Load and Capacity Simulation for Design of Combined Wired and Wireless LAN

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Abstract

This paper examines different aspects of and approaches to capacity analysis of combined (wired/wireless) local area networks. First, different approaches to load estimation are examined. Then, capacity analyses of the considered network can be carried out based on the gained information. This paper addresses methods on the basis of queueing theory and event-driven simulation. The presented methods are integrated in the CANDY network design environment.

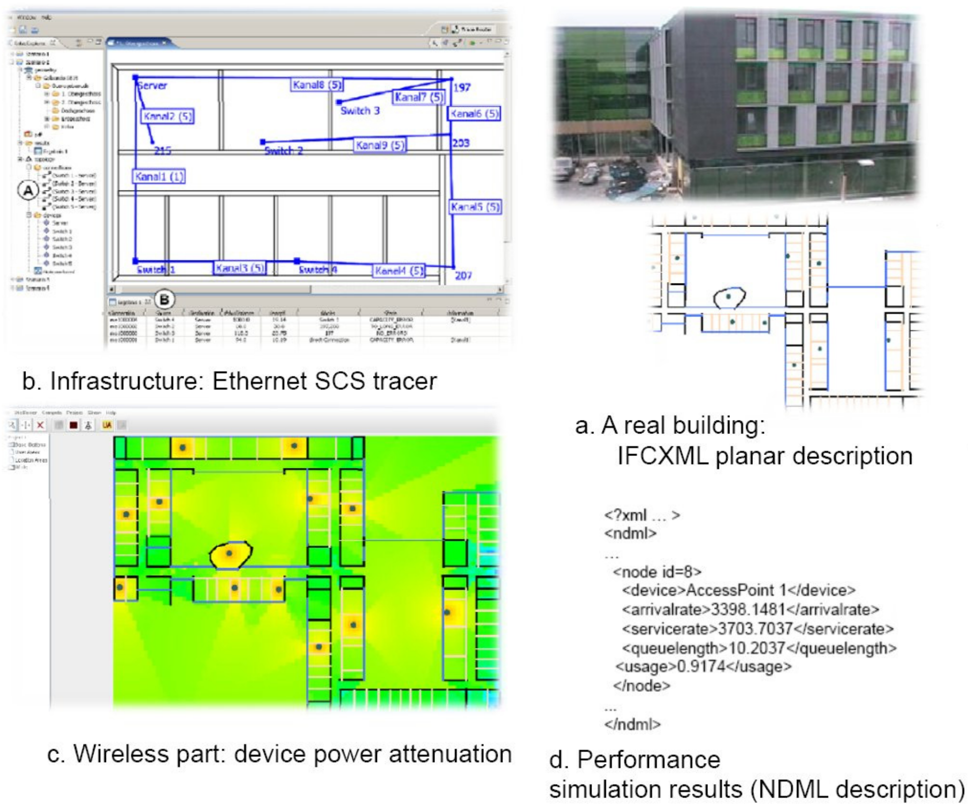

Fig. 1. A real building and CANDY workflow

1. INTRODUCTION

Among questions of topology and technology, the design of large local area networks always involves the problem of dimensioning of the network. Throughput requirements are difficult to estimate in advance. False estimation will either lead to oversizing or undersizing of the network. While the first can be seen as investment into the future, the second is a more serious problem, as business will be spoiled by shortages in network traffic. To ensure adequate dimensioning of the network, two steps have to be carried out:

- appropriate estimation of the network traffic that is to be expected
- Application of the traffic values to a model of the planned network, in order to find out if the design will suffice the requirements.

Both sub-tasks are addressed within this paper.

This work was conducted in scope of the CANDY (computer aided network design utility) project at Dresden University of Technology. The project aims at development of a Java/XML-based integrated environment that supports the process of network design and automates involved routine tasks. CANDY supports combined wired/wireless networks consisting of:

- 802.3 Ethernet,
- 802.11 WLAN and
- 802.16 WiMAX.

Fig. 1 depicts a sample scenario and the use of appropriate CANDY tools for planning of the data network of the building. Chart a) shows a photograph and a part of the ground plan of the building. CANDY supports import of geometry data from the widely-used IFCXML format. In b) the CANDY Trace Router is employed for planning of the infrastructure network. The Trace Router computes the cabling of a network taking into account different aspects like allowed cable lengths, capacity of cable ducts and sparing material usage. Chart c) depicts the use of CANDY Site Finder for WLAN access point optimization. The Site Finder offers various empirical/semi-empirical and ray optical radio propagation models to obtain data on characteristics of wireless networks, like coverage and available data rates. Chart d) illustrates capacity analysis of the network using the CANDY Queueing Tool. Other available tools include graphical topology input and cost calculation.

The rest of this paper is organized as follows: Section 2 describes the overall approach to capacity modeling of computer networks that was adopted for CANDY. Section 3 presents methods to gain information on load requirements of the network. Section 4 describes network modeling based on queueing theory and section 5 is dedicated to network simulation using the NS-2 network simulator. Section 6 concludes the paper by summarizing the results and giving an outlook to future work.

2. OVERALL PROCESS OF CAPACITY ANALYSIS

The task of capacity analysis of a planned, not yet existing computer network requires as a first step the acquirement of data regarding the expected network loads. This can be accomplished in different ways:

- Adoption of load measurements from existing networks
- Estimation

The first approach provides accurate data. But load measurements are costly, and the gained results have to be analyzed and adjusted thoroughly to ensure their appropriateness for the planed network. So often load estimations are more practicable. Two such procedures based on load questionnaires are presented in the next section. Resulting from the load estimation load values a_i will be known for each network node or network link i. These values can be related to the capacity of the node/link, resulting in three cases:

1. $a_i << c_i$. The required loads are by order of magnitude smaller then the capacity of the resource. In this case the planned network surely will suffice the requirements and no further examinations are necessary.
2. $a_i \approx> c_i$. The required loads are close to or exceed the available network capacity. A redesign of the network is necessary in order to avoid decreases of network performance.
3. $a_i < c_i$. For all other cases, further investigations on the capacity of the planned network are necessary. Appropriate methods could be queueing analysis or simulation.

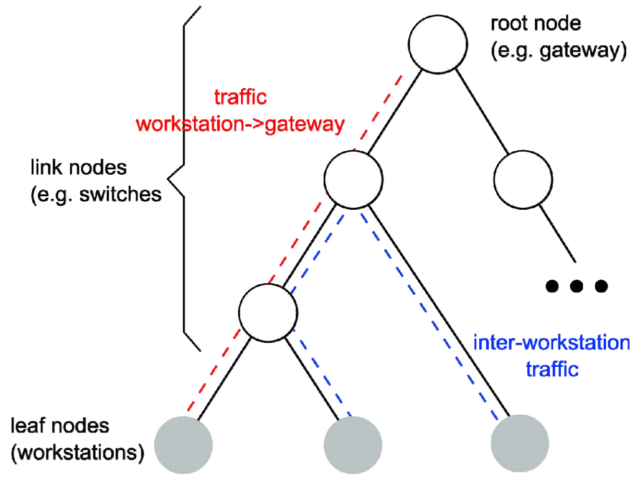

Fig. 2. Tree representation of a network

3. TRAFFIC ESTIMATION

Appropriate traffic estimation is a precondition to realistic network capacity planning. Various approaches to this topic have been proposed in an area of conflict between the demands for analytical tractability and close matching of reality. This section presents the approaches to this topic that are used within the CANDY project.

As the different methods present different characteristics regarding complexity, general parameters and level of abstraction, at first a classification of possible network scenarios is conducted, in order to be able to recommend appropriate methods (compare Figure 2):

Class 1 networks:

- LAN with potentially high number of nodes ($n \approx 100$) to be considered
- The traffic between workstations and a central gateway/proxy server/file server is dominant, traffic among the workstations can be neglected
- The network is strictly based on principles of structured cabling (SCS)

Class 2 networks:

- LAN with limited number of nodes ($n<=30$) to consider
- Arbitrary traffic patterns (including traffic among the workstations themselves)

3.1. Estimation based on load questionnaire

In [1] a method to obtain load values based on a load questionnaire – so called Expert emphasis method - was presented. The method assumed a SCS-compliant, i.e. tree-shaped network structure and captured traffic from workstations, i.e. a subset of the leaf-nodes of the network tree, to the gateway or a central server, which is the root of the network tree. First, each leaf node was assigned a load profile based on the results of a load questionnaire. In a second step, load data was aggregated along the edges of the network tree. Only static load values were considered, the analytical complexity of the method is O(N). This method mainly is applicable for network scenarios described as class 1 in the beginning of this section.

This method was extended in order to model dynamic loads and arbitrary communication patterns. Therefore, traffic is evaluated on a per-hour base. For each workstation, idle periods can be specified. Then, each workstation can be assigned an arbitrary number of network services. For each service, destination node, intensity of usage and times with peak loads are specified. Fig. 3 shows an example of the corresponding load questionnaire. The results from the load questionnaire are interpreted in order to adjust data from reference measurements for each service to the actual situation. The following evaluation scheme is applied:

- The assumed average traffic for a network service is based on reference measurements that are weighted by the given usage intensity
- during idle hours no traffic is generated
- during peak hours, the traffic evaluates to average traffic times a factor, that is parameter of the model
- two hours before/after peak hours network traffic increases/decreases linearly from/to average traffic
- for the remaining time, average traffic is assumed.

The traffic amounts are added up for all services on a workstation.

As next step, traffic on network links and internal nodes (switches, hubs etc.) is calculated by employing a backtracking algorithm. This results in a traffic matrix specifying the total traffic requirement between each pair of nodes of the network:

$$T = \begin{pmatrix} 0 & t_{12} & \cdots & t_{1m} \\ t_{21} & 0 & \cdots & t_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ t_{m1} & t_{m2} & \cdots & 0 \end{pmatrix} \qquad (1)$$

with m=n+o and n being the number of leaf nodes and o being the number of internal nodes of the network.

The presented method has an analytical complexity of $O(N^2)$ and is applicable for network scenarios of the afore-defined class 2.

3.2. MAP-2 traffic model

Currently a statistical approach to load estimation is evaluated for usability within CANDY. The method was presented in [2] and is based on Markovian Arrival processes. The problem of traffic estimation is divided into two sub-problems: First, a series of traffic matrices M_t is determined that show the expected network traffic at points in time T_t,t=1..T. Usually these traffic values result from

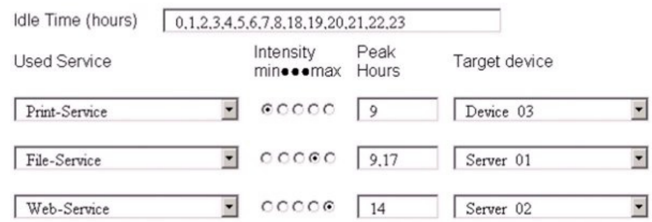

Fig. 3. Load questionnaire for dynamic loads

reference measurements. In a second step a Markovian Arrival Process of order two (MAP-2) is used to model the counting process that is formed by the series of traffic matrices.

A MAP-2 process is uniquely characterized by six parameters:

1. Mean arrival rate - E[N(t)],
2. Index of dispersion for counts - I(t),
3. Limiting index of dispersion for counts - $I(\infty)$,
4. Squared coefficient of variation of the counts – c^2,
5. Covariance of the counts in intervals (0,t] and (t,2t] – C(t) and
6. Third moment of the counts - $\mu_3(t)$.

By using six parameters (instead of e.g. only one parameter for a Poisson process) a better representation of characteristics of real network traffic is possible (e.g. burstiness).

In [2] closed-form expressions for all six parameters are given, resulting in a non-linear system of equations. To obtain the parameters for the MAP-2 model, the six parameters are evaluated based on the measured data. Then a minimization problem is solved, trying to minimize the difference between the characteristics based on the measurement and the analytical expressions:

$$\sum_{i=1}^{6}[F_i(P) - C_i]^2 \longrightarrow MIN \qquad (2)$$

Details can be found in [2]. As this model was specified for highly aggregated traffic in backbone networks, currently we investigate, if it can be employed usefully in LAN or campus size scenarios, too.

4. QUEUEING ANALYSIS

[1] presented methods for performance analyses for CSMA/CD and CSMA/CA based on queueing theory. The models were based on M/M/1 queueing systems, which are popular due to their simple mathematics. Investigations during the past years have shown that the Poisson distribution captures characteristics of real network traffic only inadequately. This especially pertains to properties like burstiness and self-similarity [3].

If the traffic generated by a network application (e.g. SCP) is examined on the transport layer, the inter-arrival times i_n between individual TCP segments are not adequately characterized by the Poisson distribution, since the individual segments are not independent from each other. One file transfer usually consists of a series of TCP segments. Looking on the transfer on the application layer, the inter-arrival times t_n between single jobs can be modeled by the Poisson distribution, since the file transfers are independent from each other (See Fig. 4). Currently we investigate models on higher layers in order to be able to make use of simple models (M/M/1 queueing systems) without making improper assumptions.

5. SIMULATION WITH NS-2

The second approach taken within the CANDY project to perform capacity analyses of computer networks is the integration of simulation software. There exists an interface to the popular ns-2 simulator (see [4]), other efforts aim on integration of Omnet++ ([5]).

Within CANDY, the modeled network is described using NDML (Network Design Markup Language), a XML-based problem-oriented language. Concept and design of NDML were described in [6] and [7]. Ns-2 uses the oTcl scripting language to describe simulation scenarios. Therefore, a conversion between NDML and oTCL is needed in order to tie ns-2 to CANDY. This is done using XSLT. This approach results in two advantages. Firstly, the project data that was acquired for previous design steps can be used directly. On the other hand, the need for creating the oTcl file manually is eliminated. oTcl is a quite simple language, nevertheless the creation of a ns-2 simulation scenario can be complex and time-consuming. Figure 5 depicts the overall procedure. The tracefiles produced by ns-2 simulation can be evaluated in different ways, e.g. by visualization using xgraph or numerical evaluation using Excel.

In order to be able to run ns-2 simulations for complex network scenarios, it is planned to run ns-2 on high-performance computers, using Web Service architecture as interface for data transfer.

6. CONCLUSION

Different aspects and problems of load and capacity analysis for computer networks in the phase of computer design were investigated in this paper. Certain scenarios of combined wired-wireless LAN are discussed and an example of real building network design support is presented. Further investigations will be conducted in the field of traffic estimation/modeling and adequate modeling of LANs by queueing systems.

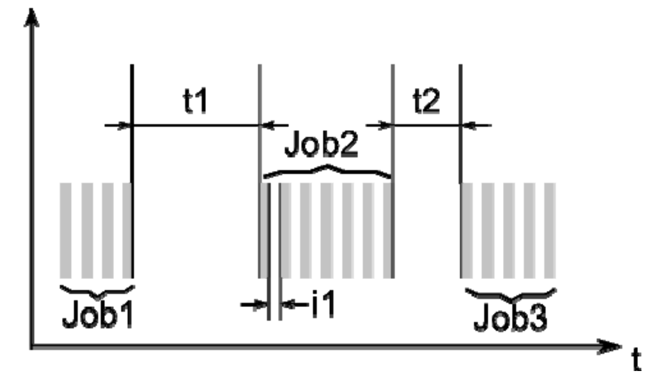

Fig. 4. TCP stream for a application (e.g. SCP)

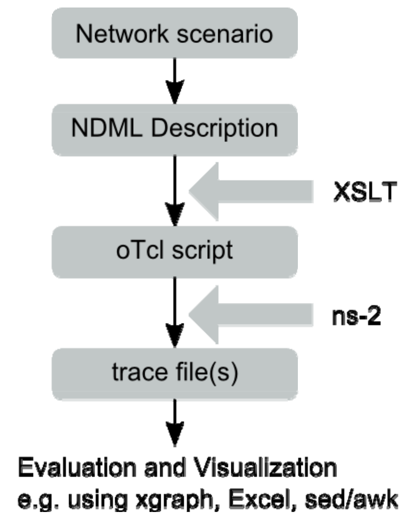

Fig. 5. Network simulation using ns-2

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