Mass Configuration of Network Devices in Industrial Environments

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***Abstract*—Industrial Ethernet offers greater flexibility and potentially lower deployment costs than traditional fieldbuses. Although similar, the configuration and engineering of these networks need considerable effort. This paper presents the lessons learned from an approach to bulk configuration of an Ethernet infrastructure for industrial applications. The paper presents different approaches and decisions taken for the proof of concept implementation. The paper gives an overview about the issues related to representation and generation of configuration data, support of multiple vendors in the engineering phase and also during operation. An outlook for possible improvements and promising features is given.**

***Index Terms*—industrial Ethernet; infrastructure; switch; configuration; life cycle; multi vendor**

I. Introduction

A modern industrial communication system contains a considerable amount of nodes interconnected with Ethernet and current trends point towards moving the Ethernet connectivity down to instrument level. Having an all-Ethernet infrastructure offers several advantages over traditional fieldbus-based or Ethernet-fieldbus mixed networks. These include simpler deployment by using the same connectors and wires over the whole network, ample bandwidth, wide range of communication hardware and easy connectivity towards office networks or the internet.

One of the main drawbacks is a result of the inherently different network topology compared to office environments. In industry, the bus-like structure has proven to reduce costs with cutting cabling need. In these scenarios, the backbone is usually composed as a ring and the devices, subnetworks or other devices are connected to this with small switches (up to approx. 10 ports).

As the networks are built with mainly these small switches, the whole installation typically contains a magnitude more devices than a comparable office network (e.g.¨a bigger refinery can have several hundreds). During engineering and Factory Acceptance Test (FAT), the effort of configuring these devices is high and severely influences the competetiveness. In the majority of cases, the actual configuration of the devices can be described with setting port-VLAN allocations, RSTP priorities, SNMP parameters and performance monitoring. These steps currently require manual work, which is incresing cost during engineering and also leads to increased resource usage during FAT as configuration errors may happen.

The use of small switches in addition results in issues associated with e.g. Quality of Service (QoS) and management.

A. Topology

A key area, where industrial networks do differ considerably from their office counterparts is the topology used. In an office environment the network is structured to resemble an equalized tree as much as possible. Also, high port density switches are used to lower the hierarchy levels in the network.

The industrial environment, as stated earlier, resembles more a bus-like topology. Ring-based redundancy solutions [4], traditional planning and cabling cost both force network engineering towards the use of rings as backbone and small switches to connect the few nodes which are located close.

Ring structures are beneficial for redundancy, but are problematic for traffic engineering. These rings aggregate traffic and force longer paths in the network than in a comparable office counterpart.

B. Network segmentation

The traffic aggregation of rings do cause other issues too, especially if multi- or broadcast traffic is involved. In a typical installation, several industrial protocols are in use. In order to reach a more stable network and avoid that nodes are receiving unnecessary traffic, these networks are often segmented into several Virtual LANs (VLANs).

C. Configuration and Maintenance

Current industry practice builds on a detailed network drawing and unit-to-unit configuration of the network devices as part of the deployment. Here in most cases the built-in web configuration solutions of the different vendors are used, although some provide their tools for own product lines e.g. Hirschmann HiVision or Cisco Network Assistant, which support configuration of multiple units.

From the engineering viewpoint, setting up these devices one-by-one is a great risk, as the chance of human error is high. This risk is mitigated with additional resources, meaning more work hours to check the actual setup [5].

From maintenance viewpoint, this situation is even worse. Most installations have a long life expectancy and therefore future maintenance engineers will either face 10-15 year old web interfaces if they have to modify something or the the problems associated with replacing the old device and migrating the configuration to a new one.

II. Motivation

The motivation behind this work was to reduce engineering costs and to explore possible solutions for provider-independent configuration representation and setup of multiple devices at the same time [6], [7]. The potential cost reduction in the engineering phase is expected to reach 20-25% of the total cost, not counting the life cycle support.

The review of a project portfolio revealed that in most installations 2-3 vendors are involved in supplying network infrastructure based on various preferences. Although the planning of the network is done independently from the actual manufacturers, the configuration and acceptance checks do depend on per vendor knowledge and tools.

The expected result of the research task was in addition to explore possible solutions, to create a proof-of-concept tool, which can compose, deploy and modify configuration of one or multiple Ethernet switches in the same work session.

In long-term, the vision of a common configuration and management tool was defined, where planning, configuration, as-planned checking, monitoring and life cycle management was provided. Such a tool could offer a common interface to plan a network with defining the segmentation and port distribution (this covers the current network drawing step), generate configuration for the devices (which is done typically by engineers), deploy and then through discovery, check that the network has the same structure as planned (for example the VLANs are set up correctly). During operation, the tool could read out the current configuration from a device and upload it to a replacement unit, even if these are from different manufacturers.

III. Background

To explore configuration possibilities, remote configuration features of selected product lines were reviewed:

- *RuggedCom RS9xx* [2]: This switch line supports configuration update using a builtin Trivial FTP (TFTP) client or server, depending on requirements. In addition, Secure Copy (SCP), terminal with Command Line Interface (CLI) and Simple Network Management Protocol (SNMP) is supported for file and configuration manipulation. As all of the reviewed managed switches, this unit offers a web interface. A vendor-specific tool for monitoring is available[1].
- *Hirschmann RSRxx* [1]: This switch line offers a TFTP Client, CLI access through telnet or the web interface, a java-based web interface, SCP file transfers and a proprietary Automatic Configuration Adapter. This adapter, if physically connected to the device, uploads or downloads configuration enabling easy replacement from the same vendor.
- *Moxa EDS-508* [3]: Has TFTP server and client, CLI, SCP transfers and offers a web interface. A proprietary Auto-Backup Configurator is offered for backup and restore, allowing easy replacement from the same vendor.

[1]RuggedNMS

The research also showed that SNMP is supported on all units, although the features were focused on monitoring and not on configuration.

The review showed considerable differences between web interface structures and the available options. The differences were big enough to limit reuse of configuration knowledge and proved to support the initial assumption about cost reduction potential.

Configuration data was accessible on all devices as structured text files, which were human readable and could be a base for the configuration tool design. In figure 1, the expected coverage of a configuration tool is shown. The objective was to allow up- and downloading, manipulation and storage of configuration information.

A. Multiple unit configuration

One of the most important features was to check the feasibility of configuring multiple units in the same time and to explore the possible issues.

As part of the planning, a feature set was identified, which were set the same on all devices or could be calculated automatically. An example is the selection of the Rapid Spanning Tree (RSTP) root bridge.

Other questions were risen in connection with the long paths and rings used in these networks. It was assumed, that depending on the behavior of the devices, the configuration might need to be topology aware.

The user interface was also a crucial point, as the objective was to reduce engineering cost, which pointed towards a simpler interface then most of the switches offered. This request was supported by, that only a handful of features needed to be set and most of the parameters were left at factory defaults.

IV. Proof-of-Concept

The implementation was focused on a subset of the possible features. Based on feedback from engineering, configuration of multiple devices and support of multiple vendors were selected as key features, which should be supported by a simple user interface. In figures 2 and 3, the test user interface is shown for single- and multi-unit mode.

The planned system was designed to cover tasks associated with configuration and deployment stages of the engineering process. To ensure that options, which are not being used by the system are preserved, the tool only replaces relevant parts of the original configuration files with new data (figure 4).

A. Requirements

- vendor independent, simple user interface
- remote configuration of one or multiple devices
- life cycle support with configuration versioning and cloning
- configure selected features

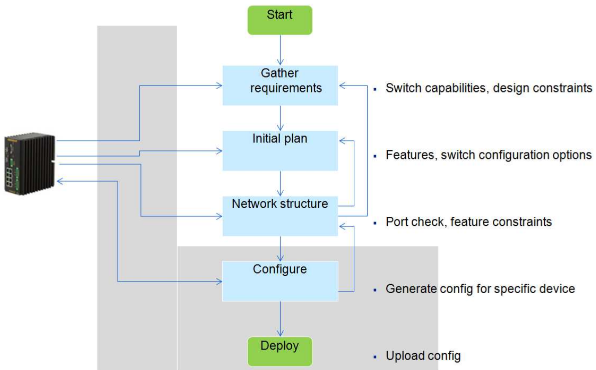

Fig. 1. Proof of concept coverage

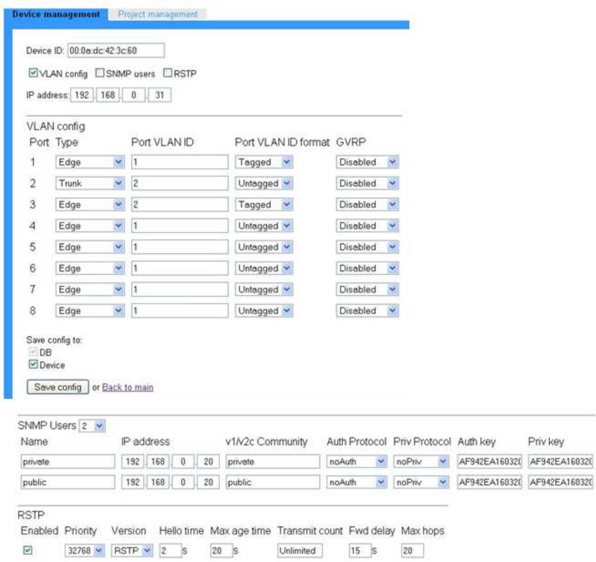

Fig. 2. Single unit configuration

B. Features

A subset of available features on the switches was selected based on experiences from engineering. This set was planned to cover most of the engineering needs without resulting in a complex interface.

The feature set was defined for both single and multi mode as:

- *Host IP*: to be able to set the device's IP
- *Port-based VLAN*: allow the setup of per-port VLANs
- *SNMP setup*: configure SNMP access rights and community memberships
- *Spanning Tree*: select STP protocol and allow changes in bridge priority

To support documentation, an automatic network documentation generator function was also included.

A single unit configuration section was included for practical purposes and served also as a testbed for checking the configuration generation capabilities.

The system was designed so that it would preserve changes

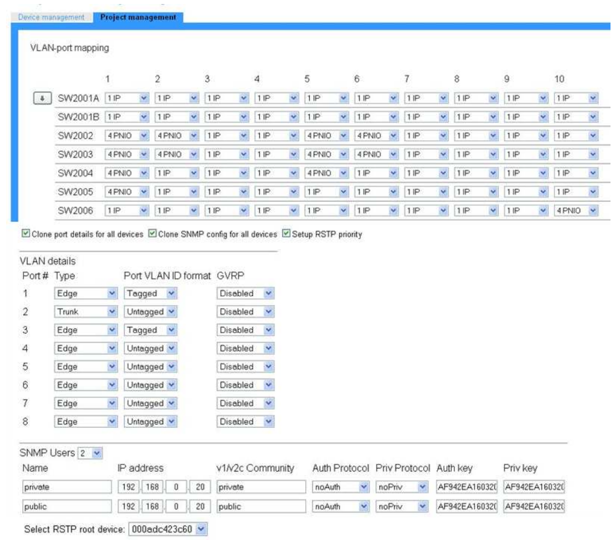

Fig. 3. Multiple unit configuration

made outside the configuration tool (thus allowing device specific configuration for features not covered by the tool), so the composition of the configuration data was implemented in a way, that it is only changing the relevant part and keeps the rest of the data untouched.

C. Multiple vendor support

Enabling support for multiple vendors has risen several issues, which were not foreseen. Even if all the switches covered were complying the same IEEE standards, the actual implementation and availability of features depends on the vendor.

As a result, a vendor independent representation of the configuration data was needed and the configuration generation process had to be split into storage, representation and actual configuration data.

D. Multiple device support

Configuring multiple devices in one session was considered as the most important feature, as this would result in the highest cost cut. Covering multiple devices also meant, that the difference between the per unit web interfaces and the configuration tool might be the most emphasized.

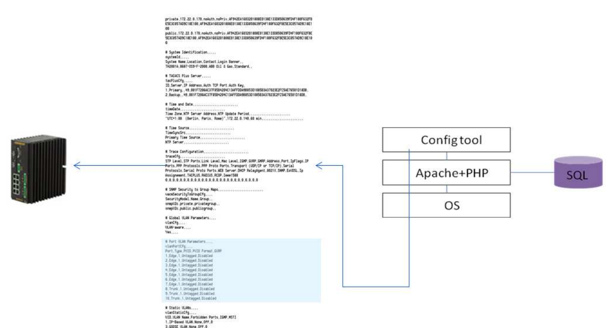

Fig. 4. Composition of the configuration

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For the IP configuration and VLAN settings, a matrix of switches and VLANs was generated. This offers a single-screen overview of a typical network in the evaluated projects. The drawback of this representation is, that if a large number of ports and switches are used, the size of the matrix is getting large. This limitation was found acceptable in this case, as in a typical industrial environment low port count switches are used, so adding more switches will result in a longer matrix, but the width will stay limited.

The tool offers cloning of the port and SNMP settings to all devices and setting the root RSTP bridge.

E. Connectivity

The review of connectivity methods has shown, that it is problematic to choose one specific solution. Even in case of just the three product lines reviewed, different protocols turned out to be easier to use.

For the proof of concept, for one vendor (RuggedCom) TFTP was chosen for up- and downloading configuration data. For the other vendor (Hirschmann), CLI-based configuration and telnet. While being aware, that none of these protocols provide secure transfers, this requirement was relaxed for the current version. This decision was supported by that the tool is intended to be used during engineering, where these networks operate as isolated islands.

V. Lessons learned

There are several important issues which were identified during the evaluation and development of the configuration tool.

A. Vendor independent configuration data

In order to support multiple vendors, the configuration data needs to be stored in an independent format. Generation of the appropriate configuration file or script depends on the vendor's implementation and there might be considerable differences.

Changes between vendors in most of the cases results in information loss about the configuration of the device. An example is the support of vendor specific spanning tree protocols. The use of these proprietary protocols is beneficial if the network is homogenous, but might cause problems if multiple vendors are present. If the original configuration was set up e.g. to use RuggedCom's eRSTP and the device is replaced with an other manufacturer's switch, the configuration tool has to fall back on e.g. RSTP, as that is the nearest standard protocol which is supported by the new device.

If later the device is changed back (e.g. a device needed to be taken out from the network and was temporarly replaced by an other), if the configuration storage depends on the vendor, then only RSTP will be used even if eRSTP is available, as the migration process will only create a representation of the current configuration in the new device.

B. Topology-awareness

An interesting issue with configuration was raised while the tests of the multiple unit configuration were executed. In single unit mode, were no problems, the configuration was updated, the device was reset and after some seconds, network operation was restored. The same happened if multiple units were configured in an office-like topology (equalized tree), where only a few levels of switches were involved and the longest path was 3-4 hops. In case of industry-typical rings, anomalies and connectivity errors happened.

The investigation showed, that while the update operation itself is done in a fraction of a second and it takes approximately 2-3 seconds for a device to reset, this was too short to update all members of the ring. In the tree topology, the devices were updated before the first unit decided to reset. In the ring, however, these resets happened before all members were updated. The result was that the network was falling into fractions and in some cases one had to approach each *lost* device separately.

As a result, it was identified, that it would be beneficial if in case of multiple unit configuration, the update would be done with respect to the topology, starting from the leaves and progressing upwards in the tree. The same approach can be used in rings, as these will be represented as a long unbalanced tree (in normal operation RSTP is disabling the redundant link to avoid a loop).

C. Identical configurations

Although the switches used in this work were not the most complex units available, it turned out to be a complicated task to reach exactly the same configuration on devices from different vendors.

A typical example is the configuration of a trunk port. In one case, this option was available directly on the webinterface and in the configuration file, but on a different switch at least 6 commands in the CLI were required.

An other example is the above mentioned case of RSTP. In practice, all major vendors have their own enhancements to RSTP to achieve better convergence times. This also means, that these proprietary solutions can only used on homogenous fractions of the network. If a device is replaced by a device from a different vendor can result in weaker performance, as all the units have to fall back on the first standard solution, which in most cases will be RSTP.

VI. Future work

Future work will focus on topology awareness to mitigate the restart anomalies. By having a representation of the network, also as planned checks could be executed and discovery of previously unknown networks can be enabled. This functionality extends the usage area of the tool towards the network management systems.

Security is an important topic and for the current stage of the work, no emphasis was put on this field. While some possible threats were identified, currently leaving a device open for remote configuration does in most cases result in vulnerabilities. A possible area of research here is how to provide an easy to use interface while having a detailed logging system and secure connections to the devices with respect to the limited possibilities.

VII. Conclusion

The background research of this paper has shown, that there is a considerable potential to cut costs in network engineering if appropriate tools are available. Although network management software are available and widely used in office environments, their resource need and cost render them unrealistic for industrial deployment.

The paper has shown a proof of concept implementation of a configuration tool, which can partially automate the setup of Ethernet switches. The main difference compared to proprietary solutions is, that this tool supports multiple vendors and with a vendor independent representation of configuration data, also allows future extensions.

Testing of the tool revealed several issues associated with device configuration, especially related to problems caused by the topology and the complexity of generating identical configurations for switches from different vendors.

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