EVALUATING DEVICE MANAGEMENT CAPABILITIES IN LARGE SCALE AMR INSTALLATIONS USING EVIDENTIAL REASONING

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ABSTRACT

This paper presents a framework for evaluating Device Management functionality for AMR systems. The underlying idea is that AMR systems can be evaluated against this framework in order to identify areas in need of improvement. The framework has two components; first it proposes a simplified modelling, or breakdown, of the concept of Device Management of AMR systems into a set of sub-properties important from a device management perspective. Second it consists of an evaluation algorithm, based on extended evidential reasoning statistics derived from Dempster-Shafer, which is a development of Bayesian reasoning. The paper presents the background in the area of device management in general. It then goes on to describe the breakdown of device management into sub-components, and gives a background to the evaluation algorithm. Finally, the paper is concluded with a description of an application of the algorithm on two large scale AMR installations at a utility in Sweden.

INTRODUCTION

Large scale Automatic Meter Reading (AMR) systems are becoming the standard in Sweden due to legislation requiring monthly reading of customer's meters. The utilities in Sweden are currently implementing AMR-systems including new meters, communications infrastructure and central systems.

This effort requires a significant amount of resources, especially in terms of field crews that replace meters at customer premises making the costs for the projects high. Once installed, the plan is that the meters will remain in place at the customer's premises for at least 15 years, mainly because the cost of replacing them is prohibitively high. Eventually the utility will be operating a large scale communications network with intelligent terminals that will require management in line with that of a traditional communications network provider such as an Internet Service Provider or a telecommunications operator or a Telco. One specific challenge in management of this infrastructure is that of managing the meters themselves in terms of keeping track of configuration, upgrades and patches as well as their revision history. It is imperative that all changes and updates in the meters can be done remotely in order to avoid costly visits on site at thousands of meters.

DEVICE MANAGEMENT

Device Management is, for the purpose of the study presented in this paper, defined as *The act, manner or practice of managing; handling, supervising, or controlling a large number simplified machines intended to perform relatively simple tasks* In this case the simple task is metering of energy consumption.

In order to describe what needs to be "managed" in device management consider the following user scenario: An AMR system where several meters have been reported to measure incorrect values. After an in depth investigation the problem is narrowed down to a specific version of the firmware of the meters in question. The task at hand now is to identify the effected subset of meters, and patch up the glitch. This problem is in effect a network configuration management problem.

Consider now that the affected subset of meters has been identified and is in need of a patch. At this point there is a need to have the possibility to remotely update the software of the meters as well as the ability to keep track of which changes are being made to what meters. This problem is similar to the configuration management problem faced by software developers as well as network managers. Device management is therefore related to network configuration management as well as software configuration management.

Network Configuration Management

Network management is a set of processes designed to maintain, secure and monitor a data network, these processes are supported by management systems. There are five main function groups within *Network management: Fault Management, Configuration Management, Security Management, Performance Management* and *Accounting Management* [4]. Of particular interest here is Configuration Management which is the process of register keeping of all network devices connected to the network. An effective configuration management tool can help a network manager to maintain up to date records of all devices connected to the data network, hardware revisions and firmware versions, etc. This enables simple identification when an upgrade is necessary.

Software Configuration Management

According to [1] and [8] a Software Configuration Management system consists of the functionality listed in

- **Construction**
  - Building
  - Snapshots
  - Optimization
  - Change impact analysis
  - Regeneration
- **Structure**
  - System model
  - Interfaces
  - Relationships
  - Selection
  - Consistency
- **Components**
  - Versions
  - Configurations
  - Baselines
  - Project context
  - Repository
  - Types of components
- **Controlling**
  - Access control
  - Change requests
  - Bug tracking
  - Change propagation
  - Partitioning
- **Accounting**
  - Statistics
  - Status
  - Reports
- **Auditing**
  - History
  - Traceability
  - Logging

Figure 1 A listing of functionality in typical Configuration management systems, compiled from [1] and [8]

For the study in question, the evaluation framework has been built on the topics identified in the above mentioned sources and others.

THE FRAMEWORK IN REVIEW

This section describes the framework for evidential reasoning used for assessing for example device management in AMR systems. In general, the framework offers improved support to decision-makers when evaluating qualitative aspects, of information systems. A similar application of the framework is described in [5]. When assessing a heterogeneous property, such as device management capabilities of a system a common approach is to:

1. Decompose the property into operational properties that can be measured,
2. Attempt to answer the operational properties; and
3. Aggregate the values of the operational properties according to some scheme.

This method appears intuitively straightforward but does however still pose a number of challenges in each step.

Decomposing Device Management

The framework we are proposing in this paper follows the above basic flow. First, for property breakdown, we propose the use of Architecture Theory Diagrams (ATD). ATDs are composed of nodes, which represent properties, and arcs, which represent relations. The use of ATDs for this type of analysis has been presented in [1]. An ATD consists of a set of layers

$$P = \{P_0 \quad P_1 \quad \dots \quad P_\lambda \quad \dots \quad P_\Lambda\}$$

Each layer contains a set of properties

$$P_\lambda = \{p_{\lambda,1} \quad p_{\lambda,2} \quad \dots \quad p_{\lambda,l} \quad \dots \quad p_{\lambda,L_\lambda}\}$$

where $P_0 = \{p_{0,1}\}$ is the singleton abstract property, in our case Device Management capabilities, and

$$P_\Lambda = \{p_{\Lambda,1} \quad p_{\Lambda,2} \quad \dots \quad p_{\Lambda,i} \quad \dots \quad p_{\Lambda,L_\Lambda}\}$$

constitute the operational properties. An example of such an operational property is to verify whether a remote connection to a device is possible or not. We further assume that the properties can assume values on a graded evaluation scale. The set of evaluation grades is defined by $\varepsilon = \{\varepsilon_1 \quad \varepsilon_2 \cdots \quad \varepsilon_n \quad \cdots \quad \varepsilon_N\}$. In this study, ε_1 denotes *poor*, ε_2 denotes *average*, and ε_3 *good* device management capabilities.

Collecting data and representing credibility

One of the most problematic issues with assessing information system properties is the effort required to collect data about the system. It is expensive to search for and document information and it is very common that the collected information is incomplete and partially incorrect. From a credibility perspective the sources of information, such as interviews studies of documentation observations, and hands-on work with the system, must be graded differently. Intuitively, a statement by a person in an interview is most likely to be flawed in terms of ignorance or political bias whereas hands-on experience by the assessor is the most credible type of information. Naturally, several independent sources providing the same answers would result in a value with higher credibility.

In order to take in to account variations in credibility, the framework uses Dempster-Shafer [6] belief functions. Let $\beta_{n,\lambda,i} = [0,1]$ represent some agent's degree of belief that the property $p_{\lambda,i}$ evaluates to a grade of ε_n. $\beta_{n,\lambda,i} = 1$ represents that the agent has a certain belief that the property evaluates to this grade. If $\sum_{n=1}^{N} \beta_{n,\lambda,i} < 1$ means that there is not full confidence in the assessment, and that the agent does not have complete confidence in the response.

Utility function

To facilitate the intuitive understanding of the belief values, a utility function is introduced such that the utility $u = \beta_1\varepsilon_1 + \beta_2\varepsilon_2 + \beta_3\varepsilon_3$ By using $\varepsilon_1 = 0$, $\varepsilon_2 = 0,5$ and $\varepsilon_3 = 1$, we get that if the aggregated property for device management capabilities has a high belief value of being evaluated to grade ε_1, the utility function is near zero. On the other hand if the aggregated property for device management capabilities has a high belief of being evaluated to grade ε_1 the value of u is near 1.

Importance of the sub-properties

The different sub-properties have more or less impact on the value of their respective overlying properties. For instance, the importance of the existence of firewalls is different than the importance of having security policies documented. In order to represent these varying degrees of importance, we represent the importance of each sub-property k in relation to its overlying property λ by its *weight* $\omega_{\lambda,k}$

We now have a complete formalisation with which we can represent how an abstract property such as Device

Management capabilities is broken down into sub-properties. Additionally we have a means of representing the *belief* that a property evaluates to a certain *grade* as well as the sub-properties respective *importance* for the evaluation of the upper level properties. Also, by using the *utility function*, we can derive an intuitive value for the overall goodness of the device management capabilities. For illustration

Aggregating data

Dempster-Shafer theory [6] has been proposed as a generalization of Bayesian statistics. The main difference between the two is that Dempster-Shafer theory makes it possible to express ignorance. It is thus possible to state that we know nothing about the values of the sub- properties. There is therefore no longer any need for the a priori knowledge that hinders the application of Bayesian statistics to this type of evaluation. We have therefore chosen to use Dempster-Shafer theory to aggregate the collected data. According to [1] the aggregated value of a property can be calculated by aggregating the belief values of sub-properties. $B_{n,\lambda-1,i}$ denotes the degree of belief that the aggregated property $P_{\lambda-1,k}$ evaluates to grade ε_n, which is generated by combining the assessments for all its sub-properties $p_{\lambda,i}$ $(i = 1,...,L)$. $\beta_{n,\lambda-1,i}$ is calculated by

$$\{\varepsilon_n\}: \ \beta_{n,\lambda-1,k} = \frac{m_{n,\lambda,I(L)}}{1-\overline{m}_{\varepsilon,\lambda,I(L)}}$$

Where $m_{n,\lambda,i}$ is the basic probability mass representing the degree to which the i^{th} property $p_{\lambda,i}$ supports the hypothesis that the aggregating property $p_{\lambda-1,k}$ evaluates to grade ε_n. and $\overline{m}_{\varepsilon,\lambda,i} = 1-\omega_{\lambda,i}$. By using this algorithm recursively, the credibility evaluations for the individual properties are aggregated into a comprehensive credibility evaluation of the value of the abstract property. For a complete description of the aggregation process see [1].

APPLICATION OF THE FRAMEWORK

This section describes application of the steps of the framework to two real-world AMR systems installed in Sweden. The breakdown of device management capabilities in an ATD, the collection of data and ensuing aggregation and analysis, outlined in the preceding section is described.

System Breakdown

The study was started by breaking down the concept *Device management capabilities in AMR systems* into sub-properties. It is important that the breakdown results in operationalised properties that can be measured. In this case we employed a combination of sources including [1], [4] and [8] to create the operationalised properties. The structure ATD is therefore influenced not so much by the system architecture, but instead by the structure imposed by the theoretical background to the area of Device Management in the referenced sources. Figure 2 shows the complete ATD created. The top three properties that constitute Device Management of AMR systems are Operational Management, Configuration management and Metering Device Properties. These three are further broken down in to sub-properties as illustrated in Figure 2

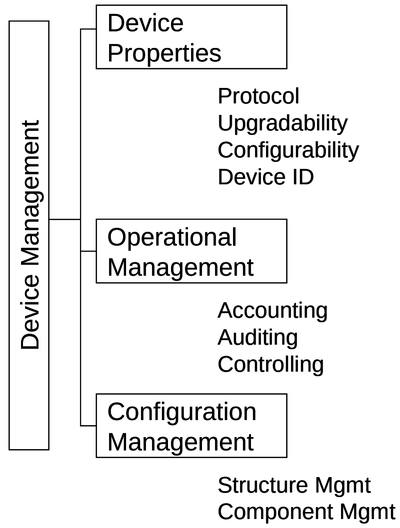

Figure 2 Overview of the complete ATD created to represent Device management capabilities

After breakdown, we estimated the relative importance of the constituent sub-properties by letting several respondents grade the importance of a sub-property. The grading was done in one of three discrete steps. Importance one (1) equalling No or low impact on manageability, importance two (2) equalling average impact on manageability and importance three (3) high or very high impact on manageability. All the grades were then calculated into a continuous mean value from one to three (1-3).

Data collection

To assess the credibility of the data to be collected a credibility framework was defined. In this study, the Each source is given 100% credibility to begin with. Then, based on several factors, credibility is reduced. The subset of factors that effect credibility is: Reflected credibility; Time proximity; Motivation; Source type; and Presentation. [2].

With this framework in place, data was collected by studying documentation, interviewing experts and observing users. For each of these up to three different sources of information were examined. That a measurement point was evaluated from a varying number of sources depended largely on the availability of people to interview and/or observe. The result of the data collection was of a set of grades with sources for each operationalised property in the ATD. Each source provides a belief value for a specific grade for the property and an associated credibility as described above. The source's credibility and belief in a grade is then translated into a set of beliefs for all possible grades for that property using Dempster-Shafer theory.

Aggregation & Analysis

The final step of the framework involved aggregating the collected data. This was in the study done by using the recursive evidential reasoning algorithm described above. The resulting Belief values for the three different grades for the two systems studied are shown in Figure 3 and Figure 4 below

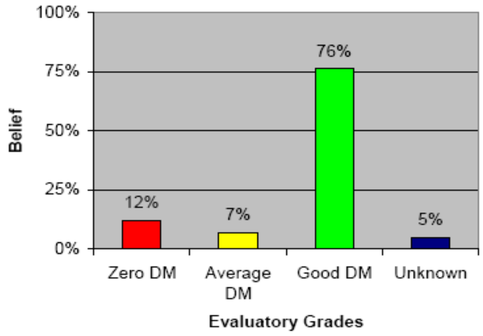

Figure 3 The aggregated belief values for the three grade levels for system 1

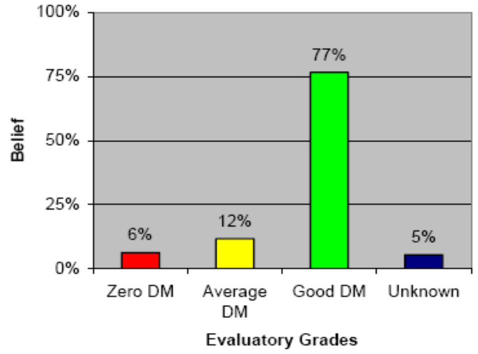

Figure 4 The aggregated belief values for the three grade levels for system 2

The belief values for the top three levels of the ATD where then used to calculate the utility value of each of these second level properties. The utility value is more intuitively translated into the goodness of Device management as opposed to the belief values for individual grades.

	Device Properties	Operational Management	Configuration Management
System 1	0,76	0,65	0,91
System 2	0,84	0,74	0,85

Table 1 The utility values for the three properties of the second layer of the ATD for Device Management, with values for the two studied systems.

RESULTS & CONCLUDING REMARKS

The top level belief values for the two systems are only useful in that they allow comparison between the two systems. For more detailed analysis of the device management capabilities, the second level properties are more interesting. From Table 1 we see that for system 1 the operational management is the weak point, while its strengths lie in the configuration management support offered by the system. The metering devices in system 2 offer more support for device management, than those in system 1. For more detailed analysis, the lower levels of the ATD need to be studied.

To summarize, the evaluation framework described provides a simple and intuitive method for assessing the heterogeneous property of Device Management in complex systems such as an AMR system. The method is robust in the sense that it allows for incomplete data. The application of the method in a real world setting provided the decision-makers with valuable input for further refinement of the device management capability levels of the AMR system in question.

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