P2P over MANET: Indirect Tree-based Routing

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***Abstract*—Mobile Ad hoc NETworks (MANET) and Peer-To-Peer (P2P) systems are emerging technologies sharing a common underlying decentralized networking paradigm. However, the related research activities have been mainly developed by different research communities, nullifying therefore the idea of an unitary approach able to assure effectiveness integrated solutions. In this paper, we propose a DHT-based routing protocol which integrates at the network layer both traditional direct routing, i.e. MANET routing, and indirect key-based routing, i.e. P2P routing. The feature of our proposal is the ability to build an overlay network in which the logical and physical proximity agree. The effectiveness of the proposed solution has been proved by numerical simulations.**

I. Introduction

Peer-To-Peer (P2P) and Mobile Ad hoc NETworks (MANETs) share the same key concepts of self-organization and distributing computing, and both aim to provide connectivity in a completely decentralized environment [1], [2]. Moreover, both lack central entities to which delegate the management and the coordination of the network and relay on a time-variant topology. In fact, in P2P networks the time-variability is due to joining/leaving peers, while in MANET ones it is due to both node mobility and propagation condition instability.

Despite these similarities, the adoption of the P2P paradigm to disseminate and discover information in a MANET scenario rises to new and challenging problems [1], [3]. The main issue concerns the layer where they operate: P2Ps build and maintain overlay networks at the application-layer, assuming the presence of an underlying network routing which assures connectivity among nodes, while MANETs focus on providing a multi-hop wireless connectivity among nodes.

This issue is a major problem in trying to couple a P2P overlay network over a MANET: in [4], [5] it has been proved that simply deploying P2P over MANETs may cause poor performances due to the lack of cooperation and communication between the two layers, causing so significant message overhead and redundancy. For these reasons, different cross-layer approaches have been presented and they can be classified according to the adopted solution for the resource discovery procedure.

More specifically, in *unstructured* P2Ps, peers are unaware of the resources that neighboring peers in the overlay network maintain [6], [7]. So, they typically resolve search requests by means of flooding techniques and rely on resource replication to improve the lookup performance and reliability. Differently, in *structured* P2P networks peers have knowledge about the resources offered by overlay neighbors, usually by resorting to the Distributed Hash Table (DHT) paradigm and, therefore, the search requests are forwarded by means of unicast communications.

Clearly, the scenarios where MANETS operate make unsuitable both flooding and replication mechanisms, except for small networks and/or high joining/leaving peer rates. In the last years structured P2P networks have gained attention: EKTA [8] and DPSR [9] integrate a Pastry-like [10] structured P2P protocol with the DSR routing algorithm, while CROSS-Road [11] integrates a Pastry-like DHT over the OLSR routing algorithm, and VRR [12] proposes a routing algorithm which provides indirect routing by resorting to a Pastry-like structure too. All these techniques associate an identifier, namely a key, to each peer by means of an hash function and organize the keys in a ring structure. Since the identifiers are randomly assigned to peers, the P2P overlay topology is usually built independently from the physical one, and thus no relationship exists between overlay and physical proximity (Fig. 1). As shown in [13], [14], this implies that overlay hops can give rise to physical routes which are unnecessary long. Kademlia [15] shares several similarity with Indirect Tree-based Routing, in particular as regards to routing table maintenance. However the overlay and physical proximity are not fully related, since it resorts to a XOR-based distance, which cannot fully take into account the physical topology. MADPastry [16], [17] integrates the Pastry protocol with the AODV routing algorithm and tries to overcome this issue by resorting to clustering. However, the overlay and physical proximity are in someway related only for inter-cluster communications. In [18], it is proposed to associate location-dependent identifiers to nodes with a distribute procedure and to organize node in a tree-based overlay structure.

In this paper, according to [18], we give a contribution

This work is partially supported by the Italian National Project “Wireless multiplatfOrm mimo active access netwoRks for QoS-demanding muLtimedia Delivery” (WORLD) under grant number 2007R989S, and by the Regional project “REmote e COntinuous Monitoring” (RECOM).

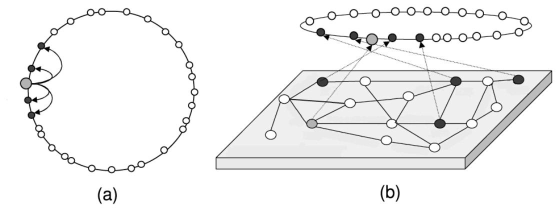

Fig. 1: Traditional P2P overlay networks

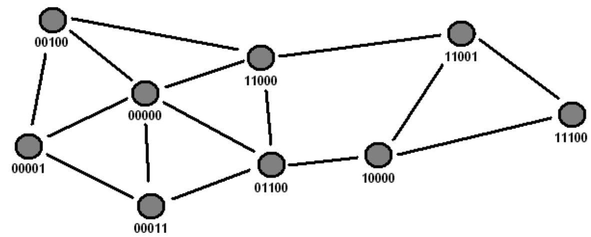

Fig. 3: Physical network topology

toward the structured P2P approach presenting a DHT-based routing protocol, namely Indirect Tree-based Routing (ITR), which integrates both traditional direct routing and indirect key-based routing at the network layer. Indirect Tree-based Routing extends the Augmented Tree-based Routing (ATR) [19], a hierarchical multi-path routing protocol for scalable ad-hoc networks, by providing fully functional P2P services. Like [19], we resort to an augmented tree-based structure, in order to assure that the logical and the physical proximity agree, as shown in Fig. 2. For both direct and indirect routing, each node maintains a unique routing table which stores only physical 1-hop neighbors, i.e. only peers with which the node can communicate at the link layer. As result, each overlay hop consists of only one physical hop. To test the effectiveness of our proposal, numerical simulations on 802.11 technology have been carried out across a wide range of environments and workloads. It is worthwhile to underline that ITR can be accommodated with slight modifications to operate over any link layer technology and, moreover, it does not require any change in both transport and application layers.
The outline of the paper is the following: Section II presents the design and implementation details of ITR, whereas Section III presents the performance evaluation. Finally, in the last section conclusion and open problems are drawn.

II. Indirect Tree-based Routing

A. Overview

As mentioned before, Indirect Tree-based Routing extends the Augmented Tree-based Routing (ATR) by providing fully functional P2P services. Both assign location-dependent identifiers, namely strings of l bits, to peers by means of a distribute procedure and of locally broadcasted hello packets. The peer identifier space can be represented as a *complete binary tree* of $l+1$ levels, that is a binary tree in which every vertex has zero or two children and all leaves are at the same level (Fig. 2-a). In the tree structure, each leaf is associated with a peer identifier, and a inner vertex of level k, namely a *level-k subtree*, represents a set of leaves (that is a set of peer identifiers) sharing a prefix of $l-k$ bits. For example, with reference to Fig. 2-a, the vertex with the label *01X* is a level-1 subtree and represents the leaves *010* and *011*. Let us define as *level-k sibling* of a leaf as the level-k subtree which shares the same parent with the level-k subtree the leaf belongs to. Referring to the previous example, the vertex with the label *1XX* is the level-2 sibling of the address *000*.
Indirect Tree-based Routing performs the whole routing resorting to an iterative procedure which explores the topological meaning of the node identifiers with a hierarchical form of multi-path proactive distance-vector routing. Like ATR, each node stores a routing table with l sections, one for each sibling, and the k-th section stores the physical 1-hop neighbor peers which can forward a packet towards peers whose location-dependent identifiers belong to the level-k sibling. With reference to the topology depicted in Fig. 3 where the location identifiers are 5 bit long, we suppose that the node with identifier *10000* has to communicate with the node with identifier *00000*. Since *00000* belongs to the level-4 sibling of identifier *10000*, the source will forward a packet to the physical neighbor with identifier *01000*, according to its routing table shown in Fig. 4 (further details on the routing table maintenance could be found in [19]).

From an operational point of view, Indirect Tree-based Routing performs like traditional P2P systems: namely, when a node stores a resource, it sends periodically a pointer

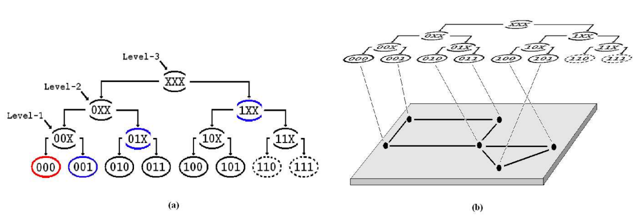

Fig. 2: Indirect Tree-based Routing overlay network

destination	next hop	path quality	route log
10001	------	------	------
1001X	------	------	------
101XX	------	------	------
11XXX	11001 11100	1.60 3.80	01000 01000
0XXXX	01100 11001 11100	1.25 5.80 9.30	01000 01000 10000

Fig. 4: Node 10000 routing table

Algorithm 1 forwarding(dst)

```
//l is the bit length of a network address
//src is the forwarder identifier
//dst is the peer identifier computed by the hash function
//computing the level-i sibling to which dst belongs to
//with respect to src
i = level = sibling(src,dst)
bitPosition = 0
nextHop = NULL
cost = maxCost
while nextHop = NULL do
  for each entry in routing table towards the i-th sibling
  do
    if sibling(dst, entry.nextHop) < level OR (sibling(dst,
    entry.nextHop) == level AND entry.routeCost < cost)
    then
      nextHop = entry.nextHop
      level = (dst, entry.nextHop)
      cost = entry.routeCost
    end if
  end for
  peerLocation.reset(bitPosition++) //setting the i-th bit to
  zero
end while
return nextHop
```

(a pair <resource identifier, storing peer identifier>) to the *rendezvous-point*, i.e. the node responsible (according to the hash function) for that resource, whereas if a node has to retrieve a resource, it sends a resource query to the rendezvous-point. Both these tasks resort to the algorithm presented in Section II-B, while the rendezvous-point's reply and the following communications needed to retrieve the resource will follow the routing procedure illustrated before.
Similarly, for MANET communications, each node periodically sends its current identifier to the rendezvous-point. When a node has to communicate with that node, it will send a identifier query to the rendezvous-point. After the reception of the query reply, the node can start a MANET communication.

B. Routing

As described in Section II-A, Indirect Tree-based Routing routes packets accounting for the location-dependent identifier of the destination. Since the identifiers are transient, and since they have to be recovered resorting to indirect key-based routing, both traditional MANET communications and resource queries are forwarded in a similar manner. In the case of traditional MANET communications, a source node knows the IP address of the destination, but not its identifier. In the same way, as regards a resource query, a peer knows the key associated with the needed resource, but not the identity of the peer storing the resource.
To overcome this issue, Indirect Tree-based Routing resorts to two globally known hash functions which return location dependent identifiers, the former defined on the IP address

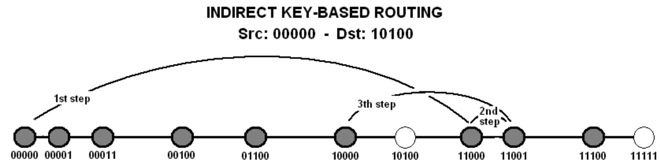

Fig. 5: Physical-proximity-aware overlay

space and latter defined on the resource key space.
Clearly, peer identifiers are assigned to nodes according to the network topology, and thus, there is no assurance that the identifier computed by one of the hash functions is valid, i.e. it has been assigned to a node. As mentioned in Section I, previous proposals overcome the problem organizing the peer identifier space with a virtual ring and forwarding the resource queries toward the ring. The forwarding stops when the query reaches the peer with the identifier closest to the computed identifier, according to a globally known metric. However, each overlay hop may correspond to multiple physical hops (1).
Differently, our proposal is able to forward both resource and identifier queries without introducing overlay overhead. The procedure is illustrated by Alg. 1, and we make an example to illustrate the basic idea by considering the topology depicted in Fig. 3. We suppose that the node *00000* has to forward a resource query (or a identifier query) to the identifier *10100* computed by one of the hash functions. According to Fig. 3, the computed identifier is not valid, i.e. it has not been assigned to a node. However, since the query source has at least one entry in its routing table towards the level-4 sibling *1XXXX*, that is the peer with identifier *11000*, the query can be forwarded through the network resorting to physical neighbors as illustrated in Fig. 5, reaching so the peer with identifier *11000*. Also the second and the third steps resort to physical neighbors, and the query reaches so the peer with identifier *10000*. Thanks to the augmented tree-based structure, this peer is aware that the identifier *10100* is not valid. In fact, looking at its routing table depicted in Fig. 4, the second section, i.e. the section toward the *101XX* sibling, is empty. At this point, the peer forwards the query following up the tree-structure, namely resetting the destination identifier one bit at time from the right. As result, the query is able to reach a valid identifier, *10000*, without introducing any overlay overhead (three physical hops for three overlay hops).

III. Experimental results

To evaluate the performance of Indirect Tree-based Routing, we implemented it as a routing agent on the widely adopted network simulator ns-2 [20] version 2.33 using the wireless extension developed by the CMU Monarch project [21]. We ran different sets of experiments to explore the impact of different workload and environmental parameters on the Indirect Tree-based Routing performances, resorting to an experimental setup very close to the one used in [16], [17] to facilitate

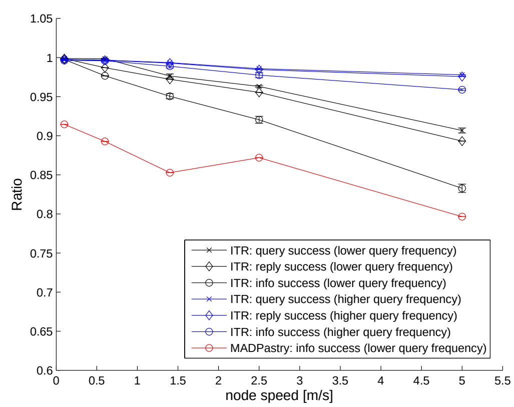

Fig. 6: Success rates

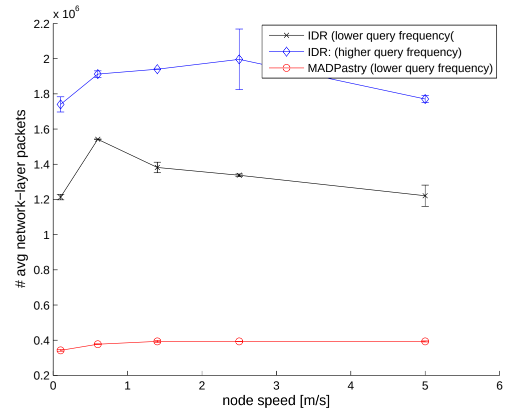

Fig. 8: Network-layer overhead

a comparison with previous works. Moreover, we compare the ITR performances with those obtained by the MADPastry protocol [16].

We adopt the standard values for both the physical and the link layer to simulate an IEEE 802.11b network interface with CCK11 modulation and Two-Ray Ground as channel model, resulting in a transmission range of 250 meters and a transmission rate of 11 Mbps. The duration of each simulation experiment is set to 3660 seconds. Nodes move in accordance with the *random way-point* model [22] with no pause time and at a steady speed, and the sizes of the scenario areas are chosen to keep the node density equal to 100 nodes/Km^2.

At the start of the simulation, 50 nodes are randomly allocated on a two-dimensional square space and the nodes start to move immediately. In the interval [700s, 1400s] each node has to store a fixed number of resources, while in the interval [1600s, 3600s], each node sends periodically a query for a resource randomly selected according to a uniform distribution.

Like [16], [17], we evaluate the performances in terms of *query success rate*, i.e. the fraction of resource queries correctly delivered to the rendezvous-point and *network-layer overhead*, i.e. the number of all the network packets generated during the simulation.

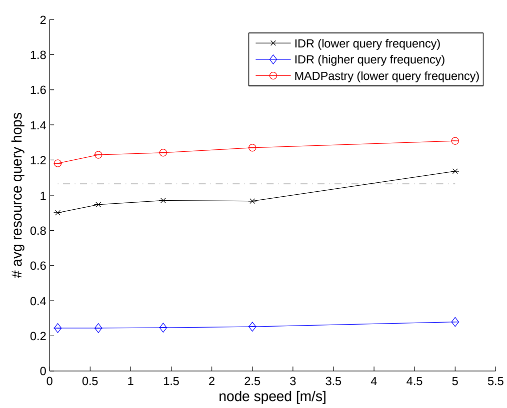

Fig. 7: Path length

Moreover, we introduce two new metrics: the *reply success rate* and the *resource success rate*. The former is defined as the ratio between the number of resource replies correctly delivered to the query sources and the number of generated resource queries. The latter is the ratio between the number of resources correctly delivered to the query sources and the number of generated resource queries, and we resort to it in order to compare the Indirect Tree-based performances with the MADPastry ones. Moreover, we evaluate also the average hop number of resource queries, i.e. the average number of times that a resource query has been forwarded. Such a metric allows us to assess the ability of a P2P protocol to effectively build a physical proximity-aware overlay network.

Regarding Indirect Tree-based Routing, we present the results for two different set of experiments as the node speed grows (Fig. 6-8). In both sets each node has to store one hundred resources, but the resource query frequency changes, respectively 0.1 and 0.5 query/s, to explore the impact of the caching techniques (the resources are indefinitely cached by each forwarder node, while the resource pointers are cached for 10 seconds). As regard to MADPastry, we set the number of resources to one hundred and the query frequency to 0.1. Each experiment ran five times, and for each metric we estimated both its average value and the standard deviation.

More in detail, Fig. 6 we account for the success ratios. Indirect Tree-based Routing outperforms MADPastry in the case of moderate mobility, whereas for relatively high mobility ITR suffers for the lack of data redundancy. Simulations, here non reported for sake of brevity, show that the performance gain becomes larger when the resource query frequency increases. If the resource query interval is smaller than the cache retain time, the Indirect Tree-based Routing is able to delivery all the queries to the correct rendezvous-point as well as to retrieve all the required resources. Also in absence of cache hits, the ITR is able to correctly delivery almost all the resource queries and to correctly retrieve more than the 80% of the required resources.

Fig. 7 shows the results in terms of resource query hop count. As regards to Indirect-Tree-based Routing, the numerical simulations show that in absence of caching techniques the average overlay hop number agrees with the average physical hop number. In fact, by bounding the average shortest path length $\overline{h}$ measured in hop number as [23]:

$$\overline{h} = \frac{2\sqrt{\frac{n}{\delta}}}{3\sqrt{\pi}r} \qquad (1)$$

where n is the number of nodes, δ is the node density and r is the transmissions range, we have that $\overline{h} = 1.06$ for a network with 50 nodes. Moreover, the same numerical simulations show the effectiveness of the adopted caching techniques. Regarding to MADPastry, the results shows clearly the presence of an overlay stretch effect.

Finally, Fig. 8 accounts for the last metric, the network-layer overhead. MADPastry, thanks to the reactive approach of its routing procedure, is able to outperform Indirect Tree-based Routing. However, we note that the highest values of ITR overhead account also for the differences in the number of resource queries between the two scenarios. We note that the proactive routing table maintenance affects the overhead for about the 20% of the generated routing packets. At the moment, we conjecture that the peak in correspondence of 1.4 m/s is caused by the timing of the distributed procedure for identifier allocation, but the analysis is still carrying on to gain more insight.

IV. Conclusion

The paper proposes the Indirect Tree-based Routing, a network-layer protocol which integrates both traditional direct routing and indirect key-based routing. Resorting to a location-dependent peer identifiers and to a augmented tree-based structure, the proposal is able to build an overlay network in which the logical proximity agrees with the physical proximity. Simulation results substantiate the effectiveness of the Indirect Tree-based Routing for MANET scenarios across different environmental conditions. Currently, we are working on an performance comparison of our proposal with other representative P2P protocols and we plain to extend the Indirect Tree-based Routing to work in scenarios characterized by high mobility, resorting to the *opportunistic routing* paradigm.

Acknowledgment

The authors would like to thank Dr. T. Zahn and Prof. J. Schiller for providing the MADPastry source code.

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