Optimising P2P Overlays for Pervasive Environments

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Abstract. In this paper we propose a topology optimisation algorithm for multi-layer P2P overlays on top of pervasive computing environments based on ant algorithms for the distributed network-wide collection of information. Our goal is to construct a robust and responsive overlay with low overhead so that it suits the highly dynamic and heterogeneous characteristics of pervasive environments.

1 Introduction

Pervasive computing environments are built over highly dynamic heterogeneous networks. Moreover, diversity exists in all aspects of such environments, including computing performance, network connections, mobility, etc. In order to reduce the perceived complexity of the underlying network, P2P overlays are usually adopted by large-scale network applications for resource discovery and network management [3]. However, the robustness of P2P overlays can be adversely affected under dynamic conditions. Existing works have made attempts to optimise overlay topologies in different ways, e.g. by considering superpeer architectures [5] or self-organised approaches [1] inspired by sophisticated and robust solutions found in nature. Nonetheless, these approaches consider environments with low dynamicity.

The responsiveness and overhead traffic of P2P overlays are critical concerns in pervasive computing. We propose a topology optimisation algorithm called X-Ant that is based on the theory of Ant Colony Optimisation (ACO) [2]. By developing different families of artificial ants with unique features, network information can be collected rapidly with low overhead traffic, hence supporting responsive overlay topology optimisation over dynamic underlying networks. Moreover, considering the wide range of information collected by ants, overlay layers with different links of diverse quality features can be simultaneously maintained, therefore increasing the overall robustness. A similar approach was used by the CAN [4] overlay on top of a low dynamicity underlying network.

The rest of this paper is as follows. Section 2 presents the research problem by describing the goal of this project and the proposed methodology. In section 3 we discuss our proposed X-Ant algorithm by describing its multi-layer overlay design, the ant families used for network parameter collection, and the corresponding topology optimisation. Section 4 concludes this paper by presenting our current work as well as giving insight to future plans.

2 Research Problem

Our goal is to promote the responsiveness, efficiency and robustness of P2P overlay networks built on top of pervasive environments by employing bio-inspired methods. Although no special restriction is imposed on the type of applications, those for semi-public urban spaces, supporting socialization by enabling people to meet, work, learn and have fun, will be considered with high priority.

Our research is based on the theory of ACO, which has shown fruitful outcomes utilising artificial ants to optimise overlays, e.g. the BlatAnt algorithm [1] that effectively bounds the diameter of grid overlays. However, the characteristics of our considered underlying networks are essentially different from grids in that the dynamicity and device heterogeneity are much higher. To address these unique features, we first aim at reducing the overhead traffic by creating new ant families and new types of pheromones to optimise information collection. This information will then be used to restructure and optimise overlay topology. Additionally, maintaining a multi-layer overlay composed of diverse types of virtual links according to different quality criteria, complemented by an adaptive layer switching mechanism, are expected to increase the overall overlay robustness.

3 X-Ant Algorithm

3.1 Multi-layer Overlay

To tackle the multifold requirements of different pervasive applications, we propose an overlay structure composed of different layers each of which being optimised in terms of different network parameters, such as bandwidth, latency, packet loss rate, link type (wired or wireless), etc.

According to the requirements from pervasive applications, these layers can be maintained with identical or near identical priority so that all of them can simultaneously serve different applications' needs. Alternatively, as illustrated in Fig.1, a selected layer can be given the highest priority (active), while other layers are maintained in the background (standby). The latter mode generates less overhead traffic, making it particularly suitable for networks with restrained bandwidth. An advantage shared by both modes of operation is that the topology of one layer is not likely to overlap with another, thus increasing the overall robustness by means of available backup paths for recovery.

Layer switching is triggered by applications. Whenever an overlay optimised for a different parameter is needed, the corresponding standby layer will become the active one. Furthermore, standby layers also serve as backup layers. In case of link disconnections in the active layer, links in backup layers can be temporarily exploited as alternatives to ensure connectivity. Therefore backup layers can help the recovery of the active layer.

3.2 Ant Families

For the collection of multiple network parameters, we propose a bio-inspired, lightweight and responsive information collection mechanism. We draw inspira-

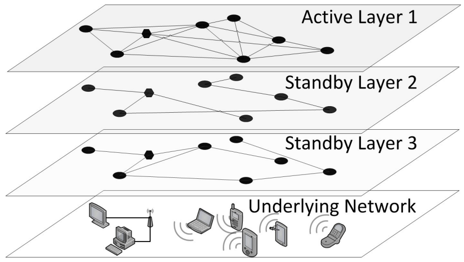

Fig. 1. Multi-layer overlay deployment scenario.

tion from ant algorithms and plan to expoit three families of ants. Ants migrate from node to node and gather new information regarding the node and its neighbourhood, while also exchanging their stored information with the node they are visiting, leading thus to information dissemination across the network. Ants indirectly interact with each other via several types of pheromones.

Long-range Ants are responsible for network-wide information collection and exchange. They have a large TTL (Time-To-Live) and are capable of collecting multiple parameters during their life time. Migration of ants is biased by the pheromone concentration of the node's outgoing links. During migration, long-range ants reinforce outgoing and incoming pheromone concentration on the two connected nodes to reflect the latest status of the link. High pheromone concentration indicates links with relatively optimal quality characteristics in regard to the aforementioned network parameters. Pheromones evaporate at a constant rate; complete evaporation implies that a link is no longer active. The overhead traffic generated by long-range ants is composed of a standard 384 bits IPv6 (UDP) packet header, 96 bits ant header (ID, timing) and data payload. The payload contains information of visited nodes and their neighbours. Each visited node contributes 272 bits, plus 192 bits for every neighour.

Short-range Ants monitor the mobility of neighbouring nodes by frequently collecting relevant information. They differ from long-range ants in three aspects, i.e. the ant size, the activity frequency, and their migration behaviour. Their activity range is restricted to 2 hops, effectively leading to the collection of fewer information. This limits the short-range ants size to around 1/9 of the average size of long-range ants, and therefore we can increase their dispatch frequency without incurring too much additional overhead. The migration of short-range ants differs from that of long-range ants in that they leave pheromone trails labeled with their nest IDs, i.e. the dispatching node, to ensure that ants always return to the nest.

Messenger Ants are responsible for enforcing management decisions such as layer switching as instructed by higher-level applications. Messenger ants are in charge of propagating the decisions across the network, i.e. they do not collect information. This means that messenger ants should avoid following the footsteps of others. In this respect, we use a negative pheromone to guide the messenger ants to visit less explored links and nodes.

3.3 Topology Optimisation

Based on parameter information collected by ants, each node periodically optimises its overlay links to other nodes by initiating connections and disconnections and maintaining its neighbours. Each node keeps a local view of the network topology based on the information provided by long-range and short-range ants. This helps nodes to optimise their neighbour sets by comparing properties of the links to their current neighbours to those of other nodes in the local view. Better qualified nodes replace existing neighbours by setting up new overlay links to remote nodes and removing existing links to old neighbours, while additionally ensuring that all neighbours of the requesting node are kept connected. Although any change to a node's neighbour set can eventually be detected by ants, it is more efficient for the node to directly notify its neighbours via a simple message when a new neighbour has been detected. These messages do not flood the whole network and only affect the routing table of direct neighbours. Long-range ants will eventually propagate the change to other nodes.

4 Conclusion and Future Works

We report here the key concepts of our ongoing research work. Currently, the algorithm including the long-range and short-range ants have been implemented, while messenger ants are under development. Initial simulations using OMNeT++ in low dynamicity environments have shown promising results in constructing P2P overlays with desired characteristics and with low overhead. Our future work mainly focuses on three aspects. First, the model of ants needs to be further improved to eliminate any unnecessary information. Second, a better topology optimising algorithm utilising the information collected by all ants and taking into account the different layers is necessary. Last, balancing the performance of the algorithm and its overhead traffic is also an open issue.

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