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Traffic Engineering in Ambient Networks: Challenges and Approaches

Henrik Abrahamsson Anders Gunnar

{henrik,aeg}@sics.se
Swedish Institute of Computer Science
Box 1263, SE-164 29 Kista, Sweden

Abstract

The focus of this paper is on traffic engineering in ambient networks. We describe and categorize different alternatives for making the routing more adaptive to the current traffic situation and discuss the challenges that ambient networks pose on traffic engineering methods. One of the main objectives of traffic engineering is to avoid congestion by controlling and optimising the routing function, or in short, to put the traffic where the capacity is. The main challenge for traffic engineering in ambient networks is to cope with the dynamics of both topology and traffic demands. Mechanisms are needed that can handle traffic load dynamics in scenarios with sudden changes in traffic demand and dynamically distribute traffic to benefit from available resources. Trade-offs between optimality, stability and signaling overhead that are important for traffic engineering methods in the fixed Internet becomes even more critical in a dynamic ambient environment.

1. Introduction

The existing mobile and wireless link layer technologies like WLAN, GSM, 3G, etc, lack a common control plane in order to enable end-users to benefit fully from the offered access connectivity. For instance, operators only grant access to users with whom they have previously signed an agreement. Similarly, there is no technology to automatically and transparently select the best and most cost effective link technology for the end-user. The Ambient Networks project [2] aims to address these issues and to provide an affordable, robust and technology independent communication platform beyond 3G. Ambient networks also support cooperation between operators to handle control functions such as managing mobility, security, and quality of service. The key concept of ambient networks is network composition. Networks establish inter-network agreements on-demand without human interaction. Network composition will provide access to any network instantly anywhere at any time.

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Instant network composition brings new challenges to traffic engineering and monitoring of the network. Traffic engineering encompasses performance evaluation and performance optimization of operational networks. An important goal is to avoid congestion in the network and to make better use of available network resources by adapting the routing to the current traffic situation. More efficient operation of a network means more traffic can be handled with the same resources which enables a more affordable service. As ambient networks compose and decompose the topology and traffic patterns can change rapidly. This means that one can not rely only on long-term network planning and dimensioning that are done when the network is first built. Traffic engineering mechanisms are needed to adapt to changes in topology and traffic demand and dynamically distribute traffic to benefit from available resources.

In this paper we identify and analyse the challenges ambient networks pose to traffic engineering. At this stage, we intend to identify research issues and discuss how we intend to address them. Consequently, we do not aim to provide integrated solutions to the problems identified.

The rest of the paper is organized as follows. In the next section we introduce Ambient Networks. In the following section we give a short introduction to traffic engineering. Section 4 discuss the challenges and research issues for traffic engineering in Ambient Networks. Finally, in the last section we give a short summary and discussion.

2. Ambient Networks

The Ambient Networks project [2], started in 2004, is an integrated project within the EU's 6th Framework Programme. The overall purpose of the project is to build an architecture for mobile communication networks beyond 3G [11]. Ambient networks represents a new networking concept which aims to enable the cooperation of heterogeneous networks belonging to different operators or technology domains.

The basis for communication in Ambient Networks is IP. However, the architecture should overcome the diversity in access network technologies. To be specific, Ambient Networks should support present access technologies as well as enable incremental introduction of new access technologies and services to the communication architecture. Further, the project aims to enable cooperation between operators to handle control functions such as managing mobility, security, and quality of service.

A key concept in ambient networks is network composition. The vision is to allow agreement for cooperation between networks on demand and without the need of preconfiguration or offline negotiation between network operators. The composition should also be rapid enough to handle adaptation to moving networks such as a train with an internal access network passing through an operators network. This instant network composition brings new challenges to network management and traffic engineering in ambient networks [6].

In conventional IP backbone networks the variability both in traffic patterns as well as in topology is small. The network topology only changes if routers or links go up/down or when new links are added to the network. Internet traffic has been shown to have very bursty and self-similar behaviour on short time-scales but if we consider timescales of tens of minutes the variability in traffic basically follow diurnal patterns in a highly predictable manner. In Ambient Networks on the other hand, network topology and traffic patterns is expected to be under constant change as networks compose and de-compose. This is further illustrated in Figure 1. The figure shows variability in traffic patterns along the x-axis and variability in topology along the y-axis. To some extent the characteristics of Ambient Networks overlap the characteristics of conventional IP networks. However, Ambient Networks cover a much broader spectrum of variability in both topology and traffic patterns.

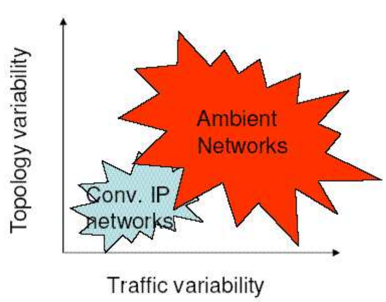

Fig. 1. Characteristics of Ambient Networks compared to conventional IP networks.

In ambient networks we can expect both conditions similar to current IP backbone networking as well as conditions where the topology changes are similar to ad-hoc networks and traffic demands shift due to mobility of networks and network composition. However, this paper is focused on traffic engineering under varying traffic patterns. The behaviour of network topology is considered to be similar to the conditions in conventional IP networks.

3. Traffic Engineering

For a network operator it is important to analyse and tune the performance of the network in order to make the best use of it. The process of performance evaluation and optimization of operational IP-networks is often referred to as traffic engineering. One of the major objectives is to avoid congestion by controlling and optimizing the routing function. The traffic engineering process can be divided in three parts as illustrated in Figure 2. The first step is the collection of necessary information about network state. To be specific, the current traffic situation and network topology. The second step is the optimisation calculations. And finally, the third step is the mapping from optimization to routing parameters. Current routing protocols are designed to be simple and robust rather than to optimize the resource usage. The two most common intra-domain routing protocols today are OSPF (Open Shortest Path First) and IS-IS (Intermediate System to Intermediate System). They are both link-state protocols and the routing decisions are typically based on link costs and a shortest (least-cost) path calculation. While this approach is simple, highly distributed and scalable these protocols do not consider network utilization and do not always make good use of network resources. The traffic is routed on the shortest path through the network even if the shortest path is overloaded and there exist alternative paths. With an extension to the routing protocols like equal-cost multi-path (ECMP) the traffic can be distributed over several paths but the basic problems remain. An underutilized longer path cannot be used and every equal cost path will have an equal share of load.

Fig. 2. The traffi c engineering process.

This section introduces and analyses different approaches to traffic engineering in IP networks. In the next subsection we present a framework to categorize different methods of traffic engineering. This framework is used in the following section to analyse a selection of suggested methods for traffic engineering.

3.1. Classification of Traffic Engineering Methods

A classification of traffic engineering schemes is possible along numerous axis. Our framework is intended to facilitate the analysis and help us identify the requirements for traffic engineering in Ambient Networks.

• **Optimize legacy routing vs novel routing mechanisms**. One approach is to optimize legacy routing protocols. The advantage is easy deployment of the traffic engineering mechanism. However, the disadvantage is the constraints imposed by legacy routing.

• **Centralized vs distributed solutions**. A centralized solution is often simpler and less complex than a distributed, but is more vulnerable than a distributed solution.

• **Local vs global information**. Global information of the current traffic situation enables the traffic engineering mechanism to find a global optimum for the load balancing. The downside is the signaling required to collect the information. In addition, in a dynamic environment, the information quickly becomes obsolete.

• **Off-line vs on-line traffic engineering**. Off-line traffic engineering is intended to support the operator in the management and planning of the network. On-line traffic engineering on the other hand, reacts to a signal from the network and perform some action to remedy the problem.

The taxonomy above is intended to assist us in the analysis of traffic engineering methods in Ambient Networks and should not be regarded as complete. A detailed taxonomy of traffic engineering methods can be found in RFC 3272 [4].

3.2. Previous Work

The general problem of finding the best way to route traffic through a network can be mathematically formulated as a multi-commodity flow (MCF) optimization problem. This has recently been used by several research groups to address traffic engineering problems [1], [7], [10], [12], [14]. In the simplest case the optimization result can be used as just a benchmark when evaluating the performance of the network to see how far from optimal the current routing is. A number of attempts has been made to optimize legacy routing protocols [7], [12], [14]. Fortz *et.al* [7] uses a search heuristic to optimize the OSPF link weights to balance load in a network and the MCF optimization serves as a benchmark for the search heuristic. Similarly, Wang *et.al* attempts to find the optimal link weights for OSPF routing. However, they formulate the problem as a linear program and find the link weights by solving the dual problem. The optimization can also be used as a basis for allocating Label Switch Paths (LSP) in MPLS [10], [5]. A more long-term research goal would be to construct a new multi-path routing protocol based on flow optimization [1]. A somewhat different approach is taken by Sridharan *et.al* [12]. Instead of calculating the link weights the authors use a heuristic to allocate routing prefixes to equal-cost multi-paths. Again the MCF optimization serves as a benchmark for the heuristic.

All global optimization methods require an estimate of the current traffic situation as input to the estimation. The current traffic situation can be succinctly captured in a traffic matrix that has one entry for each origin-to-destination traffic demand. However, the support in routers to measure the traffic matrix is only rudimentary. Instead operators are forced to estimate the traffic matrix from incomplete data. This estimation problem has recently been addressed by many researcher. An evaluation of a wide selection of estimation methods and further references can be found in Gunnar *et.al* [9].

An attempt to localize and distribute the routing decisions is Adaptive Multi-path routing (AMP) [8]. In AMP information on the traffic situation on links is only distributed to the immediate neighbors of each router. Hence, AMP relies on local information in neighboring routers to calculate next hop towards the destination. Andres-Colas *et.al* [3] introduces Multi-Path Routing with Dynamic Variance (MRDV), where load on the next hop towards the destination is included in the selection of next hop towards the destination. In this approach no load information is exchanged between routers. Instead the cost of each path towards the destination is weighted by a variance factor which reflect load on the next hop. Hence, traffic is shifted from heavily loaded links to links with less load. A related approach is introduced by Vutukury *et.al* [13]. Here the routing decision is divided into two steps. First, multiple loop-free paths are established using long term delay information. In the second step the routing parameters along the precomputed paths are adjusted using only local short-term delay information.

4. Challenges for Traffic Engineering in Ambient Networks

The main challenge for traffic engineering in Ambient Networks is to cope with the dynamics of both topology and traffic demands. Mechanisms are needed that can handle traffic load dynamics in scenarios with sudden changes in traffic demand and dynamically distribute traffic to benefit from available resources. As described in section 3.1. , different traffic engineering methods can be categorized by how much network state information they use. This ranges from methods that only use local state information to improve the load-balancing to optimization methods that need global state information in the form of link capacities and a traffic matrix as input. The trade-offs between optimality, stability and signaling overhead are crucial for traffic engineering methods in the fixed Internet and it is even more critical in a dynamic ambient environment.

The traffic engineering problem can best be modeled as a multi-commodity flow optimisation problem. This type of optimisation techniques take as input global information about the network state (i.e., traffic demands and link capacities) and can calculate the global optimal solution. In practice though, there might be several reasons why we need to deviate from the optimal use of the network. This could be because the calculations are too resource consuming and take too long time. It could also be because the input needed is hard to measure and collect and that it varies too much over time so it would create too much signaling overhead or create instabilities.

MCF optimisation problems easily becomes large with tens of thousands of variables and constraints. But it is possible to calculate the global optimal solution in tens of seconds even for large networks [1] if no constraints are given on the number of paths that can be used. Finding the optimal set of weights in OSPF though usually has to rely on heuristic methods.

One can argue that, if it is important to make the best possible use of network resources then the routing should not be restricted to what can be achieved by tuning the weights in the legacy routing protocols. Instead, the optimisation should come first and the result should be implemented using new routing mechanisms if needed. On the other hand, the study by Fortz *et.al* [7] shows that in practice the solutions that can be achieved by proper weight settings in OSPF are close to the optimal at least for the networks they investigated.

Multi-commodity flow optimization as well as heuristic methods for setting optimal weights in OSPF are both typical examples of centralised schemes that use global information in the form of topology and traffic matrix and produce global optimum routing or at least results that are good for the network as a whole. The problems with this type of solution is measuring the traffic demands that are needed as input and the signaling overhead created when collecting this data. A centralised solution also creates a possible bottleneck and a single point of failure. Further, in a dynamic environment the traffic data quickly becomes obsolete. If the routing decisions are based on the wrong input we may create congestion that would not be there if just shortest-path routing had been used. This sensitivity to the traffic dynamics of course holds for all types of load-sensitive routing.

Examples of other schemes that uses global information about both the topology and the traffic situation but takes local decisions (and so avoids some of the problems with a centralised solution) is different kinds of QoS-routing schemes. Here information about for instance delay or load on each link in the network is flooded to all nodes. Each node then makes shortest-path (or least-cost) calculations in this metric. Each node chooses the best paths through the network from its own perspective but the decisions are all local decisions without consideration of the network as a whole. So care must be taken with this type of mechanism to avoid hot-spots where everybody moves traffic to underutilised links and route flapping were nodes constantly shift load back and forth.

Another possibility would be to only use local information when taking local decisions and so avoid all the signaling overhead [3]. If we can assume that the topology is much more constant than the traffic load then we can use global information about the topology i.e using legacy protocols like OSPF to calculate the connectivity (shortest paths) and use only local information about the traffic situation to balance the load in the network. This is an interesting approach in a dynamic environment such as ambient networks, with sudden changes in traffic demand. For instance in a scenario with a moving network such as a train with an internal access network passing through an operators network. Instead of flooding the network with load information and wait for a new routing to be calculated a node can make local decisions and adapt to the situation. A node that experiences a sudden increase in traffic demand can directly shift load from heavily loaded links to underutilised paths. The drawback of this is of course that the consequences of the local decisions for the network as a whole are difficult to grasp. Care must be taken so that local improvements don't create overload somewhere else in the network. So, a careful evaluation of this type of mechanism is needed.

There are different timescales for traffic engineering. An interesting approach would be if global information reflecting the traffic situation in a coarser and longer time perspective could be used to make a tentative routing calculation for the whole network. And let the nodes fine-tune the routing parameters with respect to local information in the nodes or information gained from the immediate vicinity of respective node. But this is a topic for further study.

5. Summary

This paper identifies the requirements and challenges for traffic engineering in a dynamic environment. We give a short introduction to the Ambient Networks project which aims to provide a novel mobile communication platform beyond 3G. Further, a framework for classification of traffic engineering methods is introduced to facilitate the analysis and identification of challenges for traffic engineering in Ambient Networks. This framework is used to discuss the properties a traffic engineering scheme must hold in order to meet the requirements of Ambient Networks.

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References

[1] H. Abrahamsson, J. Alonso, B. Ahlgren, A. Andersson, and P. Kreuger. A Multi Path Routing Algorithm for IP Networks Based on Flow Optimisation. In *Proceedings of QofIS 2002*, pages 135–144, Zürich, Switzerland, Oct 2002.

[2] WWI-AN Ambient Networks Project WWW Server. http://www.ambient-networks.org.

[3] J. Andres-Colas, F. J. Ramon-Salguero, A. Molins-Jimenez, and J. Enriquez-Gabeiras. Multipath Routing with Dynamic Variance. COST 279 Technical Report TD02043, Telefonica Investigación y Desarrollo, 2002.

[4] D. Awduche, A. Chiu, A. Elwalid, I. Widjaja, and X. Xiao. Overview and principles of Internet Traffic Engineering. Internet RFC 3272, May 2002.

[5] D. Awduche, J. Malcolm, J. Agogbua, M. O'Dell, and J. McManus. Requirements for Traffic Engineering Over MPLS. Internet RFC 2702, September 1999.

[6] M. Brunner, A. Galis, L. Cheng, J. Andrés Colás, B. Ahlgren, A. Gunnar, H. Abrahamsson, R. Szabo, S. Csaba, J. Nielsen, A. Gonzalez Prieto, R. Stadler, and G. Molnar. Ambient Networks Management Challenges and Approaches. In *IEEE MATA 2004 1st International Workshop on Mobility Aware Technologies and Applications*, Florianopolis, Brazil, October 2004.

[7] B. Fortz and M. Thorup. Internet Traffic Engineering by Optimizing OSPF Weights. In *Proceedings IEEE INFOCOM 2000*, pages 519–528, Israel, March 2000.

[8] I. Gojmerac, T. Ziegler, and P. Reichel. Adaptive Multipath Routing Based on Local Distribution of Link Load Information. In *Proceedings of QofIS 2003*, pages 122–131, Stockholm, Sweden, Oct 2003.

[9] A. Gunnar, M. Johansson, and T. Telkamp. Traffic Matrix Estimation on a Large IP Backbone - a Comparison on Real Data. In *Proc. ACM Internet Measurement Conference*, Taormina, Sicily, Italy, October 2004.

[10] D. Mitra and K. G. Ramakrishnan. A Case Study of Multiservice, Multipriority Traffic Engineering Design for Data Networks. In *Proceedings of Globecom'99*, Brazil, 1999.

[11] N. Niebert, A. Schieder, H. Abramowicz, G. Malmgren, J. Sachs, U. Horn, C. Prehofer, and H. Karl. Ambient Networks: An Architecture for Communication Networks Beyond 3G. *IEEE Wireless Communications*, 11(2):14–22, April 2004.

[12] A. Sridharan, R. Guerin, and C. Diot. Achieving Near-Optimal Traffic Engineering Solutions for Current OSPF/IS-IS Networks. In *Proceedings of IEEE INFOCOM 2003*, San Francisco, USA, mars 2003.

[13] S. Vutukury and J.J. Garcia-Luna-Aceves. A Simple Approximation to Minimum Delay Routing. In *Proceedings of ACM SIGCOMM'99*, Cambridge, Massachusetts, September 1999.

[14] Y. Wang, Z. Wang, and L. Zhang. Internet Traffic Engineering without Full Mesh Overlaying. In *Proceedings of IEEE INFOCOM 2001*, Anchorage, Alaska, 2001.