Thesis work and research project

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1 Thesis work on Distributed algorithms for end-to-end QoS contract negotiation

Deploying critical services (e.g. VPN etc.) over the Internet X-domain topology requires to be able to guarantee *end-to-end QoS*. For this, and to guarantee privacy, *Service Level Agreements (SLAs)*, also called *QoS contracts*, are committed pairwise between domains. If local QoS control issues *inside* on each participating domain can be considered solved, open problems persist in the field of end-to-end QoS provisioning and monitoring for *multi-domain services*. The key factors to be taken into account are the heterogeneity, independence and privacy requirements of the individual domains.

Before establishing a service, a *negotiation* has to occur: it consists in selecting a chain of pair-wise commitments (Fig.1), that satisfies the end-to-end QoS requirements, given that global QoS is subject to cumulation effects: for instance, delays on each domain *sum up* along a path. We use the term of *QoS budget* to reflect how the customer's tolerance (w.r.t to end-to-end delay, jitter, etc.) is *consumed* by the actual services on each component, leaving a reduced margin for the rest of the chain. Once a contract chain is selected by the negotiation, QoS contracts are *reserved* and the service is established. Each domain *monitors* the QoS contract agreed on with its neighbor in the path, and also its local QoS provisioning. If the domain observes repeated contract violations by its neighbor, it can activate a *re-negotiation* process to select another partner in the path and thus changing the sub-path of the contract chain.

So, the problem addressed is to satisfy a QoS budget by a contract chain taking into account *i*) cumulative effect of QoS parameters; *ii*) domain in-

dependence and contract privacy, which forbid any centralized solution, and *iii*) a global cost function; this cost function can capture different optimization criteria (e.g. the sum of contract prices). We address different cost optimization problems under QoS budget constraints. They have been identified as Integer Linear Programming problems and reduce to the general assignment problem, which is NP-Hard. If they can be solved using centralized ILP techniques in principle, domain independence and contract privacy constrain us to design *fully distributed* solutions based on the *Dynamic Programming* (DP) principles. We develop also self-repairing mechanisms in case of negotiation failures and contract violations (re-negotiation).

1.1 Motivation and Context

Pair-wise interconnected domains which constituted the Internet are facing new supervision problems due to these interconnections. Each domain is administrated by an infrastructure, possibly different from its neighbor, and managed independently. In a network of networks where commercial issues exist, confidentiality of supervision information is a key aspect.

Since some years, service provider domains propose services accessible from other domains. Such services concerns often private network access (VPN) or multi-media services (video-conference, voice-over-ip, etc.). These services require an end-to-end guaranteed Quality of Service (QoS) X-domain connection for end-users outside from the domain.

Establishing, guaranteeing, observing or verifying such services is one of the main challenge service providers have to face if they wish to handle their management and production costs along with the satisfaction of a maximum of clients.

The contract approach is a recent solution to guarantee QoS. A contract aggregates different QoS parameters (e.g. delay, bandwidth etc.) on which a provider agreed to ensure a certain threshold corresponding to a numerical value (e.g. delay < 25ms). A contract contains also some juridical information (duration, penalties etc.). The QoS part of a contract corresponds a QoS class defined by the domain for a particular type of service. Therefore, contracts can be called QoS class instances of allocations. QoS classes are associated to a price which is linear to the resource consumptions involved by the allocation of the class.

In order to establish an end-to-end service (between two end points, end-users or servers of the X-domain network), we need also to ensure a required end-to-end QoS, especially since such services are multimedia or VPN related. But, QoS data are available through the QoS classes of the domains

concerned by the service establishment. Note that in the considered X-domain context, we suppose pre-established BGP-like routing tables exist. Such tables provide a main route based on shortest-path but also alternative routes corresponding to 2nd/3rd/etc. shortest paths. In the solution we proposed, we consider most of the time the exploration of the main route.

To treat a request of service establishment, involved domains have to accumulate the different classes which may satisfy the end-to-end required QoS. Due to multi-dimensional (several parameters) QoS class nature, the accumulation of QoS classes in not trivial: for instance the end-to-end delay is a sum whereas the end-to-end error rate is a product. Therefore, we call QoS budget the end-to-end QoS requirement. The term budget underlines the fact that the QoS will be consumed or expended by QoS classes of the domains, thus forming a contract chain.

1.2 Problem statements and approachs

This thesis proposed a new QoS negotiation paradigm consisting in formulating the problem as an optimization problem where we would wish to:

- Obtain the best contract chain, subject to,
- The initial budget requirement, and,
- The local domain capacity of resources.

In a first time, we designed a framework allowing composing and decomposing QoS vectors. QoS vectors represent either QoS classes or budgets. Using this framework, we formulate the negotiation problem of a single request of service establishment. This formulation brought us to propose a distributed Dynamic Programming algorithm: each domain belonging to the route of the request computes sub-budgets from input budgets and local admissible classes, and the prices associated to these sub-budgets. The last domain is therefore able to select the contract chain with the minimal sum of prices.

Then, we considered the problem of optimizing the total set of request appearing a finite number of domains. We proposed a symmetrical distributed Dynamic Programming algorithm. At each service establishment request, the computing of sub-budget phase is performed twice, from the source domain and from the target. Once these phases are both achieved, global QoS constraints are available on each domain: each domain is then

able to solve a local optimization problem, the selection of each domain converging to the global optimum. Thus, this algorithm implies some potential local re-optimizations.

We also designed control concurrency techniques to handle the fact that local re-optimizations on a same chain may not occur simultaneously. Thus, we defined a protocol. In the same idea, we analyzed failure cases of the negotiation process and explained the mechanisms to handle them. We also proposed a solution for re-negotiating a chain in the case of contract violations when a chain is monitored.

Since the algorithm and protocol we proposed could appear to be slow in term of performances, we studied the possibility of designing a mechanism to negotiate " a priori " a set of contract chains. Such a set, called aggregate or pipe, answer also to the demand of a flow management: a domain will wish to have a set of N chains of contracts satisfying a certain end-to-end QoS. This kind of problem is quite close to network flow problems. Thus, we presented a distributed and under constraints version of the Busacker-Gowen algorithm.

Finally, we considered two extensions of the negotiation problem. The first one concerns the exploration of several routes. Therefore, we included some termination detection mechanisms which could be integrated in the negotiation protocol. The second extension is the possibility of a large-scale negotiation. In the considered problems, we required from the domains to be cooperative. But this assumption may not appear realistic in large scale. So, we proposed a view of the large scale system as a set of finite cooperative groups: for a group request coming from the others are assimilated to perturbations.

1.3 Experiments

This thesis was funded by the French National Agency of Research (ANR), SWAN which involved several partners both academics and industrials. The SWAN project studied mechanisms for autonomous self-managed systems.

We developed a negotiation and re-negotiation module in Web Services that was integrated in a platform made by Alcatel. This negotiation module had two versions: one corresponding to the very first problem of one request establishment negotiation and the other to the extension for negotiating several requests. Moreover, we compare our approach to centralized algorithms under a MatLab simulator. The distributed version of the Busacker-Gowen algorithm has also been included in this MatLab simulator.

2 Research project

2.1 Outlook of realized work

My thesis work is highly related to other questions whose issues is major challenge for Internet Service Providers. Self-aware management is indeed a key issue for them to be able to control their own costs beside satisfying customers'requirements.

Negotiation for multi-pipes and self-healing of pipes. The optimization for multiple pipe allocation remain to be fully studied. As the pipe problem can be designed as a network flow problem, the multi-pipe optimization should be related as a multi-flow problem. The re-negotiation and monitoring of pipes remains also an open problem which is different than in the simple chain case due to the particular nature of pipes. If a chain of the pipe is violated, should we re-negotiate the whole pipe, or only a sub-pipe or should we wait to violations on a set of chains belonging to the pipe ? Such questions has to be the object of an advanced studied and reached to the definition of policies.

Politiques de négociation et de re-négociation. Related to the previous point, another outlook concerns the management of the "'margin"'. A service estabmishment request asks for the meeting of QoS requirements. The outcome of the negotiation process may let a margin between the chain of composed contracts and the QoS budget required. This margin may be known by every participants of the chain, as it is the case in the Forward-Backward algorithm we proposed. For other algorithms we would have to think about a process to advertise the margin. On the other hand, the margin could play a significant role in QoS monitoring policies.

QoS learning. The end-to-end QoS learning is a natural outlook of this thesis. Often routing protocols that have been proposed compute shortest path based on one, eventually two QoS criteria. The QoS classes we use consider in the negotiation process are QoS vectors, therefore they aggregate different QoS parameters. We have explain why a routing protocol including end-to-end QoS parameters should not be substituted to the negotiation, unless it becomes a negotiation process in the sense of our paradigm. However, under the assumption of a routing protocol including one or more QoS criteria, the failure and success cases of negotiation would be an interesting source of information to contribuate to the dynamicity of such a routing protocol.

2.2 Other topics

QoS pricing. We mentioned that contracts contain a juridical part which is defined at the instanciation of the classes: penalties, duration, time of service etc. We also assumed that QoS classes are associated to a static price. In the perspective of a micro-economic approach, penalties and QoS pricing should have to be modeled. This approach would be particularly relevant in the context of a full exploration of the domain network where competition between chains would occur. MOreover, proposing an automated process for penalties, in the context of general monitoring policies is major issue for autonomous contract management.

Negotiation in a large-opened scale system, the price of anarchy. One of a hot topic in network management concerns the study of strategies opposing "'cooperative"' set of nodes to "'non-cooperative"' nodes. This discipline, called "'the price of the anarchy"', could have interesting outcomes applied to the negotiation process in a large-scale system. In our study, we assumed teh set of domains is bounded. It would be fussy to try to optimize the contract allocation in an infinite set of domains. Thus, we plan to consider service establishing requests coming from domains outside of a cooperative set, as a perturbation for the cooperative set.

Services Computing Science. The Web Services community is particularly active and is currently considering different hot topics: automated composition of Web Services driven by some criteria, the security of Web Services, the reusability, the controling and monitoring of composed processes etc. Some of these topics are highly related to the self-aware management of networ resources. The negotiation process has been originally designed with the purpose of serving the management of Web Services, using Web Services (negotiation module is implemented in Web Services). As we have seen, this work on negotiation is connected to many outlooks in the self-aware management area. We aim at working on the other management topics in the field of Web Services because in our point of view, they are one the major challenge for Services Computing Science.

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