On Constructing Small Worlds in Unstructured Peer-to-Peer Systems

Yannis Petrakis and Evaggelia Pitoura

Department of Computer Science, University of Ioannina, Greece
{pgiannis,pitoura}@cs.uoi.gr

Abstract. Peer-to-peer systems have evolved as a means to share large amounts of data among autonomous nodes. A central issue in this context is locating nodes with data matching a user query. In this paper, we consider building peer-to-peer systems with small-world properties, that is, connecting the nodes to each other so that: (i) the distance between any two nodes is small and (ii) relevant nodes are connected to each other. Relevance between nodes is defined based on the probability that the two nodes match similar queries. We propose decentralized procedures for constructing small worlds based on routing indexes that describe the content of neighboring nodes. Our experimental results show that small-world peer-to-peer systems built with these procedures increase recall, that is, the percentage of relevant results returned.

1 Introduction

The popularity of file sharing systems such as Napster, Gnutella and Kazaa has spurred much current attention to peer-to-peer (P2P) computing. Peer-to-peer computing refers to a form of distributed computing that involves a large number of autonomous computing nodes (the peers) that cooperate to share resources and services. A central issue in P2P systems is identifying which peers contain data relevant to a user query.

In this paper, we propose building small worlds based on the content of the peers. Small worlds are networks with (i) a small distance between any two nodes (small diameter) and (ii) a large number of connections among relevant nodes (large clustering coefficient) [16]. We define the relevance of two nodes (peers) based on the probability of them matching the same set of queries. Intuitively, the topology of a small-world network represents a number of smaller networks (groups) that are rich in links between their peers (short-range connections), while they are linked to each other with a few random connections (long-range connections). The motivation for such small-world P2P networks is that once in the appropriate group, all relevant to a query peers are a few links apart. Long-range links are used for routing among groups.

We present an approach for building small worlds based on a fully decentralized procedure. Our construction is based on using local indexes. A local index is a characterization of the content of a peer. By aggregating local indexes of neighboring nodes, we create small worlds in a fully distributed manner.

* Work supported in part by the IST programme of the European Commission FET under the IST-2001-32645 DBGlobe project

© Springer-Verlag Berlin Heidelberg 2004
To demonstrate our approach, we implemented routing indexes using Bloom filters. Bloom filters are bit vectors used for probabilistic representation of a set to support membership queries. Our performance results show that networks constructed by our procedures have the small-world properties. Moreover, they maximize recall and precision, that is, for a given query they increase the number of matching data returned while maintaining the number of peers visited small.

The remainder of this paper is structured as follows. In Section 2, we put our work in context with related research. In Section 3, we present the model of our system, while in Section 4, we describe how small worlds are built. In Section 5, we present experimental results. Section 6 concludes the paper.

2 Related Work

There are two basic types of P2P systems: structured and unstructured ones. In structured P2P systems, documents (or indexes of documents) are placed at specific nodes (peers) usually based on distributed hashing (DHTs) such as in CAN and Chord. With distributed hashing, each document is associated with a key and each peer is assigned a range of keys and thus documents. Peers are interconnected via a regular topology where peers that are close in the identifier space are highly interconnected. Very recently, researchers have proposed extending DHTs (e.g. Chord) with long range links towards creating small worlds. In addition, recent extensions propose instead of associating keys to documents based on just the identifier of the document, to associate with each document (or peer) a vector describing its content extracted using IR algorithms and then use this vector as input to the hashing functions. However, this creates a dimensionality reduction problem, since the dimension of the vectors should match the dimension of the DHT.

These proposals can collectively be seen as an approach of building content-based small worlds in DHT-based P2P systems. In this case, the usual problems with structured P2P systems arise, since although DHTs provide very efficient searching, they compromise peer autonomy. The DHT topology is regulated since all peers have the same number of neighboring peers and the selection of peers is strictly determined by the DHTs semantics. Furthermore, sophisticated load balancing procedures are required.

We propose building small worlds in unstructured (non DHT-based) P2P systems. Unstructured P2P systems can be further distinguished between systems that use indexes and those that are based on flooding and its variations. With flooding (such as in Gnutella), a peer searching for a document contacts its neighbor peers which in turn contact their own neighbors until a matching peer is reached. Flooding incurs large network overheads. In the case of indexes, these can be either centralized (as in Napster), or distributed among the peers (as in routing indexes) providing for each peer a partial view of the system. We show how by using such indexes, we can organize the peers in small worlds in a fully decentralized manner. Small-worlds in non DHT P2P systems are also discussed in [1] in the context of searchable querical data networks; however, this work does not include a concrete decentralized small-world construction procedure.