Geographical Routing for Heterogeneous Wireless Systems

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Abstract— **The aim of this paper is to consider the problem of node localization for geographical routing protocols in ad hoc networks. We propose a distributed positioning algorithm that does not rely only on GPS-like systems (Global Positioning System). Instead, it is assumed that just a part of the nodes belonging to that network is GPS-compliant. Therefore in this paper it is proposed to give position information to the nodes who are not GPS-compliant. To achieve this, we use distance measurement, known as trilateration, between nodes to compute relative positions, and in some case global positions if GPS-compliant nodes are nearby.**

Keywords— **ad hoc network, localization information, routing, mobile, wireless network, self-locating.**

I. Introduction

With the development of wireless devices, a large amount of research is being conducted in mobile and wireless communications. This new topic of research focuses in particular on how to use and how to deal simultaneously with all these heterogeneous devices and how to organize them into self configuring networks that do not require a pre-established infrastructure. These autonomous networks are called ad hoc networks. To make these networks autonomous, each node has to collaborate with its neighbours in order to exchange information. Thus nodes can behave at the same time as routers or end systems.

Due to the unpredictable mobility of nodes, the topology of an ad hoc network is unstable and likely to change frequently. Routing in such conditions becomes then a challenging task. The scalability issue in ad hoc networks appears to be an important matter when the number of mobile nodes increases. Indeed IP addresses are still to be used in ad hoc networks in order to maintain utilization of existing applications and to provide with authentication facilities, but routing can not be based anymore on IP addresses network identifiers. As each mobile node joining an ad hoc network is to keep its home IP address in order to maintain communication while moving, then the network ID will not reflect anymore its new network attachment. So mobility issue complicates the routing process as routing tables will have to contain every single IP address and would not be only based on the network part of the address.

Topology based protocols are the ones currently used and proposed for routing in IP ad hoc networks but it appears interesting to look at other alternatives in order to improve routing performances and scalability.

In parallel to the development of ad hoc routing algorithms, new routing protocols are being developed for large scale routing : the position-based protocols. It appears interesting to study this other approach in combination with others routing protocols.

In this paper, we first present a short survey of existing position-based routing protocols. In a second time we will expose our idea of using a greedy position-based routing protocol in a heterogeneous system, where not all nodes are self-positioning (GPS or Galileo compliant devices). We will also provide some keys for giving position information computations to the relative positioning devices. Section (IV) will concluded the paper.

II. Related Work

For position-based routing protocols, if a node wants to communicate with another one, the source node knows the position of its destination. This assumption taken in most approaches is not currently possible unless if using localization services. Although this service is very interesting, this is not covered by the scope of paper. A survey of these localization services can be found in [1].

Routing decision in position-based protocols is based on the position of the destination. Packets are forwarded to the next hop in the direction of the destination until they reach their destination. Three schemes for selecting the next hop are proposed, each one defining a different type of optimizations :

- The minimization of the number of forwarding nodes : the forwarding node is the closest to the destination.
- The distance minimization : the next node is the closest neighbour on a virtual line between the source and the destination node [2].
- The energy minimization : The power-saving approach consists in choosing the next hop as the nearest node in the direction of the destination. Thus the emitted power is reduced [3].

Four main forwarding strategies can also be defined. Each of these strategies is based on one of the approaches seen above:

- Greedy Strategy : Packets are forwarded to only one next hop. The selection of the forwarding node can be done by one of the three approaches described previously. The main problem of a such strategy is in case of a routing failure, when the determined forwarding node isn't reachable, because out of the *radio range*. This case usually comes up when nodes have got different radio ranges. To avoid this problem, a solution is the right-hand rule that consists in choosing an alternate forwarding node in case of failure. GPSR [4] and GPS-free [5] are two protocols based on a greedy approach and both minimize the total number of *hops*. GPSR uses GPS position information as the routing key, whereas GPS-free assumes that no GPS-like system is available. A system of relative position coordinates is then defined and used as the routing key.

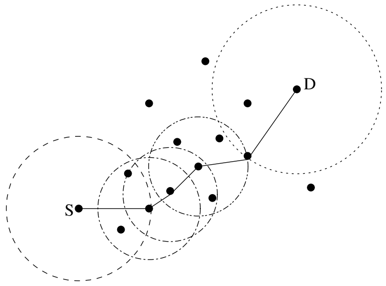

Fig. 1. Greedy position routing example.

- Directional Strategy: In opposition to the greedy approach, the directional proposal forwards a packet to all the nodes in the direction of an area associated to the destination. DREAM (Distance Routing Effect Algorithm for Mobility) [6] is a proposal based on this scheme. This strategy can also be useful to other routing protocols in a case of a route failure, when position information is known. Location Aided Routing (LAR) [7] protocol is an example based on this approach. The authors have shown that LAR can work in complementary with a non-geographic route protocol such as AODV [8], when a route failure occurs.
- Hierarchical Strategy: Hierarchical routing allows networks to scale more nodes. The "GPS-Based Addressing and Routing" proposal [9] defined different nodes classes: GeoRouter, GeoNode and GeoHost. Each of these nodes are at a different level of hierarchy. Geohosts belong to the lowest hierarchical nodes like end-users devices, whereas GeoNodes act as routers for a region, and GeoRouter are top level in this hierarchy, acting as router between regions, country. These classes can also be subdivided into subclasses.
- Proxy Strategy : The proxy approach [10] is dedicated to networks where some of the nodes don't have a positioning information. These nodes will then select the nearest node with a positioning information to become their proxy. Classical IP routing protocols, such as DSDV [11], AODV are used in the area with no geographical information and then replaced by position-based routing protocols.

III. Proposed Scheme

As shown before, most proposals assume that ad hoc networks are composed of homogeneous devices (GPS Aware Nodes for GPSR or normal devices for GPSfree). This assumption doesn't seem realistic, as localization chips will not be present in all mobile wireless devices, mostly for cost reasons.

We therefore assume, as for the proxy approach, that future networks will rely on different technologies and some nodes will possess an absolute geographical information and some won't.

Nevertheless, this previous approach has several drawbacks:

1) it first implies that the proxy, acting as a gateway, will concentrate the traffic dedicated to the nodes with no direct localization information. Thus generating a bottleneck in case of an increased traffic.
2) if a node with a positioning information is surrounded by nodes without localization information, this node can not be reached with geographical routing protocols. Moreover, it could even be chosen as a proxy whereas it would be unable to route any packets. Fig. 2a.
3) This approach does not consider the case of the Swiss-cheese network topology, where holes are either empty or filled with nodes without positioning systems. Then all routes generated by the geographical routing protocols will bypass these gaps. In some cases, this could delay the end-to-end communication if a shorter path could be used through these zones. Fig. 2b.

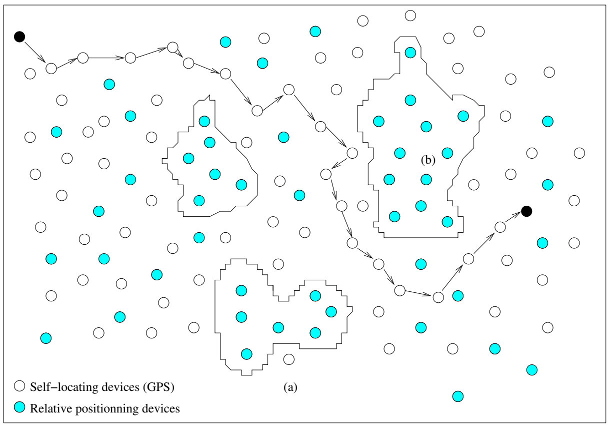

Fig. 2. GPSR Routing in an heterogeneous network.

A way to prevent such phenomenon would be to infer a localization information to every nodes in the network. This is the aim of our proposal in this paper. Therefore, we propose a simple protocol which makes end-to-end position-based routing possible even if all network nodes are not self-positioning devices.

We choose a greedy position-based routing protocol as our main routing protocol. We are interested in the greedy approach for several reasons:

- Only one node is chosen as the next one-hop forwarding node, like in wired IP networks for unicast approach.
- Simple algorithm, simple implementation.

GPSR has been chosen as our greedy position-based reference routing protocol. Fig. 2 shows an example where only a greedy position-based routing protocol is used in an heterogeneous networks.

Our aim is to make reliable and realistic an end-to-end position-based routing protocol in such heterogeneous networks , as shown in Fig. 3:

- The reachability of the nodes is increased : every node in the network will be reached.
- Optimization of the end-to-end delay, by reducing the number of forwarding nodes needed to reach the destination.
- Better load repartition over the network as bottlenecks triggered by the proxy based approach is avoided.

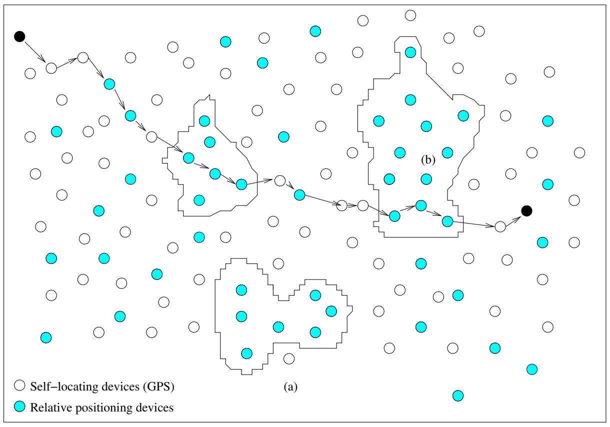

Fig. 3. Greedy routing with localization schemes for relative position nodes in an heterogeneous network.

We assume that:

- All nodes have the same hardware characteristics concerning the radio propagation model, the radio range, the energy, and are not synchronized to each other.
- Two types of nodes are considered: self-locating devices using for example GPS, and relative positioning devices.
- Each node has at least one neighbor.

A. The protocol

An important amount of research is also being conducted in position estimation in wireless networks among which we can quote GPS-free [5], RADAR [12], and some surveys such as [13] and [14]. Our proposal is based on these researches. The different computing position types will be discussed in section III-B.

Our proposal consists in inferring a position to nodes which are unprovided with localization information. This can be explicitly requested by a node, the protocol is in active mode, or it can be done implicitly, when the protocol is passive mode, as described below. The choice of the operating mode can be either determined by the user or by the operating system depending on the context, such as available resources, node mobility,...

For this protocol, three control messages are defined, which are implemented as UDP datagrams: *position_request_msg*, *position_answer_msg*, *position_update_msg*.

- *position_request_msg*
  This message is used by nodes requesting a position information to the neighborhood. This can be done either during the initialization (Algorithm 1)or the position update phase. The first phase happens when a node enters the network, or when it requires to send data and doesn't know its own position. Otherwise when a node or its environment are mobile, it is necessary to update the location information, thus the position update phase is triggered. For both these cases, the *position_request_msg* is broadcasted to all the node in its neighborhood. This message is composed of several fields:
  – The Source IP address, used by the receiver to send back a *position_answer_msg* to the requesting node.
  – The *type* specifies to the receiver what kind of position information the requesting node wants. The different choices to obtain the position information are detailed in section III-B. Only nodes who can answer this request with the desired type replies to the source node.
  – An optional field which contains information relative to the method used to evaluate the distance or the position to the receiver. For instance, the source timestamp, which is returned by the receiver so that the source node can evaluate the round trip time.
- *position_answer_msg*
  The node which has got a valid position information answers the *position_request_msg* with a message containing:
  – its IP address and the destination IP address.
  – the type, defining the method used to calculate the position and determines the optional fields of the message.
  – the optional fields can contain its position, its speed, its position information class (that determines the precision of the information) or time-stamps for the source or the destination,...
- *position_update_msg*
  This message is only used to broadcast the position information to the neighborhood in case of mobility. It is similar to the *position_request_msg*, but also contains information on the source speed, its last known position and its position information class.

The frequency of broadcasting these messages depends on the nodes mobility.

Position information retrieval methods have been divided into two policies : the active one and the passive one.

Algorithm 1 Initialization method

```
global pos
global pos_class
global timestamps
if stealth_mode then
  if self_positioned then
    pos ⇐ get_pos()
    pos_class ⇐ get_posclass()
    timestamps ⇐ get_timestamps()
  end if
else
  if self_positioned then
    pos ⇐ get_pos()
    pos_class ⇐ get_posclass()
    timestamps ⇐ get_timestamps()
    send(position_update_msg)
  else
    timestamps ⇐ get_timestamps()
    send(position_request_msg)
  end if
end if
```

- Passive: In this case, a node does not need to always know its own localization. It just listens to broadcasted *position_update_msg* messages from its neighborhood, to compute its approximate position. Then the node can inform its neighborhood of its new position by broadcasting another *position_update_msg*.

  Nodes in *stealth* mode are also passive, but no *position_update_msg* messages are emitted. This mode can be useful for devices which only want to be aware of their neighborhood without being located or sharing position information.
- Active: Here a relative positioning node wants immediately its localization information, so it sends a *position_request_msg* message and waits for some answer messages to compute its localization. We called this approach active because the position is requested, contrarily to the passive mode which updates the location simply by listening to the signalization traffic.
  Position_request_msg messages have different structures depending on the type of information that the node wants to compute (distance, coordinates, fading ...).

B. Obtaining Position Information

Most of the methods used to define a position are based on geometry computations such as triangulation (by measuring the bearings of an object from fixed points) and trilateration (by measuring the distance). The main cases are shown in Fig. 4.

The more different manner we have to get the position information, the more accurate can be the computed position.
Two position-information types can be defined : the absolute type and the relative one.

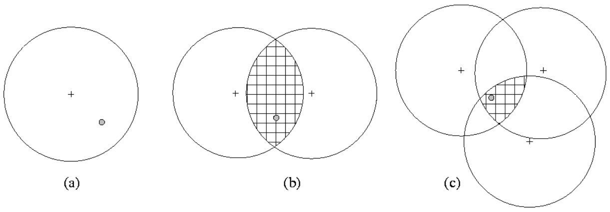

Fig. 4. Trilateration cases.

- Absolute positioning: This type of information gives an accurate position and to obtain it, several techniques can be used :
  - Time of Arrival (TOA): when nodes are synchronized, only one-way trip is needed to know the propagation time between two nodes. If not, a round-trip time is needed. TOA is used by GPS systems and Radars. TOA is also called Time-of-flight.
  - Time Difference of Arrival (TDOA): A node needs to be synchronized to two stations, to have at least two hyperbola intersects.
  - Angle of Arrival (AOA): Like Radar, VOR or GSM sector. (triangulation)
  - Signal Strength: Maps of signal strength are used to determine the distance between nodes. These maps can be determined by field measurements or by theoretical models. Multipath and obstacles make this method less accurate. RADAR [12] is an RF-based solution using this approach.
  - Carrier Phase: Used only with GPS-like systems, for accurate positions when listening to this channel.
- Relative positioning: This type of positioning gives only an idea of where nodes are from a reference node. This position information can signify the area of the location, such as in this room, or the direction, such as on the left of node x.

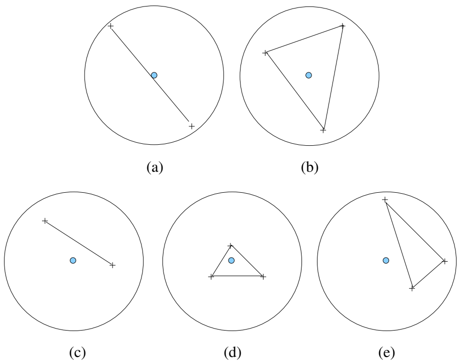

Fig. 5. Geometric cases.

- Geometric positioning
  Fig. 5 shows some simple geometric cases which can be used to deduce the position of a node. Each dot in the center of a circle represents the node requesting a position information, and the circle is used to show its transmission range. Positioning is obtained more or less accurately

from the other nodes that already know their position and transmit it to the requesting node. The accuracy depends on the geometrical configuration.

Among the proposed figures, only 5a and 5b, present cases where a quite good position information can be deduced. This is due to the particular geometric cases. In Fig 5a, the two nodes with a localization information are at both ends of the circle diameter. This happens when they are both at the edge of the radio transmission range of the requesting node and all three nodes are aligned. For case 5b, the three nodes are sufficiently apart that the requesting node can evaluate that the barycenter of the polygon will be close to its current position.

For the other cases, the interpolated position is also obtained by calculating the barycenter of the nodes. Nevertheless, it is shown in the other examples that the interpolated position is likely to be less accurate than in the first 2 figures.

C. Localization information Classification

A localization information is computed from the position information sent by the neighbor nodes. In order to determine which localization information received is pertinent for the calculation of the position, it is important to classify them according to their level of accuracy. This computation will also give the node its position accuracy.

In this part, we will expose our classification of position information in order to have equivalence between classes of interpolated positions. Classes make the interpolation more accurate giving more weight to low level classes. For example, a self-positioning node with GPS will have a position information class equal to 0, e.g. class-0, that we define as the higher degree of accuracy, whereas an interpolation with at least 3 class-0 nodes gives a class-1 or even in some cases a class-0. A class-n node as at least a class-(n-1) node in its neighborhood.

It is important to merge equivalent classes to restrict the number of classes and thus simplify as much as possible the computation. A mapping between the different classes is thus necessary but complex and requires more studies before submission. Nevertheless, the weighting of position classes information is not sufficient to determine the class of the inferred position. It is also important to take into account the the number of received information and the network topology, as explained in section III-B.

Therefore, we define a metric C_{acc} as :

$$C_{acc} = 1 - S_{overlap}/S_{coverage} \qquad (1)$$

with:

- $S_{coverage}$ representing the radio coverage of the node.
- $S_{overlap}$ the overlapping area of the radio coverage zones.

Examples have been shown in Fig. 4b, 4c. In case of 4a (a dot), $S_{overlap}$ is set to 0. In the case of the radio coverage area is defined as a disk, $S_{max} = \pi R^2$

IV. Conclusion and Future Works

We propose an extension of greedy position-based routing protocols which allows to route data to and from self-positioning or relative positioning nodes. This extension allows every nodes, possessing or not a localization information, to communicate with each other using a position based routing protocol. This solution overcomes some of the problems of the proxy-based approach, as explained in section II.

Some studies on location based routing protocols have already been done, leading to the comparison [15] between LAR and DREAM. These studies are looking at IP based routing protocol and extend them with position based routing whereas our solution proposes an global end-to-end position based routing. Our approach is likely to scale better in large networks, as no global routing tables will be needed.

The main contribution of this work is to present a protocol to infer the position information and define the precision of this information.

Our next step is to continue the implementation and simulation of these schemes under NS-2. We will compare their performances and their reliability in heterogeneous system.

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