Enhancing Location Management in Mobile Ad Hoc Networks

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Abstract—**Location management in mobile ad hoc networks are mainly motivated by the adoption of geographic routing of packets because of scalability issues. The main location management proposals have, as a common characteristic, two distinct phases: the location query of the position of a destination node and the data transmission toward that node. We propose to send the initial packets of a flow to learn the position of their destination instead of adopting a dedicated query packet. Such approach can be applied to previous schemes in location management. We identify the conditions under which the proposed scheme is worth using in comparison with the traditional one having two distinct phases. An adaptive mechanism is proposed to allow a source to evaluate which scheme is most likely to reduce the overall cost of a given transmission. As our scheme is shown to specially benefit short lived flows, we expect to give a better advantage to the majority of flows. At the longterm, as each cooperative node seeks to adopt the lowest cost scheme for each transmission, we can expect an overall cost reduction of the location management as well as a reduction in the battery consumption.**

Keywords— **Location management, geographic routing, ad hoc networks**

I. Introduction

The possibility of knowing the physical location of a host by providing just an identifier of the host enables a whole new class of location-aware applications for mobile ad hoc networks [1]. Examples of such applications are position-based filtering of content's availability, navigation and direction orientation, sending of a message to hosts within a certain region, and geographic routing of packets.

In mobile ad hoc networks, autonomous mobile nodes cooperate with each other to implement network functions, such as packet routing. As nodes may move arbitrarily without previous notification presenting also a large range of mobility patterns, the design of scalable packet routing protocols for mobile ad hoc networks becomes a challenging task [2], [3]. The high rates of change in the topology due to node mobility impose great scalability problems on traditional topology-based routing protocols. In mobile ad hoc networks, however, nearby nodes are likely to be close in the network topology. Thus, geographic routing [2], [4], [5], [6] takes advantage of such similarity to deal with the scalability issue. The general concept is that each node only needs to know the location of the destination node and of its one-hop neighbors to make a forwarding decision. The state requirements at each node depend only on the density of nodes, not on the total number of destinations. Therefore, geographic routing claims to be nearly "stateless", as it is based only on small local state. The routing decision at each node concerns the selection of the next-hop among the node's neighbors in order to get the packet closer to its final destination. Commonly, each node determines its own position through the use of GPS or some other type of positioning service [7]. The position of nearby nodes is typically learned through one-hop broadcasts.

Under geographic routing, a source must have a means of learning the geographical position of any eventual destination to be able to label packets with the destination's position. Therefore, geographical ad hoc routing protocols are heavily dependent on the existence of scalable location services [8], which are able to provide a mechanism for sources to learn the positions of destinations. Providing a scalable location service in the context of mobile ad hoc networks is a difficult problem. When a source node request position information of a destination node, the source has no knowledge beyond the identifier of the destination node. There is no static relation between the node's identifier and the node's location as a consequence of node mobility. Moreover, the location service itself must do its task using geographic routing. The problem is to establish a dynamic relation between the destination node's identifier and the physical location of the destination to allow the geographic routing of packets toward that destination.

This paper proposes an improvement to the procedure of learning the location of a destination node. The previous efforts in location management for mobile ad hoc networks, which are reviewed in further detail in Section II, operate in two sequential and distinct phases: the location query and the data transmission. We propose to use the initial packets of the flow to be transmitted to also search the location of the destination instead of adopting dedicated location query packets. Our approach can be applied to the previous works, enhancing their performance specially for short lived flows, like requests for web content. The proposed scheme, however, introduces some new tradeoffs from which a source may have to decide for adopting either the proposed scheme or the traditional one. The cost of adopting either one or another scheme depends on certain

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conditions, like the size of packets, the size of the flow to be transmitted, the number of packets to be sent through the location server, and the relative positioning of the concerned nodes. After identifying such tradeoffs, an adaptive mechanism is proposed to provide a source with indications on which scheme to adopt at an individual case basis. At the longterm, as each cooperative node seeks to adopt the lowest cost scheme for each transmission, we can expect an overall performance enhancement of the location management as well as a reduction in the battery consumption of nodes.

The remaining of the paper is organized as follows. Section II briefly surveys the related work in location management for mobile ad hoc networks. In Section III, we present the proposed scheme for enhancing location management. The analysis of the proposed scheme is carried out in Section IV as well as the identification of the tradeoffs in adopting either the proposed scheme or the traditional one. From the identified tradeoffs, a proposal of an adaptive scheme to provide the source with indications on which scheme to adopt is introduced in Section V. Finally, Section VI presents our concluding remarks and perspectives for future work.

II. Related Work

The Distance Routing Effect Algorithm for Mobility (DREAM) [9] approach requires that all nodes maintain position information about every other node. Thus, each mobile node floods its own position information at different update rates for distinct parts of the entire network. As the process uses global flooding, it is not suited for large networks. Camp et al. [10] evaluate proactive and reactive alternatives for location services in mobile ad hoc networks.

Currently, there are two different approaches to deal with the location management and scalability issues in mobile ad hoc networks: the home zone approach and the hierarchical approach. The first one assigns a home zone to each node through hash functions fed with the node's identifier. The nodes located inside the selected home zone act as location servers for the node to be located. The home-agent based approach [11] uses such strategy. A node uses its identifier to feed a hash function and obtain a position in the deployment region. Nodes around the selected position act as location servers for the node. Similarly, nodes wanting to learn the position of a node from the node's identifier use the same hash function to know where to search for the information. The home zone selected by the hash function can be viewed as a meeting point between the location updates of a node w and nodes looking for node w. The SLURP proposal [12] adopts a similar strategy.

The second approach divides the deployment region into an hierarchy. Nodes located in different portions of such hierarchy act as location servers for other nodes. Thus, for each node, several other nodes act as location servers distributed in different density levels in the hierarchical structure. Examples of such approach for location management in mobile ad hoc networks are the Grid Location Service (GLS) [13] and the Distributed Location Management (DLM) [14]. Both GLS and DLM use some nodes to act as location servers for a given node. As the group of location servers for each node is different from the correspondent group for the other nodes, the location information is distributed within the network. When a source wish to learn the location of a given node w, the source contacts a location server, say node v, of node w for the desired information. The position obtained by the source is the position registered within the location service by the node w. Cheng et al. [15] proposes an hybrid approach to combine the strengths of SLURP and GLS. Multiple home zones are assigned to each node in a hierarchical fashion throughout the deployment region aiming to reduce the volume of update messages traveling long distances in the network.

Under both approaches, a source wishing to learn a position of a destination node send a query packet to one or more location servers. The location server then forwards the request according to its most updated location information toward the destination node. The packet is then forwarded toward the destination node to obtain the most accurate location information for the source. After receiving a query packet forwarded by a location server, the destination node send its current position to the requesting source node.

III. Proposed Scheme

Geographic routing of packets selects the next node to forward a packet using the positions of the current node, of the nearby nodes, and of the destination node. The path taken by the packet from the source toward its destination is composed by the sequence of nodes that get the packet closer to its destination at each hop. An exception is the presence of void regions. In such case, the transmission range of the current node does not reach the destination although the current node is the closest node to the destination. To solve such problem, geographic routing proposals like GPSR [4] are designed to route packets around such void regions. A packet may be even forwarded in a intermediate step to a node farther from the destination than the current one. Despite such fact, the final goal of geographic routing remains to get the packet closer to the destination as long as the positioning of nodes allows it. Routing around a void region is actually making the packet move toward the destination.

Let $G = (V, E)$ denote the graph G consisting of the set V of all nodes and the set of edges $E = \{(x, y) \mid x, y \in V \text{and } d(x, y) \leq R\}$. The value R is the transmission range of nodes and $d(x, y)$ is the euclidean distance between the positions of nodes x and y. We define $E_{x,y} \subset E$ as the ordered subset of edges that compose the path between the nodes x and y. For example, in Fig. 1, $E_{a,d} = \{(a, b), (b, c), (c, d)\}$.

The scenario of adopting geographic routing to forward packets and a location service to allow a source to learn the position of the requested destination, has two distinct phases:

- location query – a source must query a location service (composed of one or more location servers) for position information about the destination. When the query

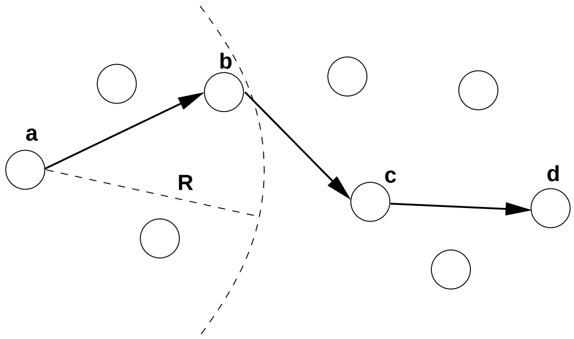


Fig. 1. Geographic routing in a mobile ad hoc network.

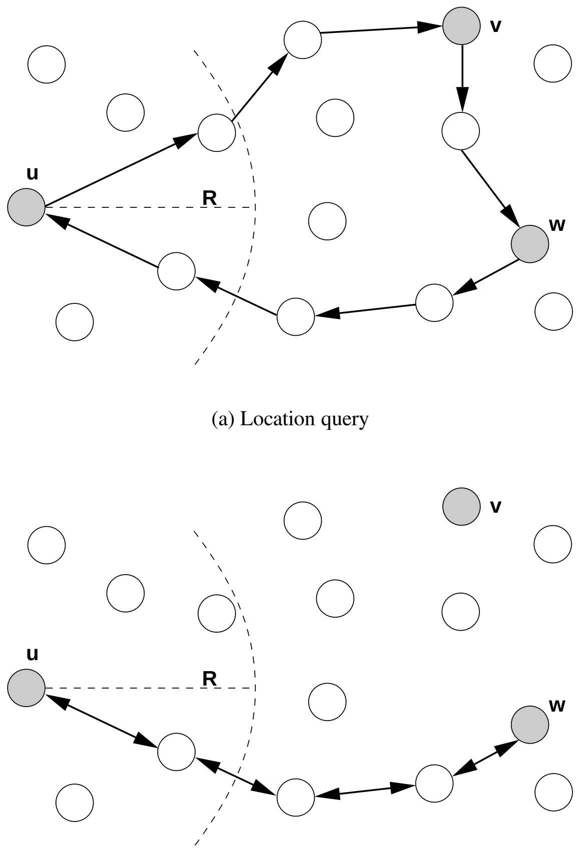
arrives at a location server, the query is then forwarded toward the destination to obtain the most possible accurate position information. The path taken by the query may actually include more than one location server with increasing accuracy about the actual location of the destination. Upon arriving at the destination, the location query makes the destination updates the source with its current location. Fig. 2(a) presents the path of a location query from the source node u requesting the position of the destination node w to the node v, which acts as a location server for node w;

- data transmission – after receiving the position information from the destination itself, the source node starts the transmission of the first packet toward the destination node. During a transmission, both the source and the destination nodes must update their positions to each other if they move. Such update position information is piggybacked onto either data or acknowledgment messages. Regular update messages may also be adopted in the absence of acknowledgments. After the first position discovery, the messages are exchanged directly between the source and the destination nodes without any participation of location servers, as shown in Fig. 2(b).

The path going from source node u to destination node w passing through node v is referred to as the *indirect path* in contrast with the *direct path* leading directly from node u to node w. We consider the cost of transmitting a packet over an edge as being dependent on the edge's length and on the packet's size. We also consider that edges have symmetric costs. The function $s(p)$ is defined returning the size of packet p. Therefore, the total cost of sending one packet p from node u to node v is

$$c(u, v, p) = s(p) \sum_{(x,y) \in E_{u,v}} d(x, y). \tag{1}$$

A node u wishing to learn about the position of a node w queries a node v that act as a location server for node w. The total cost of sending a sequence of n data packets (d) from node u to node w is defined as follows. Such cost includes the cost of a query packet (q) going from node u to node w through node v (taking the *indirect path*) and back to node u through



(a) Location query

(b) Data transmission

Fig. 2. Two phases in traditional location services for geographic routing.

the *direct path*. Also, the total cost comprises the transmission of the n data packets and their respective m $(1 \leq m \leq n)$ acknowledgments (a) if any, or position updates directly through the *direct path* between nodes u and w. Hence, the total cost C_1 of the traditional approaches considering one query packet is

$$\begin{aligned} C_1 = {} & c(u, v, q) + c(v, w, q) + c(w, u, q) \\ & + n\, c(u, w, d) + m\, c(w, u, a). \end{aligned} \tag{2}$$

We propose an improvement to the process of determining the location information and the sending of data through geographic routing. The initial packets of a communication are sent to query the location servers and then those initial packets are forwarded to their destination instead of using a dedicated query packet to perform the task. In this case, the initial k packets $(1 \leq k \leq n)$ of a flow follow the *indirect path* until the source receives the first acknowledgment or update packet from the destination. From this point on, the source can then label the $n - k$ remaining packets with the destination's accurate location allowing them to use the *direct path*. This proposal does not eliminate the query for locations, but it instead avoids the usage of an extra query packet and the waiting time for a query answer imposed on a source for starting a transmission. The total cost C_2 of the proposed approach is then given by

$$C_2 = k\,c(u,v,d) + k\,c(v,w,d) + (n-k)\,c(u,w,d) + m\,c(w,u,a). \quad (3)$$

Of course, the proposed scheme is only worth adopting when $C_2 \leq C_1$. Allowing for the possible different sizes of the different packets, it may not be worth sending a large packet to cross a long (and thus expensive) path when comparing to the sending of a smaller extra query packet. After the initial packets have traversed the longer *indirect path*, the remaining packets take the *direct path* between the source and destination nodes. It would be expected that the overall improvement of our approach would be smaller for large flows, bringing thus greater benefits for short lived flows. Such eventual tradeoffs constitute the issues focused in our analysis work of the proposed scheme.

IV. Performance Analysis

The assessment of the proposed scheme allows for the different sizes of the different packets, the size of the stream of packets to be sent, and the relative positioning of the concerned nodes, namely the source, the destination, and the location server. To analyze the proposed scheme, we consider the minimum bound costs of each approach. Applying the triangle inequality, $d(u,w) \leq d(u,v) + d(v,w)$ for all node $u, v, w \in V$ [16], to (1), we get the lower bound of the total cost of sending one packet p from node u to node v as

$$c_{\min}(u,v,p) = \min_{u,v \in V}\left(s(p)\sum_{(x,y)\in E_{u,v}} d(x,y)\right) = s(p)\,d(u,v). \quad (4)$$

Applying the minimum bound costs as stated in (4) to (2) and (3), we get the lower bound of costs C_1 and C_2, respectively. It is expected that a geographic routing protocol would make its best to achieve the closest possible cost to the considered lower bounds. Such lower bound costs are achieved in the case where all intermediate nodes are perfectly aligned with the source and destination nodes.

We define the cost improvement provided by the proposed scheme in comparison with the cost of the traditional approach as $\Psi = 1 - (C_2/C_1)$. For the considered lower bound costs of C_1 and C_2, the upper bound $\Psi_{\max}$ of the cost improvement is given by

$$\Psi_{\max} = \frac{2\,s(q)}{2\,s(q) + n\,s(d) + m\,s(a)}. \quad (5)$$

We also define $\Delta = \frac{d(u,w)}{d(u,v)+d(v,w)}$, $0 < \Delta \leq 1$, to measure the degree of dispersion between the *direct path* leading from the source node u to the destination node w and the *indirect path* containing node v, which stores the location information of node w. Fig. 3 illustrates the possible values of Δ as a function of the relative positioning of nodes u, v, and w.

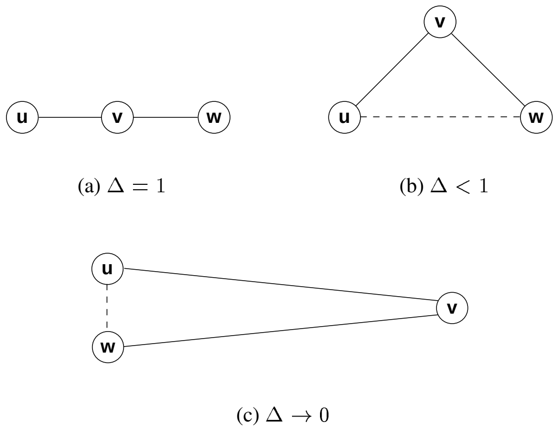


Fig. 3. The relative positioning of nodes and the values of Δ.

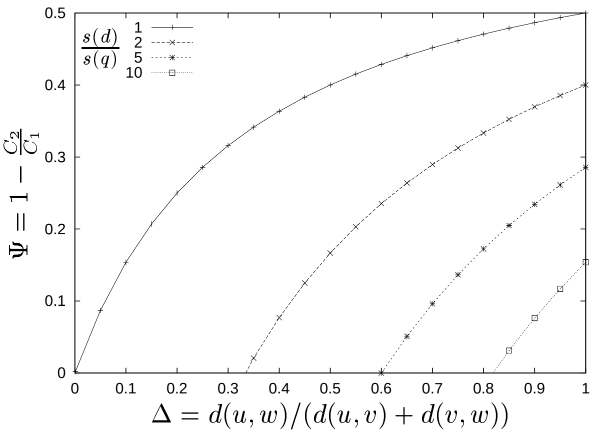


Fig. 4. Effects of the size of packets and relative positioning of nodes.

First we evaluate the achieved cost improvement of the proposed scheme considering the relative sizes of data and query packets as well as different values of Δ. Fig. 4 shows the cost improvement $\Psi = 1 - (C_2/C_1)$ for different relations between the sizes of data and query packets. The size of the query packet is considered 40 bytes. We consider query and acknowledgment packets as having the same size. We also consider in this analysis a data flow consisting of just one data packet, that is, $n = 1$ as well as k and m. Fig. 4 shows the cost improvement Ψ when the proposed scheme is worth using ($C_2 \leq C_1$).

When the initial packet of the flow has the same size of the query packet, the proposed scheme is always worth using. As the data packet gets larger than the query packet, sending it through a longer *indirected path* becomes less advantageous. Depending on the relative positioning of the concerned nodes (Δ lower than a certain value), sending a initial packet larger than a query packet through the longer *indirect path* is not interesting. Therefore, the proposed scheme specially benefits small requests instead of large initial packets. When $\Delta = 1$, the cost

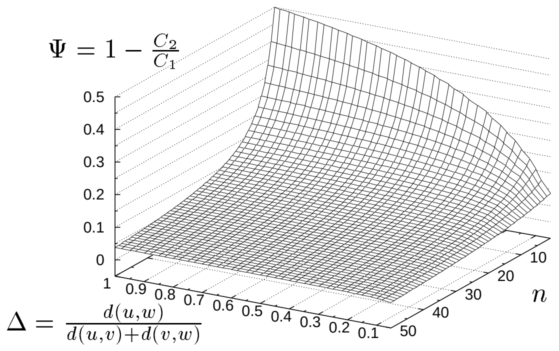


Fig. 5. Effects of the flow size and relative positioning of nodes.

improvement for each scenario reaches its upper bound value given by $\Psi_{\max}$ (see (5)).

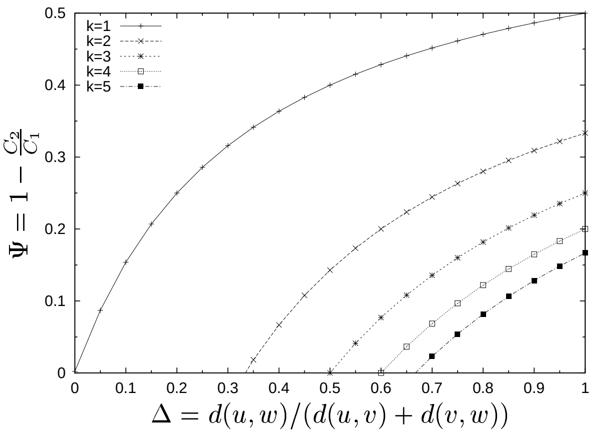
As the size of the data flow to be sent increases, the cost of discovering the destination's location is reduced when facing the whole cost of the data transmission. Fig. 5 presents the cost improvement Ψ as a function of different values of the dispersion Δ due to the relative positioning of the concerned nodes and for flows containing n packets. The data and query packets have the same size ($s(d)/s(q) = 1$). In the cost of the proposed scheme, we consider the sending of one initial packet ($k = 1$) out of the n packets composing the flow. Again, for $k = 1$, the proposed scheme is always worth using, even if the achieved cost improvement diminishes for large flows.

We now evaluate the case where more than one initial packet ($1 \leq k \leq n$) from the data flow is sent through the *indirect path*. Two options apply: either all data packets ($n = k$) or just the k first packets out of the n packets composing the flow are sent through the *indirect path*. Fig. 6 presents the results for both cases with data and query packets having again the same size ($s(d)/s(q) = 1$). Fig. 6(a) shows the results for $n = k = 1, \ldots, 5$, meaning that all packets from the flow of n packets are sent through the *indirect path*. Again, for smaller data flows the benefits of adopting the proposed scheme increases.

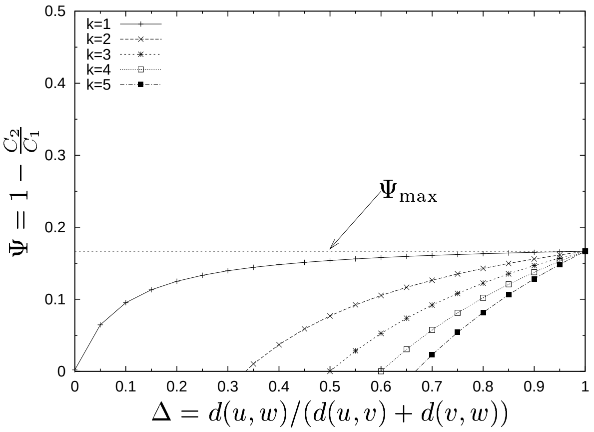
If we consider a flow containing $n = 5$ packets that send its $k = 1, \ldots, 5$ initial packets through the *indirect path*, we get the results presented in Fig. 6(b). In Fig. 6(b), all cases converge to the same value of the upper bound of the cost improvement given by $\Psi_{\max}$, as the upper bound is not dependent on the value of k (see (5)). It should be noted that the previous presented results are also all consistent with the upper bound $\Psi_{\max}$. As the upper bound is a function of the quantity n of packets presented in the flow and of the size of the concerned packets, each analyzed scenario has its own upper bound $\Psi_{\max}$.

V. Adaptation

A source node u wanting to learn the position of a certain destination node w must decide which scheme to adopt. However, at the moment of the decision, the source node u has no knowledge beyond the distance $d(u, v)$ to the location server v of node w and some characteristics of the flow to be sent. Thus, the evaluation on which scheme to adopt must be carried out based on such limited knowledge. If $d(u, w) \leq R$, the source node u and the destination node w are neighbors and thus no location query toward any remote location server is needed. From the triangle inequality and considering $d(u, w) > R$, we get that the dispersion of the concerned nodes is actually bounded by $\frac{R}{2\ d(u,v)+R} < \Delta \leq 1$.



(a) $n = k$



(b) $n = 5$

Fig. 6. Effects of the number of packets sent through the *indirect path*.

From (2) and (3), we see that to be worth using ($C_2 \leq C_1$), the proposed scheme must satisfy the condition

$$\Delta \geq \frac{k\ s(d) - s(q)}{k\ s(d) + s(q)}. \tag{6}$$

Such condition is consistent with the results presented in Fig. 4 and Fig. 6. From (6), the source knows the minimum value of Δ that assures the proposed scheme as being worth to adopt considering some characteristics of the flow to be transmitted.

Nevertheless, it should be noted that Δ measures the dispersion of the relative positioning between the three nodes u, v, and w. Clearly, the position of the destination node w is unknown as this is exactly why the source node u has to make use of the location service. Therefore, there are no means to compute the exact value of the dispersion Δ at the moment of taking a decision between which scheme to adopt.

We propose a decision mechanism that provides the source node u with the probability of achieving a given dispersion level Δ. As a consequence, the source has a base to decide on which mechanism to adopt aiming at having the lowest cost to perform the desired transmission.

Suppose node u located at the position $(0, 0)$ of a coordinate system covering the deployment region of the ad hoc network. Such node u has to contact the location server v to obtain the location information about node w. Suppose now node v located at position $(1, 0)$ on the same coordinate system of node u. The node w from which node u wishes to know the location information may be located anywhere in the deployment region, but not in the cover range R around node u. By definition, if the location service is about to be used, $d(u, w) > R$. Fig. 7 depicts the dispersion Δ between the positioning of the related nodes if the position of node w on the coordinate system is (x, y). Without loss of generality, we adopt the values on the x and y-axis as units of $d(u, v)$, which is the known information at node u. The closer node w is to node u in comparison with the distance $d(u, v)$, the lower is the dispersion Δ (see also Fig. 3).

The projected areas in the xy plane (Fig. 7) are the contour plots of the dispersion Δ, for $\Delta = 0.4, 0.6, 0.8$. The contour plots represent the cross sections of the surface with the planes having such values of Δ. If node w is located inside the area $A_{\Delta=\delta}$, then the relative positioning of nodes u, v, and w has a dispersion Δ bounded by δ. Note that $A_{\Delta=i} \supset A_{\Delta=j}$, for $i \geq j$. The area $A_{\Delta=0.8}$ indicated in Fig. 7 represents the contour for $\Delta = 0.8$. Therefore, if node w is located inside the area $A_{\Delta=0.8}$, then $\Delta \leq 0.8$. Similarly, if node w is located outside $A_{\Delta=0.8}$, *anywhere else* in the deployment region, then $\Delta > 0.8$.

A source node u knows the proposed scheme is worth adopting when the condition $\Delta \geq \delta$ is satisfied, where $\delta = \frac{k\ s(d) - s(q)}{k\ s(d) + s(q)}$ (see (6)). Such condition is satisfied if the destination node w is located outside the area $A_{\Delta=\delta}$. Let $\mathcal{A}$ denote the area of the complete deployment region and A_R denote the circular area around node u with range R. We also denote by $|A|$ the surface area of the region delimited by A. If $d(u, w) < R$, node w would be a nearby node and no location query would be needed. If a location query is being considered, node w is certainly outside the region around node u whose surface area is $|A_R| = \pi R^2$. The probability that $\Delta \geq \delta$ is exactly the same that node w is located outside the area $A_{\Delta=\delta}$. Considering $(A_{\Delta=\delta} \cup A_R) \subset \mathcal{A}$, the probability of the proposed scheme being worth using is thus given by

$$P(\Delta \geq \delta) = 1 - \frac{|A_{\Delta=\delta} - A_R|}{|\mathcal{A}|}. \qquad (7)$$

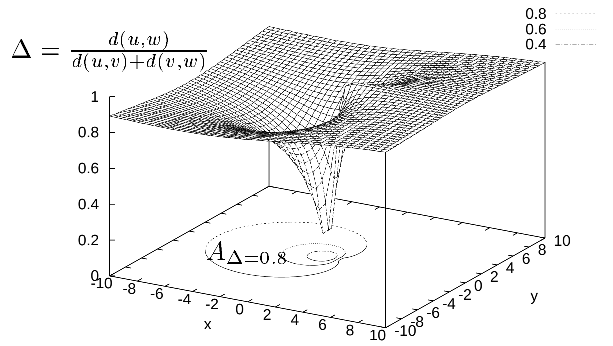


Fig. 7. Dispersion Δ for different positions of node w to be located.

The source node u calculates the needed target δ to satisfy (6) and therefore knows the probability that the proposed scheme is worth using. Then, the source node u can adopt a probability threshold β ($0 \leq \beta \leq 1$) to use the proposed scheme. If $P(\Delta \geq \delta) \geq \beta$, then the source adopts the proposed scheme. Otherwise, the source node uses the traditional one.

The computation of the probability presented in (7) considers the deployment region $\mathcal{A}$ known to all nodes. That would be the case if nodes are confined to a well known and even large region. In the case individual nodes are not aware of the dimensions of the deployment region they are located in, we propose an adaptive mechanism to estimate the deployment region $\mathcal{A}$. In this case, at the beginning, nodes have no knowledge of the deployment region. As nodes contact other remote nodes, they learn the distance from themselves to the other nodes. For example, realizing a transmission, our source node u learns the distance $d(u, w)$ to the destination node w and the distance $d(u, v)$ to the location server u of node w. If nodes keep the maximum distance $d_{\max}$ they have used, $d_{\max}$ can be used to perform an estimation $\widehat{\mathcal{A}}$ of the unknown deployment region $\mathcal{A}$. The estimated size of the deployment region would be $|\widehat{\mathcal{A}}| = \pi d_{\max}^2$.

The probability of the proposed scheme being worth using when there is no previous knowledge of the total deployment region is

$$P(\Delta \geq \delta) = 1 - \frac{|A_{\Delta=\delta} - A_R|}{|A_{\Delta=\delta} \cup A_R \cup \widehat{\mathcal{A}}|}. \qquad (8)$$

At the very first transmission of node u that requires a location query, the only knowledge node u has of the remaining ad hoc network is the distance $d(u, v)$ to the location server v of node w to be located. Therefore, $d_{\max}$ is initialized to $d(u, v)$. The estimated size of the deployment region is thus $|\widehat{\mathcal{A}}| = \pi d^2(u, v)$ in this first step. As the node u communicates with other farther nodes, the knowledge of the deployment region increases as $d_{\max}$ is updated with information of the farthest reachable known node. Alternatively, a node could also extract indications about how large the deployment region is from the packets the node forwards. Packets under geographic routing carry the position of their sources and destinations. As a node forwards a packet toward the destination, the node can use the position of the source and destination present on the packet to improve faster the estimation of the size of the deployment region the node is located in.

VI. Conclusion

One of the main motivations of adopting location management schemes in mobile ad hoc networks is to enable the geographic routing of packets because of scalability issues. We have identified a common characteristic of the previous proposals for location management in such context. The previous proposals have as a common characteristic the adoption of two distinct phases: the location query and the data transmission.

We proposed a scheme where some initial packets are sent through the *indirect path* originally destined for dedicated query packets. For small requests the proposed scheme is always better than the traditional one. Results, however, have also identified the conditions determining if the proposed scheme is worth adopting or not. Quantitative analysis has determined the bounds of the improvement achieved. The related tradeoffs between adopting the proposed scheme and the previous one have been identified in terms of the size of the related packets, how many initial packets sent through the location server, the size of the flow to be transmitted, and the relative positioning of the concerned nodes. From the identification of the limits where is worth adopting the proposed scheme, we developed a methodology that allows a source node to evaluate the probability of using the lowest cost scheme. Therefore, the source can select the adequate scheme that would most likely reduce the total cost of the intended transmission under the given conditions.

Our proposal and the methodology within are appliable to the main previous works in location management for mobile ad hoc networks. We expect that seeking to adopt the method having the lowest cost at each transmission provides, at the longterm, an overall performance improvement of the location management as well as a reduction in the battery consumption of nodes.

The proposed scheme specially benefits short lived flows, since it improves more significantly the cost for flows containing up to 10 packets, such as small requests of data. Such short lived flows represent a large portion (up to 75% [17]) of the flows in the current Internet [18]. Even if the larger amount of short lived flows represents only a much smaller portion of the load traffic, our proposition concerns just the initialization of flows. If we suppose a similar traffic pattern for future mobile ad hoc network utilization, we could expect to benefit the vast majority of flows.

As perspectives for future work, our ongoing research investigates the impact of the proposed scheme on TCP flows. Our results show that the proposed scheme is always worth using when one initial packet from the flow to be transmitted is used to learn the destination's position and when this initial packet has the size equivalent to the size of a query packet. Such conditions match exactly the conditions observed in the presence of TCP flows. A source node about to transmit over TCP uses a three-way handshake mechanism to perform the TCP connection establishment. Thus, the source node first sends a `SYN` packet, which contains just the TCP header and no payload, and waits for an acknowledgment before sending the second `SYN` packet to establish the connection. Only after the connection establishment, the flow to be sent over TCP starts being transmitted. Such features indicate the possibility of a TCP-tailored improvement to the current location services based on the proposed scheme.

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