A TCP-Tailored Approach to the Location Management in Mobile Ad Hoc Networks

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***Abstract*— The main location management proposals in mobile ad hoc networks have, as a common characteristic, two distinct phases: the location query of the position of a destination node and the transmission of a flow toward the destination node. This letter proposes to send the initial packet of a flow to learn the position of its destination instead of adopting a dedicated query packet. Such an approach specially benefits TCP flows. This TCP-tailored approach can be applied to previous proposals in location management with minor changes in their particular features. We show that the proposed TCP-tailored approach reduces the cost of location management for TCP flows with respect to conventional schemes. We also evaluate the benefits that different location services take from the TCP-tailored approach.**

***Index Terms*— Location management, ad hoc networks**

I. INTRODUCTION

LOCATION management concerns the deployment of a scalable location service able to provide a given source with the position of any eventual destination [1]–[3]. Providing a scalable location service for mobile ad hoc networks is a challenging problem as there is no fixed infrastructure.

This letter proposes a TCP-tailored approach to the location management in mobile ad hoc networks. Previous efforts on location management operate in two sequential and distinct phases: the location query of the position of a destination node and the transmission of a flow toward the destination node. We propose to use the initial packet of the flow to learn the location of the destination instead of adopting dedicated location query packets. Piggy-backing control packets in data packets, or vice-versa, is not a new technique in the general case. In spite of that, the main contribution of this letter is the analysis of the benefits from applying this technique to the location management in mobile ad hoc networks. Results show that the proposed approach reduces the transmission costs in location management for the TCP flows, specially favoring short-lived TCP flows. This improvement depends on the existing dispersion between the position of the source and destination nodes with respect to the position of the location server of the destination node. Therefore, we also investigate the behavior of the node dispersion for different location services, namely the home-agent based approach [4] and the Grid Location Service (GLS) [5].

II. TCP-TAILORED APPROACH

The path taken by a packet from the source toward its destination when using geographic routing is composed by the sequence of nodes that gets the packet closer to its destination at each hop. Let $G = (V, E)$ denote the graph G consisting of the set V of all nodes and the set of edges $E = \{(x, y) \mid x, y \in V \text{ and } \mathcal{D}(x, y) \leq R\}$. The value R is the transmission range of nodes and $\mathcal{D}(x, y)$ 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 composes the path between the nodes x and y. For example, $E_{a,d} = \{(a, b), (b, c), (c, d)\}$. The scenario of adopting geographic routing 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 arrives at a location server, it is forwarded toward the destination to obtain the most possible accurate position information. Both the home-agent based approach [4] and GLS [5] adopt this procedure. Upon arriving at the destination, the location query induces the destination to update the source with its current location;
- flow transmission – after receiving the position information from the destination itself, the source node starts the transmission of the flow 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 an update is piggybacked onto either data or acknowledgment packets. 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.

The path leading from source node u to destination node w passing through location server 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 in consumed energy of transmitting one 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 $\mathcal{S}(p)$ is defined returning the size of packet p. The total cost of sending one packet p from node u to node v is defined as

$$\mathcal{C}(u, v, p) = \mathcal{S}(p) \sum_{(x,y) \in E_{u,v}} \mathcal{D}(x, y). \quad (1)$$

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A node u wishing to learn about the position of a node w queries a node v that acts as a location server for node w. The total cost of sending a sequence of n flow packets (f) from node u to node w 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 the *direct path*. The total cost also comprises the transmission of the n flow packets and their respective m ($1 \leq m \leq n$) acknowledgments packets (a) directly through the *direct path* between nodes u and w. In the absence of acknowledgments, we consider m to represent position update messages. Hence, the total cost $\mathcal{C}_1$ of the conventional approaches considering one query packet is

$$\begin{aligned} \mathcal{C}_1 = \mathcal{C}(u, v, q) + \mathcal{C}(v, w, q) + \mathcal{C}(w, u, q) + \\ + n\ \mathcal{C}(u, w, f) + m\ \mathcal{C}(w, u, a). \end{aligned} \tag{2}$$

We propose to send the initial packets of a flow 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 approach is similar to how Mobile IP with route optimization works [6]. This proposal does not eliminate the query for locations, but it instead avoids the usage of a dedicated query packet and the waiting time for a query answer imposed on a source for starting a transmission. The total cost $\mathcal{C}_2$ of the proposed approach is then given by

$$\begin{aligned} \mathcal{C}_2 = k\ \mathcal{C}(u, v, f) + k\ \mathcal{C}(v, w, f) \\ + (n - k)\ \mathcal{C}(u, w, f) + m\ \mathcal{C}(w, u, a). \end{aligned} \tag{3}$$

For TCP flows, a source first sends a `SYN` packet. We exploit such a feature by sending the first `SYN` packet to learn the location of the destination through the *indirect path* and the remaining packets through the *direct path*.

III. Performance Analysis

The assessment of the proposed scheme considers the minimum bound costs of each approach. Combining the triangle inequality, $\mathcal{D}(u, w) \leq \mathcal{D}(u, v) + \mathcal{D}(v, w)$ for all nodes $u, v, w \in V$, with Equation (1), we get the minimum bound cost $\mathcal{C}_{\min}$ of sending one packet p from node u to node v as

$$\begin{aligned} \mathcal{C}_{\min}(u, v, p) = \min \left(\mathcal{S}(p) \sum_{(x,y) \in E_{u,v}} \mathcal{D}(x, y) \right) \\ \geq \mathcal{S}(p)\ \mathcal{D}(u, v). \end{aligned} \tag{4}$$

Applying the lower bound cost $\mathcal{C}_{\min}$ to Equations (2) and (3), we get the lower bounds of $\mathcal{C}_1$ and $\mathcal{C}_2$, respectively.

The degree of dispersion Δ is based on the minimal route distances between the concerned nodes, which can be approximated by the geographic distance between these nodes if there is sufficient node density on the network. Li *et al.* [5] show that geographic forwarding works well for a node density larger than 50 nodes per square kilometer. We thus consider this value to be the minimum sufficient node density on the network. Therefore, 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, is defined as

$$\Delta = \frac{\mathcal{D}(u, w)}{\mathcal{D}(u, v) + \mathcal{D}(v, w)}, \quad 0 < \Delta \leq 1. \tag{5}$$

We also define the cost improvement Ψ as

$$\Psi = 1 - \frac{\mathcal{C}_2}{\mathcal{C}_1}. \tag{6}$$

Note that the cost improvement Ψ is only defined when $\mathcal{D}(u, w) > R$, where R is the cover range of node u. This is so because if $\mathcal{D}(u, w) < R$, node w would be a nearby node with respect to node u and therefore no location query would be needed. For the lower bound costs of $\mathcal{C}_1$ and $\mathcal{C}_2$, the cost improvement Ψ is given by

$$\Psi = \frac{\mathcal{S}(q)\ (1 + \Delta) - k\ \mathcal{S}(f)\ (1 - \Delta)}{\mathcal{S}(q)\ (1 + \Delta) + n\ \mathcal{S}(f)\ \Delta + m\ \mathcal{S}(a)\ \Delta}. \tag{7}$$

A. Effects on TCP and UDP Flows

Short-lived TCP flows, as most web requests for instance, represent the majority of flows in the current Internet. We consider short-lived TCP flows as having five to ten packets. The minimum of five packets takes into account the minimum number of packets sent by the source to have a complete TCP connection: two packets for connection establishment, one data packet, and two packets for connection termination. Figure 1 presents the cost improvement Ψ for different flow sizes. The TCP flows have data packets of 1500 octets in contrast with the 40 octets of small packets used for location query, connection establishment, and connection termination. Supposing a similar traffic profile between the Internet and future mobile ad hoc networks, a cost reduction from 1% to 6% is achieved for the most part of flows, *i.e.* the short-lived flows with $5 \leq n \leq 10$, as shown in Figure 1. The minority of flows, either flows of larger size ($n > 10$) or short-lived flows being transmitted with a dispersion $\Delta < 0.05$, has also a cost reduction, but limited to 1%.

UDP flows may not take advantage of the proposed scheme. The sending of a first flow packet larger than a query packet through the *indirect path* may become more costly than the adoption of a small dedicated query packet.

B. Dispersion of Nodes in Different Location Services

In a home zone approach, such as the home-agent based approach [4], a node w uses its identifier to feed a hash function and obtain a position in the deployment region. A node v that is close to this position act as a location server for w. The position selected by the hash function may be viewed as a rendezvous point between the location updates of a node w and the nodes looking for the position of node w. This rendezvous position is a function of the identifier of

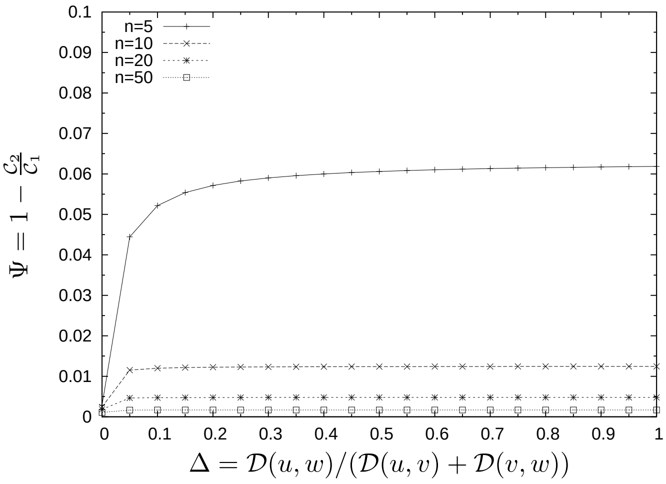

Fig. 1. Cost improvement Ψ for TCP flows with large data packets.

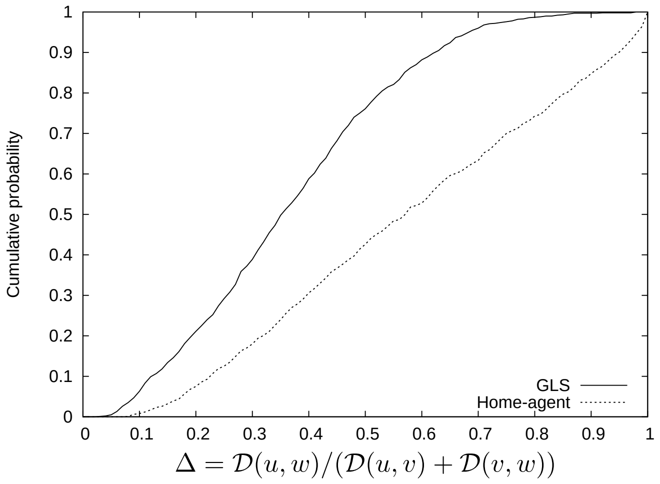

Fig. 2. Cumulative probability of the dispersion Δ for each location service.

node w, not of his current position. Therefore, the position of the location server for a node w remains the same regardless of the current position of node w.

Hierarchical approaches, such as the Grid Location Service (GLS) [5], establish that for each node, some other nodes act as location servers distributed in different density levels in the hierarchical structure throughout the deployment region. For a given node w, there are a higher density of location servers close to this node and a lower density far from it. The location server to be used in a particular location query, depends on the current position of the source node u. In this case, the dispersion tends to be lower than in the home-agent case because it is more likely that there is a location server v close to either the destination node w or the source node u.

To analyze the dispersion of nodes in the home-agent based approach and in the GLS proposition, we proceed a simulation study described as follows. Suppose a square deployment region with 1000 meters on a side. In the hierarchical case, the GLS order-1 square is 125 meters on a side. This means dividing the deployment region into a hierarchy of 64 squares, each one with 125 meters on a side. Four order-1 squares make up an order-2 square, and so on. In our case, this results in an order-4 square that corresponds to the whole deployment region. A node chooses three location servers for each level of the hierarchy, leading in our case to nine location servers for each node distributed in different density levels throughout the deployment region. The density of location servers for node w is higher close to the node w. In the home-agent approach, however, node w uses a hash function to choose a position in the deployment region. A node v, close to this position, acts as a location server for node w. The transmission range R of nodes is considered 125 meters.

Considering 1000 nodes within the deployment region, Figure 2 presents the cumulative probability of having a particular dispersion of nodes Δ for each location service. This is the result of 10,000 simulated interactions between source nodes u, location server v, and destination node w. The home-agent approach provides a higher dispersion of nodes Δ than the hierarchical GLS approach. This also indicates that the home-agent approach takes a better benefit of the TCP-tailored approach since it suffers from higher dispersion between the concerned nodes. For example, considering the scenario of Figure 1 and applying Equation (7), if $\Delta > 0.3$ and $n = 5$, then the cost improvement is $\Psi > 6\%$. From the results of Figure 2, we observe that the probability of having $\Delta > 0.3$ is 61% for GLS and 82% for the home-agent approach.

IV. CONCLUSION

We have proposed a TCP-tailored approach to the location management in mobile ad hoc networks. We evaluate the impact on previous proposals for location management in mobile ad hoc networks, either home zone or hierarchical approaches, showing that the home zone approach takes a better benefit from the TCP-tailored approach. Thus, the main previous proposals reduce the transmission costs in the location management procedure for the TCP flows with minor changes, independent of the particular features of such previous proposals. Based on the transport protocol of the flows to be transmitted, a source selects to apply either the TCP-tailored approach (for the majority of flows composed by the TCP flows) or the conventional approach (for the remaining flows). As each cooperative node in the network seeks to adopt the method having the lowest cost at each transmission, the adoption of the TCP-tailored approach provides a performance improvement of the location management.

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