Small World Model for Agent Search

(Extended Abstract)

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ABSTRACT

This paper shows how to apply an small world model to distribute AMS and DF services, forming a navigable small world network that allow to find short paths between agents using a greedy algorithm that takes into account only local information.

Categories and Subject Descriptors

C.2 [**Comp. Comm. Neetworks**]: Network Topology

General Terms

Algorithms, Management, Performance, Experimentation

Keywords

small world network, navigable network, failure tolerance

1. SMALL WORLD PHENOMENA

Small-World Networks[5] (SWN) are networks with an special structure that model the relationships existing in the real world among groups of people, ecosystems or even in the web [4][1][5]. This structure is characterized by a high clustering degree (a measure of the density of the network) and short path lengths that belongs to $O(\log n)$. It has been shown that people is good in locating these shortest paths using its limited knowledge. People does not send messages randomly, but using its own concept of *distance*. Therefore, the probability of a *proper* neighbor to be chosen is higher than to choose a *further* one, being this distance a general concept, not just a metric criteria.

This network behavior can be achieved by imposing an artificial structure that meet the requirements of an SWN. Adding random links to a 2D regular lattice results in a SWN model and there exists a delivery algorithm with cost $O((\log n)^2)$ [3]. So a decentralized algorithm can be used to send messages through the network with a bounded latency.

This structure is used to maintain a navigable network of distributed white and yellow pages services (AMS and DF) in order to manage separated groups of agents. Agents are allocated into their corresponding node of the network. When an agent asks for another agent or service, an active search is made at the level of AMSs. It exists an algorithm to locate the agent in a bounded number of steps close to the shortest path using only local knowledge (information about direct neighbors).

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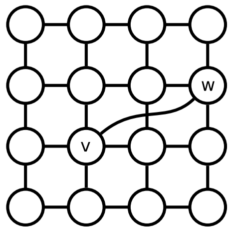

Figure 1: Kleinberg's structure. The node v has a directed edge to every other node within a lattice distance $p \geq 1$ (local contacts). Given two universal contacts $q \geq 0$ and $r \geq 0$, additional directed edges can be added from v to other q random nodes with a probability proportional to $[d(v,w)]^{-r}$, where r is a parameter to adjust the 'randomizity' of the grid and d is the Manhattan distance. In the case of AMS, to guarantee a navigable network, values of $p = 4$, $q = 1$ and $r = 2$ are used.

2. DISTRIBUTED AGENT MANAGEMENT

All AMSs are connected in a 2-dimensional regular lattice, where the boundaries are connected too (topologically equivalent to a toroid). Each AMS is a node in a $n \times n$ square. An AMS node $v = (i,j)$ is directly connected with its four neighbors $(i-1,j)$, $(i+1,j)$, $(i,j-1)$ and $(i,j+1)$—short range relationships. Over this structure, for each node v it adds a new arc—long range relationships— to a random node w with a probability proportional to $\rho(v,w)^{-\alpha}$, where $\rho(v,w)$ is the grid distance between two nodes $v = (i,j)$ and $w = (k,l)$, defined as the number of steps separating them $d((i,j),(k,l)) = |k-i| + |l-j|$ (Manhattan distance).

AMSs only know their direct neighbors, so each AMS only needs to maintain 5 links: 4 to its closer neighbors and another one that points to the long-range contact, which implies that each AMS only needs 5 permanent, open connections. When a new agent asks for registration, the platform assigns its corresponding AMS in the network. The agent is registered only in that AMS and the rest of the platform do not know even its existence. For doing that, an assignation function $f : A \rightarrow n \times n$ is defined, where A is the set of agents and the result are the AMS coordinates (i, j). This function should distribute homogeneously the agents in the network, avoiding to overload some nodes.

When the AMS v needs to address a message to the AMS w, it invokes the same f function. The AMS node v will identify the neighbor $u|u = \arg\min(d(u, w)), \forall u \in neighbor(v)$. That is, the message is redirected to the closest node to the receiver. Kleinberg's results ensures that, by repeating this process, the agent will be eventually found. Furthermore, this process takes at most $\alpha((\log n)^2)$, where α is a constant independent of the dimension of the network.

Another important observed property is the fault tolerance of this structure. Random failures do not seem to be important unless a significant number of links be affected, because long-range links allow to jump over faults. If a cluster of consecutive nodes fails, instead of surround the cluster, long-range links allow to avoid it and reduce the number of steps. Furthermore, if the cluster is a complete row or a column, long-range edges can still link the two separate components in which the network should be divided. Again, unless a significance number of links have been removed, the proposed structure can deal with the faults and maintain the network as one connected component. And this robustness is an emergent property, a consequence of the nature of the network.

3. ANALYSIS OF THE PERFORMANCE

Search process. Figure 2 shows how many messages have been exchanged between the nodes in the AMS network to find two randomly generated agents (one of them searching for the other). In each size of network, 1000 searches have been launched among randomly generated pairs of nodes. To compare the results, the graphic includes (i) the actual shortest path lengths; (ii) the theoretical bound for the Kleinberg's network; (iii) the average, median (value in the middle) and maximum values obtained in the search process; and (iv) the longest path length if the network were a lattice (without long-range contacts).

We can conclude that the number of messages between any pair of AMSs is $(\log n)^2$ in the majority of the cases, where n is the number of AMS nodeds that form the network. The average value is always under that limit and the most repeated one is barely over this limit for large networks. If the maximum values are considered, then can be ensured that **the maximum number of messages needed to connect two agents is bounded by** $2.3(\log n)^2$. That means that theoretical results can be applied to build a navigable network of AMS and DF to create an scalable solution to maintain open and highly dynamic multiagent systems.

Failure tolerance. To analyze it, only link failures will be considered: node failures can be modeled as a failure of all its connexions. It is assumed the existence of some fault detection mechanism.

When some links are broken, an alternative path have to be find. The problem appears when a broken link splits the network into two isolated parts. The analysis done regarding with this problem consists on eliminate one edge at random until the network is divided into two isolated components.

The bigger the network is the sooner a failure is produced regarding with the size if the network. Comparing it with plain lattices and different small-world network structures, as Barabasi[1] and Watts[5] models, the experiments show that for small networks (100 nodes) all of them behaves in a similar way—they fails when around a 40% of the links have been destroyed—, whereas, as the size of the network increases (until 100.000 nodes), Kleinberg network is more robust than the rest.

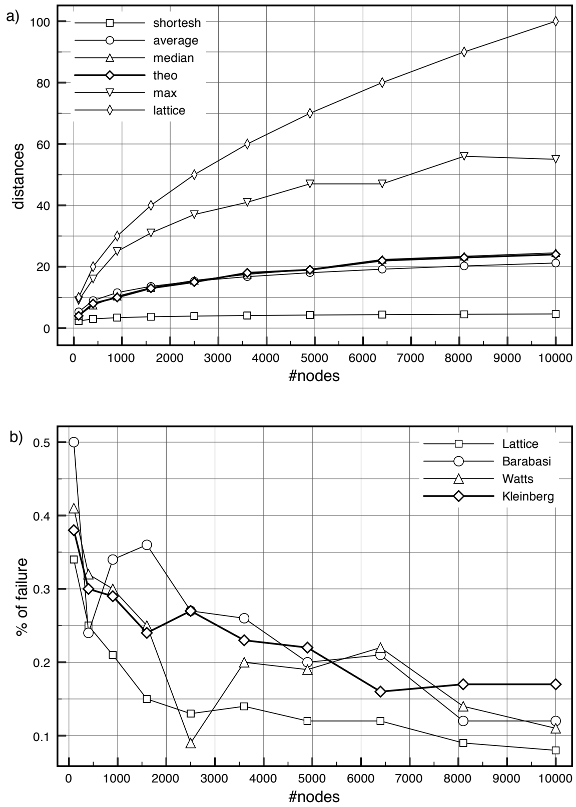

Figure 2: a) Results of 1000 searches over each configuration. b) Failure tolerance results

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