OPERATIONS RESEARCH IN TELECOMMUNICATIONS – WHY AND HOW?

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Abstract: *Advances in the operations research methods led to the adoption of optimization techniques in a variety of industrial sectors; however each of these possesses unique properties requiring customization of operations research methodology. In this paper selected aspects of the application of operations research methods in telecommunications (TC) are presented. The key unique properties of TC system: namely,, the system complexity (TC systems are very complex), properties of the traffic (TC traffic is not Poisson like but self-similar) and traffic control mechanisms (specifics like packet dropping);are being described. A general methodology of complex TC system optimization is given. The paper is concluded by a brief discussion on selected practical issues of the application of operations research methods in TC systems.*

Keywords: *Operations research, optimization, telecommunication, simulation*

1. Introduction

Practical optimization is playing an increasingly important role in the disciplines of engineering, computer science, and their many applications in industry [1]. Optimization modeling and solution techniques have seen sustained developments for many decades. Among the first optimization applications were optimal scheduling of industrial procedures, road and train traffic management and optimal distributions of commerce products [2].

After Second World War the complexity of transport and communication systems reached the level that could not be managed by human experts any more. A subfield of discrete mathematics and computer science called operations research (in USA) or operational research (in Europe) emerged dealing with discrete optimization tasks formulations, computer algorithms required to solve those tasks and the underlying theory of algorithms and their complexities. Abstract representations of optimization problems based on graph theory [3] have been developed. The classification of algorithms and complex relations among became a rich field of theoretical and applied research. Different aspects of optimality regarding effectiveness, energy saving, quality of services etc. were studied. Advances in this area, combined with the availability of ever increasing computer power led to the adoption of operations research techniques in a variety of industrial sectors, including finance, manufacturing and supply chain management, energy and utilities, environmental planning and telecommunications.

In telecommunications systems there is clearly a tradeoff between engineering and quality of service (QoS) requirements on one hand and the business objective of maximizing resource utilization on the other. Several aspects of QoS can be directly related to objective functions of optimization problems. By allowing operators to "do more with less," i.e., satisfy more customer demand with existing capacity, optimization is an important tool for improving the profit margins of service providers. Depending on the network technologies and the protocols used, this tradeoff has important consequences on the way networks are engineered and made more profitable. Traffic engineering, virtual circuit design, adaptive network configuration and optimal load balancing are just a few examples where optimization applications can produce significant business benefits.

In the early stages of development of operations research, the typical applications of operations research methods were developed for logistic problems. We are all familiar with congested roads, so it is obviously important to have a general understanding what is causing the pattern of the traffic flow through a system. Closely related issues arise also in telecommunication systems like the telephone network or the Internet. At first glance, the structure of telecommunication systems closely resembles the road traffic system where communication channels represent roads, network devices (switches, routers) represent junctions and packets (Ethernet or IP) represent vehicles. Therefore it seems like a straightforward application of logistic-oriented operations research methods (e.g. optimization of routing and scheduling, queuing and others [3]) for solving telecommunication optimization problems should be possible. . However, there are at least three essential differences among telecommunication systems and modern logistic systems:

- Differences in the system complexity ;
- Differences in the statistical properties of the traffic; and
- Differences in the traffic control mechanisms.

In this paper the mentioned differences will be discussed and the influence on the optimization methodology will be presented. For example the system complexity brings the unavoidable need for using simulations instead of a real world telecommunication system at least in some stages of optimization. The structure of the paper is therefore as follows. In Section 2 the mentioned differences are further refined. A typical optimization methodology that fits to the unique properties of telecommunication systems is given in Section 3. The discussion is presented in Section 4 followed by conclusions in Section 5.

2. Unique properties of the telecommunications systems

It was already mentioned that there exist some unique properties of telecommunications systems which influence the operations research methodology and design of operations research experiments in telecommunications. In this section an overview and the discussion of these properties are given. The list is by no means complete, in fact only the properties having the largest impact on the optimization methodology are presented.

2.1. The complexity of the system

Certain aspects of TC systems are by orders of magnitude more complex than, for instance those found in road traffic systems. The complexity of TC system is caused by several different reasons. Among others, it is caused by the hierarchical structure of traffic transmission mechanisms being realized in several protocol stack layers. This is further enhanced by the complexity of applied communication and coding standards together with the encoded data and the unimaginable capacities of modern TC hardware (communication links, storage capacities, processing power of nodes etc.). Furthermore these by itself complex subsystems are interconnected in a distributed architecture without a centralized control point. . The enormous variety of different TC services and the unpredictable behavior of their users also contribute to the overall complexity. Despite the fact that the road vehicles are driven by humans and are as such very difficult to model, the behavior of TC system users seems to be even less predictable and as such represents a significant part of TC system modeling as will be discussed in the next subsection.

2.2. Statistical properties of the traffic

As it was already mentioned the behavior of modern TC system users has a direct impact on basic statistical properties of the resulting traffic and this specific information on telecommunication traffic can be used in optimization of TC systems. This is due to the fact that the optimality of system configuration such as length of queues is dependent on the traffic specifics. Since the TC traffic is a realization of a stochastic process, the measured values cannot be used directly to guide the optimal configuration. Therefore, we have to model the traffic and then use time invariant features of model parameters.

Statistical modeling of classic and telecommunication traffic has a long and interesting history. The well known Poisson model applies well to road traffic and to classic telephone call requests. Prior to the discovery of self-similar traffic this model has also been used in packet data networks simulations. In the classic Poisson model the probability of k occurrences of a given event in a time interval of the length t equals to $P[k] = \frac{\lambda t^k}{k!} e^{-\lambda t}$, where λ is the intensity of the process. The average number of events in time t equals to λt and the probability distribution of times between successive occurrences is exponential, i.e. $P[T_1 > t] = e^{-\lambda t}$, where T_1 is the time of the first event occurrence. Event occurrences are considered to be independent. .

In the last decade the research community realized that the Poisson model does not adequately model the modern packet networks traffic. For example internet traffic significantly violates certain properties of the Poisson model and possesses the property of self-similarity [5].

As already mentioned, the measurement of a real traffic is seen as a realization of the discrete stochastic process. A realization of discrete process is denoted by $x[\xi$], where ξ is an elementary event and its value is at the time $k \in T$ is denoted by $X[\xi$, k]. The aggregation of the stochastic process (traffic) is simply a process of block by block averages. For every $m = 1, 2, 3, \ldots$ the aggregation $X^{(m)}[k]$ of order m is given by

$$X^{(m)}[k] = \frac{1}{m}(X[km - m + 1] + \cdots + X[km]), \qquad k = 1, 2, 3, \ldots \quad (1)$$

.

It turns out that the aggregations of higher orders of the Poisson process are getting smoother and the aggregation of the self similar process does not, at least over several aggregations. This is the most crucial distinction between the two traffic types. This phenomenon is depicted in Figure 1.

The left side of Figure 1 shows five levels of aggregation of self similar traffic from bottom up and as can be seen it is not getting smoother. The right side shows aggregation of Poisson traffic which does get smoother. Basic differences arise also in statistical modeling of both types of the traffic. In particular, the heavy tailed distribution of occurrence times of self similar traffic (also called long range dependency, LRD) requires new statistical models. The presence of self similarity is statistically tested using Hurst parameter theory [8]. The level of self similarity is also measured by a Hurst parameter. The most frequently used statistical models for self-similar parameters are Fractional ARIMA (FARIMA) [9] and Fractal Gaussian noise (FGN) [10].

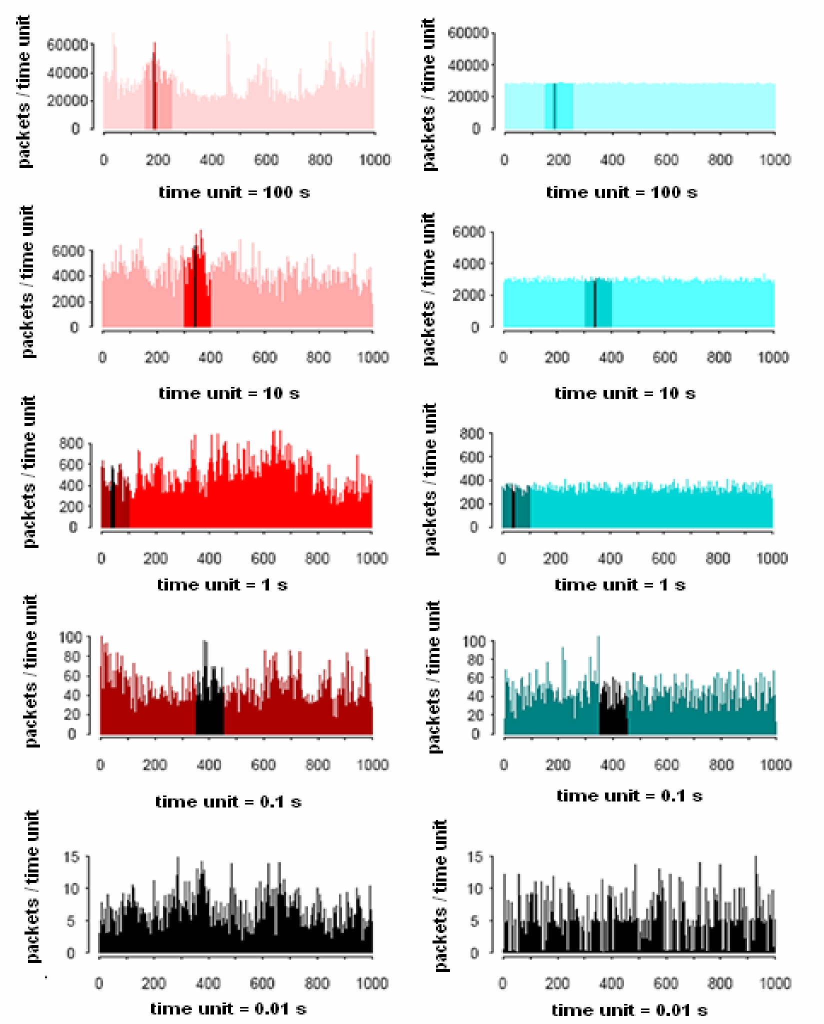

Figure 1. *The aggregation of self-similar (left) and Poisson like traffic (right). Reproduced from [5].*

2.3. Traffic control mechanisms

There are several mechanisms the telecommunication traffic undergoes during its journey from the source through the complex TC network to the destination. It is important to point out that in modern networks there are several parallel mechanisms in action at the same time. For instance, in general the IP packet is transported in the form of several Ethernet packets and several traffic control mechanisms are applied in its way such as queuing and scheduling. These mechanisms and their complex interaction are different from those found in road traffic systems. For example consider the packet dropping mechanism. To avoid buffer overflows on a given TC node the dropping mechanism drops the selected packets. Obviously, no such mechanism as vehicle dropping can be found in the logistic systems. In case of the TCP-based applications the dropping mechanism brings further complexity into the system. It is well known that TCP sources wait for the acknowledgements of successfully transmitted packets. In case some of the packets are dropped, no such acknowledgements are received and the packets are retransmitted. This simple mechanism clearly brings the feedback loop into the system and therefore brings a new level of system complexity. . .

3. The structure of optimization in telecommunications

There exist different approaches and methodologies of TC systems optimization. The choice depends on the optimization goal (such as traffic shaping, routing, scheduling etc.), the regime of optimization (offline, real time), the optimization procedure used etc.

Optimization techniques based on mathematical programming (such as linear and integer programming) are nowadays widely accepted as a decision support tool in telecommunications market. To construct such decision support applications a fast and flexible way of formulation and adaptation of optimization problems is needed. Regarding industrial optimization problems understanding the problem itself and the limitations presented by the available data is often a bigger obstacle than building and solving the resulting mathematical model. Therefore rapid prototyping of mathematical models, quick integration of data, and a fast way to check whether the approach is getting to be feasible is required.

According to the theoretical and practical experience, the optimization task usually consists of several cycles, each being composed of 1) optimization problem formulation, 2) algorithm based solution and 3) implementation of the solution in real network. The iterative approach is needed since in many cases the implementation of the estimated optimal solution in real network is simply not possible due to hardware, software of human related restrictions. Nevertheless these “unsuccessful” intermediary trials of implementation are not worthless; since they influence our decision upon how to modify the optimization problem (i.e. how to modify and supplement a set of constraint equations and modify the objective function) in order to obtain a feasible solution.

The most time consuming and error prone task in the described iterative methodology represents the verification of the applicability of optimal solution in real world environment (i.e. feasibility test). It is important to note that the optimization task formulation always represents an approximation to the real telecommunication system. The well configured simulator is much closer, but still not equivalent to the real system. Theoretically the best way of applicability verification would be by performing tests upon a real telecommunication system, however in practice this is very difficult to achieve. Therefore, the most obvious feasibility testing involves telecommunication systems simulators. The use of a network simulator such as OPNET, ns-2 or ns-3 provides a significant improvement (in terms of time and human resources) in the optimization research cycle. This makes the operations research methods appropriate (in terms of cost-benefit ratio) even for solving large scale telecommunication problems.

A simplified description of a single iteration in the optimization task is given in a form of an UML activity diagram in Figure 1. A summary of each individual subtask in the diagram is given below.

(i.) The first step in the optimization procedure represents a detailed analysis of the telecommunication system. The optimization goal is identified first. The description of network topology, hardware components, network protocol stack, services, and user scenarios and, typically, the identification of a large number of constraints follow.

(ii.) Based on the system analysis the optimization task is formulated. This includes optimization space description, objective function definition and a formal constraints set presentation. Optimization space is typically a set of vectors whose components (coordinates) represent the configuration parameters of a real world telecommunication system. The objective function represents one or more optimization objectives such as waiting times, resource costs, etc. This function is a non negative real function on the optimization space, typically a linear combination of parameters contained in a configuration vector. The constraints set represents all limitations originating from network protocol stack, hardware and software configuration and other factors (human related, project management and legal issues related etc.) influencing the optimization solution.

(iii.) An exact formulation of optimization task achieved in the previous step represents the main source of information needed to choose appropriate optimization algorithm. Other factors influencing this decision exist, such as computational complexity of the algorithm, the availability of appropriate data format translators etc.

(iv.) Solution implementation, the next step in the iteration, represents an attempt to use the obtained results of optimization algorithm in real world telecommunications system. Typically it turns out that the estimated solution can simply not be implemented for a variety of reasons. The solution implementation therefore represents a feasibility verification of the proposed optimal solution given by the optimization algorithm. As already explained the solution implementation on real telecommunication system is the best approach in terms of verification accuracy, however it is usually not possible due to experimental resources (time, budget etc.) limitations. The implementation on network simulators instead on real telecommunication systems is considered satisfactory in the majority of optimization problems. Other important reason for using network simulator is to verify the stability of the system when the optimal solution is applied and, after all, if the impact on the selected efficiency measures (only partially represented with optimization objective function) is desirable.

(v.) In a final step of the process a decision whether to continue with iteration is made. In practice, even if the solution is not entirely feasible, the attempt to solve the optimization problem provides an important insight into the operations mechanisms of the telecommunication system. With this knowledge a partial implementation of the proposed solution is usually possible. The first step of the verification is finding feasible solutions of the formulated optimization problem, which is the feasibility according to the formal optimization task (a set of constraints can be such that there is no feasible solution regardless to the objective function). The next step is a verification of feasibility using a network simulator. The last one is the implementation in real world environment being the most time consuming procedure and at the same time, the strictest regarding real feasibility of the proposed solution. When a non feasible solution is found at any of the listed three steps, the only way out is modify and supplement the set of constraints and objective function. This is the reason why the activity diagram flow returns back to step (ii.).

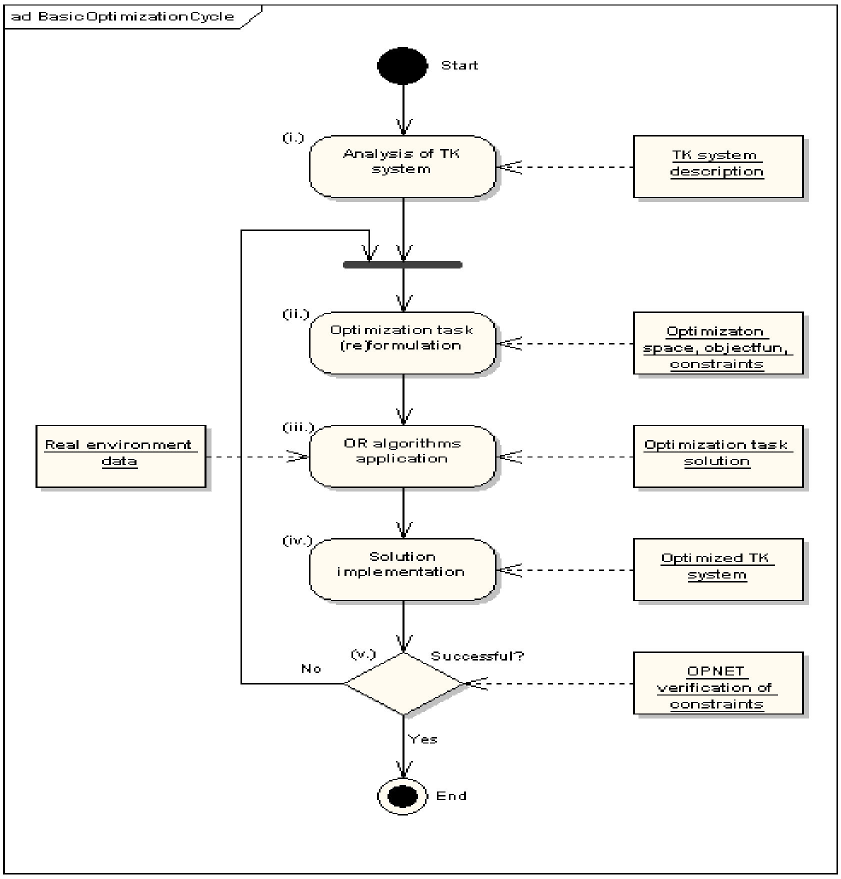

Figure 2. *Basic optimization cycle*

4. Discussion

There are several issues to be considered regarding the application of optimization techniques in TC systems. The feasibility of optimization results in practice, credibility of statistical models of the traffic and proximity of simulation results to real world system are considered to be the most critical and are discussed one by one as follows.

Feasibility of optimization results in practice must be considered, since the implementation of optimization results in real world environment is not always possible. Usually this can be overcome by the re-formulation of the optimization task. But there are other factors that influence the ability of the implementation, such as the trust of TC system maintenance personnel and the impact of the recommended changes to human relations in the system maintenance working group. Clearly, the simulated results can never cover all real world scenarios that the system can undergo. New scenarios can prove the solution to be non-optimal or even harmful in terms of system stability.

Credibility of statistical models of traffic should be evaluated in order to assess the optimization credibility. According to the stochastic nature of the internet traffic [5], the only way to capture invariant features of the traffic is to use the adequate statistical model. Models for self-similar traffic are Hurst parameter [8], FARIMA model [9] and FGN [10]. Even when a good model fit to the captured data can be assured, the time invariance (stability through time) of model parameters cannot be guaranteed. Among others, the reason for these can be unexpected events in the complex TC system. Since model parameters are to be applied in system optimization, large deviations from their true values can again cause non-optimality of the solution or even instability of the system.

Proximity of simulation results to real world system should be considered too**.** Some network simulators such as OPNET [6] have reached an extraordinary proximity to real network systems since they include software of real products. Nevertheless, the complexity of real systems (also in terms of user with at least in part unpredictable behavior) can bring up unexpected situations. Therefore, the application of conclusions made upon simulated results in a real world must always be questioned and adequate verification of selected scenarios must be performed.

5. Conclusion

An introduction of application of operations research techniques and methods is given in the paper. Selected specifics of telecommunication systems in terms of optimization comparing to logistic systems optimized by the same methods are given. These are the large complexity of TC systems, non-Poisson properties of TC traffic and specific mechanisms implemented to control the TC traffic. The structure of optimization adequate for TC systems is proposed and detailed. In particular, the need for using network simulators is pointed out. Further work, among other tasks, includes formulation of several optimization tasks utilizing statistical traffic modeling and building simulation models to verify the feasibility of optimization results in practice. As a consequence, a real world verification of optimization results and simulation studies for each optimization task is planned to be provided.

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OPERACIONA ISTRAŽIVANJA U TELEKOMUNIKACIJAMA – ZAŠTO I KAKO

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