

Mobile File-Sharing over P2P Networks

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INTRODUCTION

Peer-to-peer (P2P) computing is a networking and distributed computing paradigm which allows the sharing of computing resources and services by direct, symmetric interaction between computers. With the advance in mobile wireless communication technology and the increasing number of mobile users, peer-to-peer computing, in both academic research and industrial development, has recently begun to extend its scope to address problems relevant to mobile devices and wireless networks.

The mobile ad hoc network (MANET) and P2P systems share key characteristics including self-organization and decentralization, and both need to solve the same fundamental problem: connectivity. Although it seems natural and attractive to deploy P2P systems over MANET due to this common nature, the special characteristics of mobile environments and the diversity in wireless networks bring new challenges for research in P2P computing.

Currently, most P2P systems work on wired Internet, which depends on application layer connections among peers, forming an application layer overlay network. In MANET, overlay is also formed dynamically via connections among peers, but without requiring any wired infrastructure. So the major differences between P2P and MANET that concern us in this article are:

- a. P2P is generally referred to the application layer, but MANET is generally referred to the network layer, which is a lower layer concerning network access issues. Thus, the immediate result of this layer partition reflects the difference of the packet transmission methods between P2P and MANET: the P2P overlay is a unicast network with virtual broadcast consisting of numerous single unicast packets, while the MANET overlay always performs physical broadcasting.
- b. Peers in P2P overlay are usually referred to static node though no priori knowledge of arriving and departing is assumed, but peers in MANET are usually referred to mobile node since connections are usually constrained by physical factors like limited battery energy, bandwidth, computing power, and so forth.

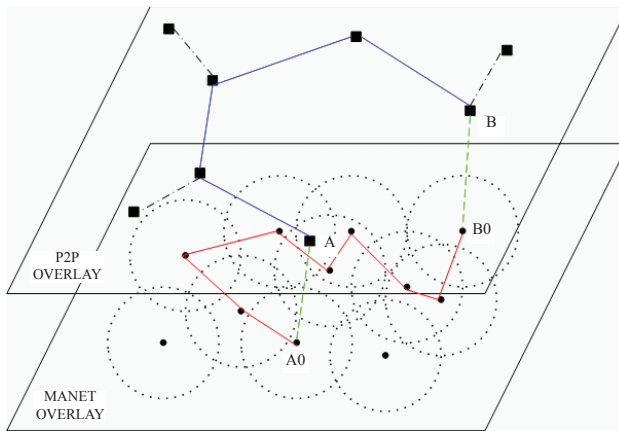
BACKGROUND

Since both P2P and MANET are becoming popular only in recent years, the research on P2P systems over MANET is still in its early stage. The first documented system is Proem (Kortuem et al., 2001), which is a P2P platform for developing mobile P2P applications, but it seems to be a rough one, and only IEEE 802.11b in ad hoc mode is supported. 7DS (Papadopouli & Schulzrinne, 2001) is another primitive attempt to enable P2P resource sharing and information dissemination in mobile environments, but it is rather a P2P architecture proposal than a practical application. In a recent paper, Lindemann and Waldhorst (2002) proposed *passive distributed indexing* for such kinds of systems to improve the search efficiency of P2P systems over MANET, and in ORION (Klemm, Lindemann & Waldhorst, 2003), a broadcast-over-broadcast routing protocol was proposed. The above works were focused on either P2P architecture or routing schema design, but how efficient the approach is and what the performance experienced by users is—these are still in need of further investigation.

Previous work on performance study of P2P over MANET was mostly based on simulative approach, and no concrete analytical mode was introduced. Performance issues of these kinds of systems were first discussed in Goel, Singh, and Xu (2002), but it simply shows the experiment results and no further analysis was presented. There is a survey of such kinds of systems in Ding and Bhargava (2004), but no further conclusions were derived. A sophisticated experiment and discussion on P2P communication in MANET can be found in Hsieh and Sivakumar (2004). However, all above works fall into a practical experience report category, and no performance models are proposed.

There have been many routing protocols in P2P networks and MANET respectively. For instance, one can find a very substantial P2P routing scheme survey from HP Labs in Milojevic et al. (2002), and U.S. Navy Research publishes ongoing MANET routing schemes (MANET, n.d.); but all of the above schemes fall into two basic categories: broadcast-like and DHT-like. More specifically, most early P2P search algorithms, such as in Gnutella (www.gnutella.com), Freenet (freenet.sourceforge.net), and Kazaa (www.kazaa.com), are

Figure 1. Broadcast over broadcast



broadcast-like, and some recent P2P searching, like in eMule (www.emule-project.net) and BitTorrent (<http://bittorrent.com/>), employs more or less some features of DHT. On the MANET side, most on-demand routing protocols such as DSR (n.d.) and AODV (n.d.) are basically broadcast-like. Therefore, we here introduce different approaches to integrate these protocols in different ways according to categories.

BROADCAST OVER BROADCAST

The most straightforward approach is to employ a broadcast-like P2P routing protocol at the application layer over a broadcast-like MANET routing protocol at the network layer. Intuitively, in the above settings, every routing message broadcasting to the virtual neighbors at the application layer will result in a full broadcast to the corresponding physical neighbors at the network layer.

The scheme is illustrated in Figure 1 with a searching example: peer A in the P2P overlay is trying to search for a particular piece of information, which is actually available in peer B. Due to broadcast mechanism, the search request is transmitted to its neighbors, and recursively to all the members in the network, until a match is found or it times-out. Here we use the blue lines to represent the routing path at this application layer. Then we map this searching process into the MANET overlay, where node A0 is the corresponding mobile node to the peer A in the P2P overlay, and B0 is related to B in the same way. Since the MANET overlay also employs a broadcast-like routing protocol, the request from node A0 is flooded (broadcast) to directly connected neighbors, which in turn flood their neighbors and so on, until the request is answered or a maximum number of flooding steps occur. The route establishing lines in that network layer

are highlighted in red, where we can find that there are few overlapping routes between these two layers, though they all employ broadcast-like protocols.

We have studied a typical broadcast-like P2P protocol, Gnutella (Clip2, 2001), in previous work (Yan & Sere, 2003). This is a pure P2P protocol, in which no advertisement of shared resources (e.g., directory or index server) occurs. Instead, each request from a peer is broadcast to directly connected peers, which themselves broadcast this request to their directly connected peers and so on, until the request is answered or a maximum number of broadcast steps occur. It is easy to see that this protocol requires a lot of network bandwidth, and it does not prove to be very scalable. The complexity of this routing algorithm is $O(n)$ (Ripeanu, Foster, & Iamnitch, 2002; Chawathe, Ratnasamy, Breslau, & Shenker, 2003).

Generally, most on-demand MANET protocols, like DSR (Johnson & Maltz, 1996) and AODV (Perkins & Royer, 2000), are broadcast-like in nature (Kojima, Harada, & Fujise, 2001). Previously, one typical broadcast-like MANET protocol, AODV, was studied (Yan & Ni, 2004). In that protocol, each node maintains a routing table only for active destinations: when a node needs a route to a destination, a path discovery procedure is started based on a RREQ (route request) packet; the packet will not collect a complete path (with all IDs of involved nodes) but only a hop count; when the packet reaches a node that has the destination in its routing table, or the destination itself, a RREP (route reply) packet is sent back to the source (through the path that has been set up by the RREQ packet), which will insert the destination in its routing table and will associate the neighbor from which the RREP was received as the preferred neighbor to that destination. Simply speaking, when a source node wants to send a packet to a destination, if it does not know a valid route, it initiates a route discovery process by flooding the RREQ packet through the network. AODV is a pure on-demand protocol, as only nodes along a path maintain routing information and exchange routing tables. The complexity of that routing algorithm is $O(n)$ (Royer & Toh, 1999).

This approach is probably the easiest one to implement, but the drawback is also obvious: the routing path of the requesting message is not the shortest path between source and destination (e.g., the red line in Figure 1), because the virtual neighbors in the P2P overlay are not necessarily also the physical neighbors in the MANET overlay, and actually these nodes might be physically far away from each other. Therefore, the resulting routing algorithm complexity of this broadcast-over-broadcast scheme is unfortunately $O(n^2)$, though each layer's routing algorithm complexity is $O(n)$ respectively.

It is not practical to deploy such a scheme for its serious scalability problem due to the double broadcast; and taking the energy consumption portion into consideration, which is somehow critical to mobile devices, the double broadcast will

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