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論文の内容の要旨

1. Research Content

The term *Operation, Administration, and Maintenance* (OAM) represents a group of network management activities that include fault detection, isolation, and restoration in order to keep a network operate stability and reliably. Generally, the OAM is essential for Internet Service Provider networks (commercial networks) and is accountable by experienced network operators with the support of tools and network equipment. Since networking is getting more complex due to the development of the information and communication technologies (ICT), automated OAM which relies on the *Artificial Intelligence for IT Operations* (AIOps) is a must to reduce the workload of human. The AIOps automates IT operations by utilizing concepts of big data analytics and machine learning to analyze data in order to detect and react to issues automatically. Smart homes are homes which utilize home appliances and a home network to connect those appliances to organize residential infrastructure so as to improve the overall quality of life of residents and assist them to live actively and independently. Following the development of the Internet of Things, home networks are becoming more and more sophisticated. Unlike, commercial networks which are monitored by experienced network operators, complex home network systems are now in the hand of naive users include children, older people, and people without the knowledge of network management. Therefore, providing automated OAM for smart homes based on the concept of AIOps is even more important.

Data is a fundamental source of building AIOps based automated solutions. Data is

collected during daily operations and also from expensive network equipment in commercial network infrastructures, however, the situation is diverse in smart home networks. Thus, the lack of network traffic data of home networks is the biggest barrier to implement automated OAM solutions for smart homes. In the smart home context, the network traffic data reflects interactions between devices and services utilized these devices, hence it matches to the concept of the IoT Area Network where devices are connected to service gateway(s) (GW) and network traffic data is the traffic between devices and the target service gateway. Generally, network traffic data is generated by real smart homes, testbeds, or simulation. However, since network simulation is one of the promising approaches to generate traffic data which achieves the low cost in terms of time and money, a home network simulator which includes (i) a device emulator and (ii) a mechanism to simulate services is proposed as a preliminary component of the network traffic generation framework. Thereafter, a solution to convert the raw network traffic into data used as input for machine learning techniques is introduced to complete the proposed framework. In the scope of the dissertation, the ECHONET Lite protocol which is a dominated protocol for smart homes in Japan is the target protocol for the proposed framework.

2. Research Purpose

To implement the proposed framework, following subtasks must be accomplished:

- The implementation of an ECHONET Lite home gateway (HGW) is one of the first steps to build the simulator. The layered architecture, which includes (i) an adaptation layer to handle the interaction inside of the IoT Area Network, and (ii) an integration layer to integrate with other systems, is proposed. The proposed HGW satisfied all requirements of a GW, as stated in the ITU-T Y.4113 and ITU-T Y.2070, which clarify functional requirements for operation, management, and operation scenarios. To verify the feasibility and reliability of the proposed HGW architecture, the integration with ambient assisted living platform, namely *universAAL*, and a Machine-to-Machine ecosystem, namely *oneM2M*, has been implemented. Experiments have been conducted with the commercial devices, and the results proved the reliability and correct operations of the proposed HGW.
- Device simulation is proposed as the last piece of the puzzle of the network simulation because it is hard to have real, controllable faulty devices to generate the faulty traffic which is required for the data set. An ECHONET Lite device emulator has been

proposed. The experiment results show that the emulator fully simulated behaviors of real commercial devices. The emulator can simulate faulty devices by extending the concepts of a fault model for the distributed system. Experiment results verified the correct operations of the emulator in simulating normal and faulty devices. By utilizing the Docker platform, automatic and scalable deployment is achievable, and the CPU and memory usage of the device emulator is **0.15%** and **100 MB** respectively to simulate a node.

- The deployment of the network simulator that includes the proposed HGW, normal device emulator, and faulty device emulator, network traffic data is collected in the form of raw captured packets. Data preparation is an essential part that requires to clean the input data and extract meaningful features from data. A network flow calculator, namely *Flowcal*, is proposed to aggregate captured packets into bidirectional flows, which reflect the interaction of devices and the HGW. The *Flowcal* is customized for the IoT area network and is able to appoint the flow initiator and also handle multicast flows. Data samples, which represent device behaviors, are prepared by extracting features from flows and combined into vectors. A total of **91080** samples representing **138** nodes (**384** device objects) are extracted from raw captured packets by the proposed solution. The distribution of data samples is visualized by applying the Principal Component Analysis to scale the data dimension. The visualized results prove that **IF-ELSE** is impossible to predict device behaviors.
- Problem detection is the starting point to build an automated OAM solution and network traffic data could be used to diagnose the health of a smart home network, a network traffic classification application for anomaly detection is implemented based on data generated from the proposed framework to verify the usability of the generated data. Three ML methods include Decision Tree (DT), Support Vector Machine, and Artificial Neural Network (ANN), are investigated for the experiments. All three models achieve high accuracy in classifying normal devices and devices with response fault from the rest of faulty devices. However, the accuracy of detecting omission fault devices and devices with three errors combined is low. The ANN achieves the best performance (average accuracy **96.72%**) with data normalization.

The DT achieves the best performance (average accuracy **93.23%**) without data normalization.

According to the results, the proposed framework is able to generate smart home network traffic data which is usable as input to build AIOps based solution to reduce human effort on network management. The proposed framework is configurable with various scenarios which is impossible to achieve in real deployments and contributes to the data generation processes in the field of data science. The proposed framework is essential and paving the way to build AIOps solutions for smart homes.

Keywords: *IoT Area Network Simulation*, *Network Traffic Generation*, *AIOps for Smart Homes*, *Machine Learning Based Network Management*, *Operation, Administration, and Maintenance*.

論文審査の結果の要旨

スマートホームは各種の IoT システムの中でも、管理者が不在であること、導入時期の異なるマルチベンダの構成となることなど、管理運用の観点では困難な課題を抱えたものとなっている。今後、各種のサービスが家庭内で定常的に提供され、場合によっては利用者の生命に影響を及ぼすような状況も生じることが想定され、人手をかけずに管理運用が行えるような技術が必要とされている。一方、社会インフラとなっている情報通信網においてもその規模の拡大と複雑さの増大から、従来は人間の管理者が担当していた通信網の管理運用の現場に AI(人工知能)を活用した管理運用支援システムを導入する動きが進んでおり、関連した技術の開発も精力的に行われている。本研究は、AI によるスマートホームの管理運用を実現するための、学習データを適切に生成することのできる機構に関するもので、まだ実データを入手することのできない新しいシステムにおける通信トラフィックを生成し、機械学習を用いた異常検出システムを事前に構築可能とするものである。

スマートホームの実現技術は日々変化しており、新しいシステム形態となった際のネットワークの振る舞いの予想を行うことは難しい。本研究ではエミュレーション技術を用いたシミュレータが実物同様の通信トラフィックを生成することで、システムの運用より前にその通信トラフィックパタンを提供するというアプローチをとる。まず、近い将来に実現されることが目されているスマートホームのシステム形態を実現することのできるサービスプラットフォームのための主要コンポーネント群を開発し、ITU-T / oneM2M、IEC / EU universAAL, ISO/IEC / ECHONET Lite に対応したシステム構築を容易としている。これらをもちいた現実的なシステムについて、各コンポーネントの動作条件を一元的に記述できる手段を与え、実際に稼働させた通信トラフィックデータを様々な条件下で生成することが可能となっている。また、このデータを用い、Neural Network、Support Vector

Machine、Decision Tree により機械学習した異常検出器の性能について評価を行い、実用レベルの能力があることを示している。

本研究の内容は IEEE の国際会議や情報処理学会論文誌で発表されているだけでなく、oneM2M、スマート IoT 推進フォーラムなど、産業界における標準化団体からも招待を受け、成果を発表するとともに、今後の規格づくりのベースともなりつつある。

以上のように、本論文は学術的な意義、産業界への貢献の意義、何れも極めて高く、博士(情報科学)の学位論文として十分に価値のあるものと認めるものである。