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Building Resilient and Autonomous Systems for IoT Network Management - Advantages and Difficulties in adopting Machine Learning Techniques

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Abstract

This document shares knowledge and insights regarding applying machine learning techniques on wireless sensor networks. It firstly introduces advantages and difficulties in adopting machine learning techniques on wireless sensor networks. Though dynamicity and unpredictability of wireless networks make it difficult to train the model with various possible scenarios, it has strong ability in terms of flexibility. This document also overviews several works that applied machine learning techniques on diverse research areas including networking, communications and lossy environment. The ultimate purpose of this document is to discuss a proper research direction aiming the realization of a system that detects, predicts and recovers from abnormal situations on wireless sensor networks.

Status of This Memo

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1. Introduction

This document shares knowledge and insights regarding applying machine learning techniques on wireless sensor networks. It firstly introduces advantages and difficulties in adopting machine learning techniques on wireless sensor networks. Though dynamicity and unpredictability of wireless networks make it difficult to train the model with various possible scenarios, it has strong ability in terms of flexibility. This document also overviews several works that applied machine learning techniques on diverse research areas including networking, communications and lossy environment. The ultimate purpose of this document is to discuss a proper research direction aiming the realization of a system that detects, predicts and recovers from abnormal situations on wireless sensor networks.

2. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

3. Terminology

Abnormal situation : In this document, we use this term on sensor network environment. We define abnormal situation as situation that should be corrected by system manager or automated management process. If this situation is not corrected or the proper action is not taken in time, the overall system performance will be degraded. For example, on sensor network, situations caused by link error, energy depletion, memory depletion, routing loop or broken sensor should be detected as soon as possible and these situations should be considered as abnormal situation. The best thing is to avoid these situations by prediction mechanism. Even if such abnormal situations were happened, a proper action should be taken soon.

4. Advantages and Difficulties in adopting ML on Wireless Networks

Recently, machine learning techniques are widely adopted on various areas including image, voice, video, public safety, medical, etc. With the evolution of more sophisticated computer-related techniques, we have a plethora of data stored at a large number of data centers and these are analyzed at a speed of real-time. Machine learning techniques can realize the implementation of human-like prediction or decision making process. Ideally, by using machine learning techniques, the whole world can be managed autonomously in safe way by the system. For example, the system collects all the information produced by each human being and learns everything in the world by itself. One of the strongest advantage of adopting machine learning techniques is that it can learn from data continuously over time. Even during the operation of the system, it can be continuously updated by using newly observed or produced data. As a result, with one machine learning algorithm, different logics are produced with different training data. It means that it can learn continuously from the experience and the system is flexible on its decision making process. Back to the example, when the system detects any dangerous or abnormal situation from the world of human beings, it can ring the alarm bell or take any action that may be deemed wise and helpful.

The reality, however, is that this ideal system is hard to construct. The first problem comes from the difficulty in collecting good training data that is including various scenarios. Even though we have good machine learning algorithms that can build strong logic and analyze the large data set in real-time training the system continuously, if we do not have effective data set, we cannot build any prediction or decision model.

Regarding researches on communications or networking, many researchers have tried to adopt machine learning techniques for decision making process in connection with channel error diagnostics, fault detection in wireless sensor networks, routing in wireless sensor networks, network attack, etc. When the environment surrounding the model is stable and persistent except some factors that are closely related to the output of the model, it is not challenging to train the model and make reliable decision. However, if the environment surrounding the model is dynamically changing, the algorithm cannot build reliable model that outputs correct decision from input data. This is because with varying condition, it is difficult to find consistent patterns from various input data to output decision. Consequently, it is hard to build reliable model. Moreover, in this dynamic environment, the system should secure data set for training that is including various scenarios. However, even collecting data set for training is difficult due to the lack consistent pattern from the data set.

In recent years, researchers and industries have been paying attention on Internet of Things. With this trend, plenty of research groups have been made accelerating a growth of relevant techniques. Due to the limited characteristics of constrained devices and low-power communication techniques, which are different from that of conventional sensor networks, networking and communication techniques especially for low power and lossy networks have been received especially huge attention compared to that of the other networks.

To enhance the reliability of communication on low power and lossy networks constructed with constrained devices, routing protocol such as RPL (Routing Protocol for Low Power and Lossy Network) [RFC6550] and special mac protocol such as TSCH (Time Slotted Channel Hopping) [IEEE802.15.4e] [RFC7554] have been proposed and widely used as standard protocols currently. To summarize briefly, RPL constructs routing paths in simple way and prevents routing loops by constructing DODAG structure. Moreover, topology created for the route management evolves continuously over time considering various network conditions and metrics. With TSCH, various channels can be used and problems caused by interference can be overcome. However, these protocols are operated on the basis of local information obtained at each node. Consequently, the problems that are not immediately captured and fixed by the protocols that are based on local information are still exist.

With a global view on a network state, various information can be used for analyze the current state and the problems that can seriously damage the network performance can be detected in advance. In sensor network, there are several abnormal situations that should be detected before they happen. For example, on an application layer, broken sensors might send wrong sensed values to a connected server continuously. If we do not aware of this, we cannot detect the situation where the accident actually happens. On a network layer, though RPL captures the network problem and the topology is continuously updated considering network conditions, each node has simple decision making process on the basis of local information. As a result, if network traffic is concentrated on a specific node, it might not be detected before the problem becomes bigger. In this case, the node with freakishly unbalanced and heavy work load will quickly consume its energy and finally it will be powered off. On a link layer, wireless network interface might broke down. In this case, with the global view on the network, all of these situations can be detected before the serious accident happens. The global view can be obtained by information collection and traffic monitoring from the high-powered root node or the server.

Following is the list of examples of faults that should be detected on a low power and lossy networks. We aim to construct reliable system that manages the network automatically or autonomously.

- No energy in a node

- Breakdown on wireless network interface in a node

- Interference on certain channel

- Overloaded CPU usage on a node

- Full memory or buffer on a node

- Abnormal sensed value

- Wrong execution of a command for network management

- Link layer problem falsified data

- Traffic overload due to attack (e.g. DDoS)

- Energy consumption due to unbalanced traffic load

We know that one of the benefits from using machine learning algorithm is that the system can learn various scenarios including unexperienced one over time since the decision making logic is not on the basis of predefined static rules. Accordingly, when we devise techniques for detecting abnormal situation described above on low power and lossy network, it seems good to have an approach by utilizing machine learning algorithms.

However, collecting data set for training the model is challenging. Moreover, the network environment on a low power lossy network is highly dynamic compared to the other networks. As a result, obtaining good data set that is including various scenarios is virtually impossible.

Though there are many researches on networking or communications on the basis of machine learning techniques, only part of that can be applied to real systems or devices. As described above, if the environment surrounding the model is huge and changes dynamically, it becomes harder and harder in training the model. Moreover, though several methods detecting fault scenarios on a sensor network by using machine learning have been proposed, they trained the model with too small data set which were made in artificial way or the data set has not including various possible scenarios. Moreover, the evaluation and the test scenario were done on rigorously restricted environment so it is uncertain whether the constructed model will work properly even with the similar but different scenarios.

In the following sections, we will introduce several works that are adopting machine learning techniques on various networks environments including wireless sensor networks. Though adopting machine learning on wireless network environment is difficult due to dynamicity and unpredictability of wireless network environment, these works are valuable and have shown notable performance improvement through their evaluation.

5. Examples of ML-based research regarding networking and communications

We introduce several works that are applying machine learning techniques regarding networking or communications. These methods have strong contribution in terms of utilizing machine learning to overcome challenging problems caused by fluctuating and unpredictable wireless channel state. Though these works have shown notable performance improvement on their evaluation, some works just concentrate on trace-driven simulation or testing using the same data set used for training rather than natural real-world experiment. Nevertheless, these works are valuable in that they paved the way for utilizing various information to construct reliable models to overcome the difficulty in predicting the future state of wireless channel.

5.1. Signal classification

To implement reliable wireless communication, the signal sent by a sender should be correctly recognized at a receiver side. The authors of [EX1] are focusing on the impact of interference from modulated signals and the influence of realistic wireless channel conditions on classification performance. They proposes machine learning approach can be used for classifying the signal on realistic wireless environment. We regards that this work is similar to pattern recognition since it classifies the signal which has been modified passing through a wireless channel.

5.2. Data collection and traffic classification for network management

The authors of [EX2] emphasize the importance of understanding the type of data that can be collected in SDNs and the process of learning information from that data. As a first step toward machine learning based network control, this work presents a simple architecture deployed in an enterprise network that gathers traffic data using the OpenFlow protocol. However, this work just concentrates on studying monitoring and classification of traffic using data obtained with the OpenFlow protocol without proposing sophisticated ML-based system or network management. Nevertheless, this work have paved the way for the use of ML-based network management and shown simple examples applying ML techniques.

5.3. Network attack prediction

The work [EX3] have proposed the method defining security rules on the SDN controller on the basis of machine learning technique. Machine learning algorithms are used to predict potential target host that can be attacked and the security rules on the SDN controller are defined to restrict the access of potential attackers by blocking the entire subnetwork. For the evaluation of the proposed method, the same datasets were split for training and testing purpose.

5.4. Wireless adaptive streaming

Network conditions fluctuates over time and vary significantly across environments. With this reason, predicting future network condition is difficult. Though many rate adaptation algorithm for high QoE video streaming have been proposed, it is not sufficient and there are much room for further improvement. Several works have proposed by adopting machine learning techniques for the video streaming services. [EX4] proposed the system that is implemented on server-side, learns critical features and make the best decision on bitrate and CDN for the streaming user to optimize QoE. [EX5] also adopted reinforcement learning to generate the best ABR algorithm automatically by considering bandwidth, buffer level and video rate.

5.5. Mobile cloud offloading

The work [EX6] introduces the use of cloud computing for mobile device computation offloading and proposes ML-based dynamic algorithm. It monitors device resources and network parameters and makes a decision to offload computation to the cloud. In this work, machine learning technique is used to make a decision on cloud computing and network information such as available bandwidth is only one of various input values. Other input values are user input, device energy level and CPU usage level and these are definite and stable compared to the values influenced by dynamic and unpredictable wireless network. Since the environment surrounding the model is stable compared to other works introduced in this document, we regards that this model is on better condition in terms of a given environment.

6. Examples of ML-based research regarding wireless sensor networks

In this section, we introduce several works that applied machine learning techniques on sensor networks. These methods also have strong contribution in terms of utilizing machine learning to overcome challenging problems caused by lossy channels and constrained devices. These works are also valuable in that they paved the way for utilizing various information to construct reliable models to overcome the difficulty in predicting the future state of lossy channels.

6.1. Channel error diagnostics

ISM band is shared by several protocols such as 802.11, 802.15.4, 802.15.1, etc. Here, different systems interfere with each other degrading communication performance. Authors of [EX7] conducted extensive experiments to study the error patterns in IEEE 802.15.4 and found that there are different patterns for major wireless scenarios. Based on this finding, they designed a machine learning mechanism to classify the wireless channel errors into different categories and proposed the system that diagnoses different troubles in IoT networks.

6.2. Spectrum decision

The work [EX8] also points out the pollution of the ISM band and the power constraints in sensor nodes. To overcome this poor environment, it proposes machine learning solution for channel selection. By using ML technique, the system predicts a number of expected transmission attempts. It uses the following attributes as input data: RSSI, number of transmission attempts, reasons of each failed attempt, performance data such as RSSI and LQI from the last received packet. From the output, it selects the best channel and a channel with low number of expected transmission attempts is considered as better one.

6.3. Outlier detection

Since wireless sensor network composed of constrained nodes is vulnerable to interference, unstable channel or cyber-intrusion, the system performance is degraded and fake data might be provided to higher management levels in a system. This might cause critical problems on sensor network systems for public safety or industry automation. Authors of [EX9] have pointed out that the existing works for outlier detection require large memory, high computation, high energy consumption, communication overhead and does not support heavy online data streaming. To solve the problem, they proposed online outliers detection by using a machine learning technique as a multi-agent framework.

6.4. Indoor localization

Generally, GPS is one of the well-known examples regarding object localization. However, inside a building, it is difficult to estimate the correct location of an object due to low received GPS signal strength. With this reason, another approaches are used. For example, several nodes are used as anchor points and these information is used to estimate a relative location of a target object. Devising an accurate indoor localization system is important since the system can be used to increase the safety in underground mines or caves. However, there still exist interference on wireless channel which decreases estimation accuracy. To overcome the problem, the work [EX10] have used seven different machine learning techniques on two different architectures to find the algorithm that shows the lowest errors and compared the performance. On testbed, the person had a wearable sensor to locate himself within the wireless sensor network.

6.5. Event detection

Wireless sensor networks are used for various purposes. The work [EX11] concentrates on detecting pipeline leakage on oil/gas and water transportation system. It uses a pattern recognition algorithm and train the sensor network to detect and classify new traces of events like leakages. Here, distributed sensor nodes cooperate to identify the leakage event and its size. Though this work includes wireless sensor network, difficulties that comes from using unpredictable and vulnerable wireless channel were scarcely considered.

6.6. Fault detection

Various problems caused by vulnerable and fluctuating wireless channel together with cheap sensors make collected data from the sink node to be faulty. Fault data should be detected and the cause of the event should be identified to quickly react and manage the system. The work [EX12] developed a statistical approach to detect and identify faults in a wireless sensor network on the basis of machine learning technique. It classified fault types into two categories: data fault and system fault. Faults caused by degraded or malfunctioning sensor are classified as data fault and the other fault types caused by low battery, calibration, communication, connection failures are classified as system fault. Authors of [EX13] also studied fault detection on similar environment by using machine learning technique. Here, they classified fault types into four categories: offset fault, gain fault, stuck-at fault and out of bounds.

6.7. Routing

By adopting ML technique, multihop routing protocol can be more energy efficient. The work [EX14] proposed ML-based clustering protocol to assign the sensor nodes to the nearest cluster in energy efficient way. The work [EX15] also used ML technique on routing method in wireless sensor network. The purpose of proposed routing scheme is to increase network lifetime and transmit information packages in shortest possible time. These works insist that applying ML techniques on WSN is beneficial in terms of resource management.

7. Concluding Remarks

From this documents, we introduced advantages and difficulties in adopting machine learning techniques on wireless sensor network environment. With machine learning algorithm, we can design a flexible system that learns and evolves continuously through experience. However, it is difficult to obtain training data that includes various scenarios. Moreover, due to dynamicity and unpredictability of wireless multi hop network, it is hard to find any regular pattern from previously experienced data. Besides, even if we have decision model, it is uncertain whether it will work properly or not in the future where the network environment continuously changing dynamically.

With this reason, it is difficult to devise a system that detects, predicts and recovers from abnormal situation on wireless sensor networks on the basis of machine learning technique. Nevertheless, as long as we have this system, managing and operating IoT network become easier establishing a foothold in IoT system.

As concluding remarks, we would like to raise the issue of devising IoT network management systems that can detect, predict and recover from abnormal situation on wireless network environment.

Until now, several works have adopted various machine learning techniques on diverse research areas including networking or communications over wireless channel. These works have shown the potential that machine learning can be used together with the conventional approaches to improve system performance in efficient way. However, it is still difficult to obtain training data that includes various scenarios on dynamic and unpredictable environment. Moreover, if we make a simple model due to difficulty in training, the application of constructed model is confined with very narrow limits. Nevertheless, these works have strong contribution in terms of adopting ML techniques to improve the performance of corresponding system and paved the way for utilizing ML to construct model that is surrounded by dynamic and unpredictable environment.

We expect many researchers actively discuss on this topic to devise resilient and automatic recovery systems on IoT network.

8. IANA Considerations

There are no IANA considerations related to this document.

9. Security Considerations

In this document, security is just considered as an example of abnormal situation (e.g. DDoS).

10. Acknowledgement

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