Brief Announcement: Solvability of Geocasting in Mobile Ad-Hoc Networks

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ABSTRACT

We present a model of a mobile ad-hoc network in which nodes can move arbitrarily on the plane with some bounded speed. We show that without any assumption on some topological stability, it is impossible to solve the geocast problem despite connectivity and no matter how slowly the nodes move. Even if each node maintains a stable connection with each of its neighbours for some period of time, it is impossible to solve geocast if nodes move too fast. Additionally, we give a tradeoff lower bound which shows that the faster the nodes can move, the more costly it would be to solve the geocast problem. Finally, for the one-dimensional case of the mobile ad-hoc network, we provide an algorithm for geocasting and we prove its correctness given exact bounds on the speed of movement.

Keywords: Mobile ad-hoc networks, geocast, speed of movement vs cost of the solution, distributed systems.

Categories and Subject Descriptors

C.2.4 [**Computer-Communication Network**]: Distributed Systems

General Terms

Theory, Algorithms

Keywords

Mobile ad-hoc networks, geocast, speed of movement vs cost of the solution, distributed systems.

1. INTRODUCTION

There has been increasing interest in mobile ad-hoc networks with nodes that move arbitrarily on the plane. This is because (wireless) mobile computing is an emerging technology and because mobile ad-hoc networks support communication between mobile nodes without relying on a stable infrastructure. There are scenarios where this fixed infrastructure cannot exist, e.g. in military operations or after some physical disaster. For such cases, it is desirable to program the mobile nodes to solve important distributed problems within specific geographical areas and without depending on a stable infrastructure. This justifies the increasing interest in studying "geo" related problems in mobile ad-hoc networks, e.g. georouting [4, 9], geocasting [5, 6, 8, 3], geoquorums [3].

When geocasting is solved for mobile ad-hoc networks, the speed of movement becomes an important factor. This is because it can heavily influence, for example, the completion time of message diffusion in a certain geographical area till making geocasting unsolvable if these speeds are too high.

To our knowledge this is the first attempt to study the relation among geocast problem solvability, the cost of a solution, and mobility. Moreover, existing geocast algorithms for mobile ad-hoc networks [5, 2, 8, 6] only provide probabilistic guarantees about information delivering.

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2. A MODEL FOR MOBILE AD-HOC NETWORKS

We consider a system composed by an unbounded number of nodes which move with bounded speeds in a continuous manner on the plane. Two nodes p and p' are *neighbours* at some time t, if their physical distance at time t, denoted distance(p, p', t), is smaller than r, for fixed $r > 0$. We assume each node to have at most H neighbours at each time.

Nodes do not have access to a global clock, but their local clocks run at the same rate. Within a small time period, called a *round*, a node can execute in a sequential and atomic manner receiving at most H messages, broadcasting at most one message, and local computation. For simplicity of presentation, the duration of a round is one time unit (i.e., in $[t, t + i]$, i rounds have elapsed).

Nodes communicate by exchanging messages over a wireless radio network. To perform a local broadcast of a message m, a node p is provided with a primitive denoted *broadcast*(m). It takes at least one round for a broadcast message m to be received by a node which then generates a *receive*(m) event. If *broadcast*(m) is performed by node p at time t then all nodes that remain neighbours of p throughout $[t, t + T]$ receive m by time $t + T$, for some fixed integer $T > 0$. It is possible that some nodes that are neighbours of p at times in $[t, t + T]$ also receive m but no node receives m after time $t + T$. Interference and messages loss due to concurrent broadcasts are assumed to be dealt by a lower level communication layer [7] within the T rounds it takes for a message to be (reliably) delivered to its destination.

The standard definition of connectivity (see [1]) allows an adversary to continually change the neighbourhood of nodes and render impossible even the basic task of geocasting (Theorem 4.1). For this reason, we assume a stronger version, called *strong connectivity*. This is based on the following observation: if there is an upper bound on the speed of nodes, then the closer two neighbours are located to each other, the longer they will remain neighbours. Hence, if nodes are located fairly close, then their connection is guaranteed for some period of time. Formally,

Definition 2.1 (Strong Neighbours). *Let $\delta_2 = r$ and δ_1 be fixed positive real numbers such that $\delta_1 < \delta_2$. Two nodes p and p' are* strong neighbours *at some time t, if there is a time $t' \leq t$ such that distance(p, p', t')$\leq \delta_1$ and distance(p, p', t'')$< \delta_2$ for all $t'' \in [t', t]$.*

Assumption 1 (Strong Connectivity). *For every pair of nodes p and p' and every time t, there is at least one path of strong neighbours connecting p and p' at t.*

By increasing δ_1, the set of strong neighbours of each node either remains the same or increases. So strong connectivity is not too much stronger than traditional one. Our results hold for any $\delta_1 \geq \frac{\delta_2}{2}$.

We assume an upper bound on the speed of node movement which exists in practical situations. Formally,

Assumption 2 (Movement Speed). *It takes at least $T' > 0$ rounds for a node to travel distance $\delta = \frac{\delta_2 - \delta_1}{2}$ on the plane.*

Then, Lemma 2.2 describes some topological stability.

Lemma 2.2. *If two nodes become strong neighbours at time t, then they remain (strong) neighbours throughout $[t, t+T']$ (i.e., for T' rounds).*

3. THE GEOCAST PROBLEM

The goal of geocasting is to deliver information to nodes in a specific geographical area. The geocast information is initially known by exactly one node, *the source*. If the source performs Geocast(I, d) at time t from location l, then:

Property 3.1 (Reliable Delivery). *There is a positive integer C such that, by time $t+C$, information I is delivered by all nodes that are located at distance at most d away from l throughout $[t, t+C]$.*

Property 3.2 (Termination). *If no other node issues another call of geocast then there is a positive integer C' such that after time $t+C'$, no node performs any communication triggered by a geocast (i.e. local broadcast).*

Property 3.3 (Integrity). *There is $d' > d$ such that, if a node has never been within distance d' from l, it never delivers I.*

4. LOWER AND UPPER BOUNDS

We present a framework, namely (k, α)-Geocast(I, d), that describes a large class of geocasting algorithms and we prove that for our mobile ad-hoc network, it is impossible to solve the geocast problem under traditional connectivity, or under strong connectivity if nodes move too fast. Any algorithm in (k, α)-Geocast(I, d) with $\alpha \geq 1$ is such that: when the source invokes (k, α)-Geocast(I, d), k messages containing I are broadcast, once every α rounds; when a node receives a message containing I, k broadcasts of messages containing I are generated, once every α rounds as long as some condition holds. To prove our impossibility results, we set this condition to be always true because if reliable delivery is impossible when the maximum broadcasts are allowed, it is also impossible for less broadcasts. Moreover, we relate the speed of movement (inversely related to T') to the speed of communication (inversely related to T). We also show how the speed of nodes relates to the cost of any (k, α) - Geocast algorithm. Formally,

Theorem 4.1. *It is impossible to solve the geocast problem using any (k, α) - Geocast(I, d) algorithm under traditional connectivity assumption no matter how slowly the nodes move.*

Theorem 4.2. *It is impossible to solve the geocast problem using any (k, α) - Geocast(I, d) algorithm if $T' < \frac{T}{4}$ even if strong connectivity holds.*

Theorem 4.3. *It is impossible to solve the geocast problem using any (k, α)-Geocast(I, d) algorithm if $T' < \frac{\delta T}{\delta_1}$, for a system with unbounded number of nodes even if strong connectivity holds.*

Theorem 4.4. *Assuming that $T' > \max\{\frac{1}{4}, \frac{\delta}{\delta_1}\}T$, then if it is possible to solve geocast, it would take more than $(\lfloor \frac{d-\delta_2}{\delta_1 - \frac{T\delta}{T'}} \rfloor + 1)T$ rounds to ensure reliable delivery, using any (k, α)-Geocast(I, d) algorithm for a system with more than $\lfloor \frac{d-\delta_2}{\delta_1 - \frac{T\delta}{T'}} \rfloor$ nodes even if strong connectivity holds.*

In [1], we provide a deterministic solution for the geocast problem in a *one-dimensional* mobile ad-hoc model (i.e. nodes move on a line). This latter belongs to the (k, α)-Geocast(I, d) class and has k and α respectively equal to 7 and T.

5. FUTURE WORK

We proved bounds on the speed of node movement which make it possible to solve geocasting and we related its time complexity to the speed. These lower bounds and the cost of our proposed algorithm do not match. Although the gap is not large, it would have theoretical interest to match these bounds. Another future direction would be to design a geocast algorithm that works for a two-dimensional model including failures.

6. ACKNOWLEDGMENTS

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