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Training network administrators in a game-like environment ☆

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ABSTRACT

Management and automated configuration of large-scale networks is one of the crucial issues for Internet Service Providers (ISPs). Since incorrect configurations may lead to loss of an enormous amount of customer traffic, highly experienced network administrators are typically the ones who are trusted for the management and configuration of a running ISP network. In this paper, we present an online management and experimentation system with a "game" interface to train network administrators and explore what-if scenarios without having to risk the large-scale network operation. The interactive environment treats the trainee network administrators as players of a game and tests them with various failures or dynamics for real-time management and configuration of large-scale networks. To prototype the concept of "network management as a game", we modified NS-2 to establish an interactive simulation engine and connected the modified engine to a graphical user interface for traffic animation and interactivity with the player. We also conducted two user experiments using different learning methods and observed sizable improvement in the capabilities of trainees on the problem of interior gateway protocol link weight setting.

1. Introduction

Online management of a running large-scale network poses many challenges that have attracted significant research. Due to the significant costs and risks (Srinagesh, 1997) of building and operating a large-scale ISP network, the challenges in managing the network resources are exacerbated (Kerravala, 2004) because the margin for error or inefficiency is slim (Enck et al., 2009; Oppenheimer et al., 2003). Today, critical applications such as VoIP, IPTV and financial markets migrating onto the Internet infrastructure, and thus making the job of provisioning high-performance network services an even more important one. From the technical side, emergence of various substrate networking technologies like 3G wireless and mesh networking is complicating the management tasks to the extent that network operators give up on optimizing their networks' configuration and barely cope with handling default configuration settings of tremendous number of components involved.

Quick and effective response to system dynamics like failures and demand spikes is a key problem in network operation. Link or node failures are not rare events for a large-scale network of thousands of devices. Even though most network components have pre-installed backups (e.g., backup links implemented using MPLS (Rosen et al., 2001)), multiple failures or major failures/events on critical links or nodes need fast and effective response. A significant portion of the cost associated with such unwanted network dynamics pertains to the detection of the event. Though standards like SNMP (Presuhn et al., 2002) have been in place for many years, swift and low-cost collection of network management data for event detection becomes tedious for larger networks (Habib et al., 2004). Yet a more significant portion of network event handling goes to the time needed to figure out how to respond, which is mostly done manually in current practice. Seeking the optimal response is mostly impractical, but even settling on a "good" response is very hard as well (Ye et al., 2008a).

Highly experienced human administrators are of critical importance as they are typically the only ones who can quickly find the optimum (or close-to-optimum) response to a major failure, e.g., finding an optimum rerouting for a large volume of traffic on a broken pipe. Answers to these questions for an online operational network necessitate meta-tools so that the network administrator can learn and characterize the network.

Good characterization and modeling calls for well-planned design of experiments on the system-at-hand. However, such experiment design on a network quickly becomes prohibitive as the number of parameters increases, also known as "curse of dimensionality"

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(Tenebaum et al., 2000; Törn and Žilinskas, 1989). Thus, there is a need for heuristic optimization algorithms to search for the minimal number of experiments that reveal the most information about the system-at-hand. In order to characterize and understand the system-at-hand well enough and manage it efficiently, there is a heavy need for meta-tools that facilitate experimentation and training capability without harming the real system. The need for such meta-tools that perform efficient experiment design is emphasized when the fact that the system-at-hand is an operational network and the cost of each experiment can be quite high.

Although there have been several tools and outcomes (Ye et al., 2008b) to automate the process of large-scale network management, network operators have found themselves more comfortable with trusting highly experienced administrators. Those well-trained administrators are of critical importance as they are typically the only ones who can quickly find the optimum (or close-to-optimum) response to a major failure, e.g., finding a reroute for a large volume of traffic on a broken pipe (Anderson and Anderson, 2003). However, the complexity of the management and configuration problem is increasing due to the growing heterogeneity in substrate technologies as well as more stringent performance targets demanded by applications (Sun et al., 2012; Benson et al., 2009). Trends in cross-layer design (Srivastava and Motani, 2005) of protocols and integration of various network components are certainly helping the overall performance; however, such methods typically complicate the configuration due to additional parameters they introduce. Thus, tools to train administrators and achieve automated management of a running network are vitally needed.

In this paper, we propose the concept of "network management game" (NMG) that frames the problem of training network administrators in exploring what-if scenarios as a "game". *The NMG aims to establish a game-like environment for trainee administrators to experiment and play with the networks. Such a "game" will enable trainee network administrators to explore what-if scenarios, without having to risk the large-scale network operation – in a way similar to what Flight Simulator provides to trainee pilots.*

Achieving higher utilizations via better load balancing (also known as traffic engineering) is one of the main management problems for network operators. Many algorithms and tools are developed to find optimal or close-to-optimal solutions for high network utilization; however, they may not be completely relied upon for handling extreme cases or large scale failures. A common implication of load balancing for network administrators is to configure interior gateway protocol (IGP) link weights so that shortest paths give result to a well-balanced traffic load on network links. Several prior studies employed advanced optimization techniques to set the IGP link weights for a given topology and traffic matrix to improve various network performance metrics such as delay, throughput, or congestion (Ye et al., 2008b; Gonen et al., 2010; Fortz, 2000; Akyildiz et al., 2014).

In this paper, we apply our network management game (NMG) framework to the problem of IGP link weight setting. We modified the simulator NS-2 and built an animator that interacts with it in real time. The player interfaces with the animator and inputs new IGP link weights as new configurations. The animator, then, conveys these new configurations to the simulation engine. We present screen snapshots of our NMG prototype while it is running and results of user experiments.

2. Related work

Currently, most of the basic training for a network administrator is performed by means of well-defined certification procedures (Cisco Certifications). The administrators receive months of education to obtain these certifications to prove that they have the basic skills and knowledge about configuring and administering a network. However, custom skills related to maximizing performance of a particular operational network cannot be attained via generic certifications. Such custom skills require long training in work environment where the certified trainee can learn what to do in action from her peers with more experience on that particular network.

Customized training of network administrators involves what-if analysis (Mate), which is done by in-house tools according to two backbone carriers we have contacted. What-if analysis is a brainstorming activity that uses extensive questioning to guess potential failures and issues in a system, and ensure that appropriate precautions are taken against those problems. For a network, it typically involves a comparison of the network's current performance and "would-be" performance under certain scenarios such as some particular links/nodes fail, and a traffic spike occurs or a new pipe is installed between two points. Network managers regularly use such analysis to quantify robustness or riskiness of the network at hand, in order to answer questions like "Is my network robust enough for potential failures?" or "Where should I put more capacity in my network?". Investment decisions, planning and dimensioning on a network are heavily guided by technical what-if analysis. Businesses often use the scenario manager tool of Excel to explore different scenarios such as the decision making process in e-commerce (Bhargava et al., 1997). Although what-if analysis has high impact within business intelligence platforms, its usage is extended for several purposes such as hazard analysis (Baybutt, 2003), index selection for relational databases (Chaudhuri and Narasayya, 1998), and multi-tier systems (Chen et al, 2009). For instance, in Tariq et al (2008), the authors developed a tool (WISE) that predicts how a deployment of a new server to an existing CDN affects service response time. They use machine learning techniques to process old dataset and discover the dependencies among system variables. Then, using these dependencies and new dataset which is representative of new deployment, WISE predicts how response time could be affected when deployment changes are done.

Furthermore, various tools have been developed to guide investments and determine how to improve network performance (Mate) with minimal investments. Though existing what-if analysis tools help a network administrator and a strategic director make an informed decision about future investments, they cannot train for dynamic events such as demand spikes or failures. A key difference in our approach is the capability of simulating the interactivity and dynamism that might take place in an operational network.

The concept of using a virtualized game-like environment for training is not new (Chatham, 2007; Nicolescu et al., 2007). It has been actively used for cases where experimentation with the real system is too costly or risky. Military training involves a lot of such practices, e.g. pilot training (Wikipedia), commander training (Serious Games by BreakAway). Financial investment training (The Stock Market Game) is another venue where a game-like environment can be used for training before deploying money on stock market. To our knowledge, using a game for training network administrators was not tried before.

Simulation for training is widely used in many areas including pilot training, computer games, mock markets for businesses (Carmen, 2013), learning nursing (Berragan, 2014), and statistics simulation (Novak, 2014). Carmen (2013) claims that simulations help overcome the major obstacle to the effectiveness of classroom-based training in which the context is different from day-to-day work context. Based on the experience of people on different areas (e.g., pilot training, computer games, and businesses), simulations serve to compress and speed up the learning experience at a fraction of cost and risk. Moreover, simulations serve as a more enjoyable learning activity in comparison to reading a textbook, listening to a lecture, or being part of a team work (Berragan, 2014).