing protocols in a same tree.

Then, let us consider position-based routing and broadcasting protocols. While the literature analyzes and classifies them differently making it impossible to find symbiosis between them, the proposed classification reaches two objectives. Firstly, it is to be able to group them in a same classification tree. As mentioned in Section 3.4, they are part of nodes' two active and inextricable modes and are performed one after the other. Secondly, it helps finding possible collaborations between both approaches. For example, DREAM is a restricted directional forwarding which belongs to position-based routing protocols. However, it could benefit from neighbor suppression techniques included in broadcasting protocols, neighbor knowledge for instance since DREAM proactively maintains the state of its one hop neighbors. Consequently, position-based routing protocols define some nodes that are able to receive a packet, while nodes that received the packet perform neighbor suppression from broadcasting protocols. The classification is therefore able to help finding symbiosis between apparently opposed approach and helps developing new protocols.

Similarly, the basic role of position-based protocols is to use position information to restrict flooding. Then, nodes able to obtain such information that use protocols defined in [17] may be named position-based protocols as well. Hence, the differences between the two approaches (see [20] and [17]) are difficult to see and cannot be understood simply by their names. In this paper, we take an abstract

point of view and name forwarding techniques by what really differentiate them: *sender* and *receiver*. Then, this classification helps clarifying protocols functioning.

Finally, a novel view proposed in this classification is the ability for antagonistic classes of protocols to work together. Let us take the example of hierarchical topology control and power control topology management. Whereas non hierarchical topology control protocols have to be power control to fulfill at least one requirement of topology control protocols, hierarchical topology control protocol may benefit from power control approaches in order to improve their behaviors. It is even conceivable, still to our knowledge not yet proposed, to use hierarchy to improve power control protocols, the COMPOW protocol for instance. Therefore, by distinguishing protocols given the order they are using a particular class and not simply which class they are using, the classification manages to combine antagonistic classes in order to better describes routing protocols.

4.2   Research Opportunities

By finding unexpected possible collaborations between apparently different, even antagonistic, routing protocol classes, this approach is by itself able to help finding new research opportunities. For example, the OLSR protocol was originally designed to work on top of the MPR topology control protocol. Yet, it could be interesting to analyze OLSR's performance when tested with a different topology control protocol. The converse part applies as well. We could imagine to use MPR along with another proactive routing protocol, or even simply as part of an on-demand broadcasting protocol.

In the introduction part, we described the evolution of routing protocols from topology-based to position-based and mobility-based. We introduced the next step to the evolution of routing protocol as the **prediction-based** models. Since prediction-based protocols can be seen more of an input data improvement than a core modification of routing protocols, they could easily be plugged into all branches of routing protocols. It is then conceivable to use predictions to simplify those protocols' behavior.

We depicted this possibility in Fig. 1 when dealing with prediction information instead of position information. Routing table-based protocols can notably benefit from this approach since they would not need to periodically update their tables. Similarly, topology control protocols may benefit from prediction-based approaches in the maintenance class. In Figure 3, prediction-based protocols are implementable in order to limit nodes' registration to a location server to only unexpected shifts. Finally, forwarding protocols can obtain significant improvements for prediction protocols since the knowledge of the destination trajectory would help forwarding a packet to the true actual destination position. Prediction protocols may be of great help for the neighbor knowledge approach as well, since it makes periodical 'Hello" messages irrelevant.

5 Conclusion

We presented in this paper a novel classification of routing protocols. The originality of this classification is that it is able to classify in a single tree routing protocols, topology control, location management and broadcasting schemes altogether.

We proposed to classify protocols given their behaviors at a node level. This made possible to differentiate protocols not on which classes they belong to, but in which order they apply classes they belong to.

We discussed the benefits of this approach. It is able to extract all particular behaviors implicitly included in global class, thus adds a smaller granularity to regular classifications. In a field where similarities and differences are hard to represent, this approach helps finding symbiosis between protocols in order to create or improve routing in mobile ad hoc networks.

We separately examined each major classes of routing protocols and gave examples of this classification applied to well known routing protocols. We finally identified in this paper direction of future research that could lead to future improvements, the prediction-based model for instance.

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