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Smart Grid Ping – A Customized Ping Tool for a Heterogeneous and Hybrid Smart Grid Communication Network

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Abstract

Heterogeneous and hybrid smart grid communication network is a network that comprises of different communication mediums and technologies. Performance evaluation is one of the main concerns in smart grid communication system. In any smart grid communication implementation, to determine the performance factor of the network, a testing of an end-to-end process flow is required. Therefore, an effective testing tool plays a crucial role in evaluating the performance of smart grid communications. Ping is currently one of the most common network testing tools. In this paper, a customized ping utility, called Smart Grid Ping, is introduced. This utility provides random ping intervals with user selectable distribution, allowing network administrators to test the reachability and availability of various applications in smart grid communication system.

Key Words

Network performance, ping, smart grid, testing tool.

I. Introduction

Over the past few years, applications of computer and communication technologies on energy delivery system have drawn a lot of attention among researchers, especially the term "Smart Grid" is gaining popularity. Smart grid has recently emerged as the next generation of electric power system which can solve multiple problems including ever increasing load demand. It is a modernized electricity distribution network that consists of diverse applications supported by different communication technologies. Since smart grid is a complex system which comprises of various intelligent devices coexisting on the same network [1], the communication system built on top of smart grid infrastructure is normally a heterogeneous and hybrid paradigm. This communication paradigm is needed to ensure a two-way flow of electricity, information and communication between the utility and household [2] [3].

In smart grid communication network, information flows in two-way direction. Since the network is made up of a variety of communication devices, the network traffic is one of the main concerns when evaluating the network performance. Currently, there are a large number of tools and utilities available with different functions to serve different purposes. However, diverse communication technologies in smart grid creates major challenges for conventional testing software, for legacy testing programs are designed for a single communication technology or standard in the network. Due to the heterogeneous and hybrid communication paradigm of smart grid, the type of network traffic is still unknown. The constant traffic no longer reflects the real traffic in multi-technology bi-directional communication. In addition, high availability is one of the standard requirements in most communication systems. Devices within the network should be reachable under all situations [4]. Therefore, a customized ping tool, named Smart Grid Ping, was implemented in this paper in order to test the network availability, measure packet loss and communication delay. Smart Grid Ping also allows users to select different types of random distribution for various ping options, allowing network administrators to analyze and evaluate the performance of a heterogeneous and hybrid smart grid communication system.

II. Objective and Scope

A. Objective

The objective of this research paper is to develop a customized ping tool to test the availability, measure packet loss and delay of various devices in smart grid communication network.

B. Scope

The customized Ping tool was developed for UNITEN-TNBR smart grid test-bed.

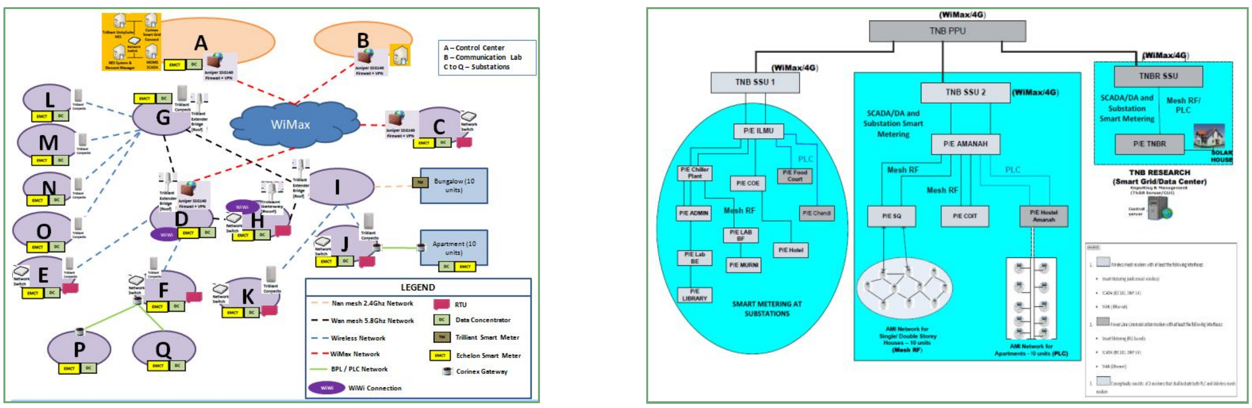
III. Background

A. Smart Grid Test-Bed

Smart grid comprises of several systems, including SCADA (Supervisory Control and Data

Acquisition Systems), EMS (Energy Management Systems), DCS (Distributed Control Systems) and AMI (Advanced Metering Infrastructure) [5]. Devices that are used to support these systems consist of RTU (Remote Terminal Units), PLC (Power Line Communication) modems, smart meters, data concentrators and so on (Figure Ia).

Wired and wireless are proposed as communication mediums for smart grid. The communication technologies that support the network include Power Line Communication (PLC), unlicensed Radio Frequency (RF), and WiMax/4G as shown in Figure Ib. PLC is one of the common technologies used to transmit data over wired network. However, the transformer normally blocks the data signal and hence the PLC technology is restricted between transformers [6]. Thus, besides wired technologies, wireless can be used as a solution. For example, RF mesh is suitable to use in smart metering applications [7], and WiMax/4G can also be used for inter-substations and backbone. Most smart grid implementation is based on open standard and TCP/IP is the dominant one.



a) b)

FIGURE I: SMART GRID NETWORK DIAGRAM.

B. Ping

Ping [8] is one of the most common tools used to test the availability and reachability of a host on an IP (Internet Protocol) network. It acts as an administrator utility which can identify if the targeted host is reachable or not. Ping operates by sending Internet Control Message Protocol (ICMP) packets, or echo-requests, to the destination host and wait for an ICMP response, or an echo-reply. During the process from transmission to reception, the time taken is measured as round-trip time, and packet loss is recorded. The ping packet is considered lost if it does not receive back a response or it has timed-out.

Once the ping command has been successfully released, the obtained results will be summarized in the ping statistics. The number of packets sent, received, percentage of packets lost and round-trip time will be displayed in the output. Ping can be used not only to test the reachability of a host, but also to record the route taken or to generate network traffic. With these functions, ping can be used as an effective tool to analyze and assess the performance of smart grid communication network.

C. Related Work

As mentioned in [9], smart grid test-bed design and implementation can be assessed by quantitative evaluation, which provides empirical data. The quantitative evaluation of the test-bed deals specifically with the performance of the network emulation. Throughput and latency of network emulation can be evaluated using software tool such as ping.

Ping was also used in [10] as a tool to measure the round-trip time for several IP technologies in smart grid, including ADSL, WiMax and 3G/GPRS. A number of tests were set up using ping by sending ICMP echo-requests and waiting for echo-replies. After several weeks, the latency for each technology was recorded and compared to evaluate if they are able to meet the performance requirements of smart grid applications or not.

Similarly, latency tests were carried out in [11] in order to analyze smart grid communication network. A test setup was build, consisting of a router, an Ethernet switch, PLC modems and several computers. Ping tests were performed for the latency analysis in the test setup. It is an important parameter especially in the protection applications.

One of the ways to protect an electric power system is to avoid outages. In [12], ping was used to confirm the locations where meter outages happen. After pinging the meter, its response time will be considered to validate the outage event, and the energized state of AMI meters can be checked using on-demand pings.

In addition, [13] described ping as an effective tool in testing the communication availability of GPRS, a technology often used as intermediate between the concentrator and the front end. The tests were conducted to check if the communication is working or not.

In most of previous research works, ping appears to be widely used for network testing in smart grid. However, the approach used to evaluate the system performance in [9] was based on a representation of the system behavior through a model. In other words, the network testing was performed using network emulation or software simulation tools. This approach has a major drawback of oversimplification of the actual scenarios. Nevertheless, the ping utility implemented in this paper was used to evaluate the network performance based on real measurement from a developed test-bed.

Currently, there are a number of tools that have been developed based on Ping utility. The features of these tools are summarized in Table I. The similarities among these tools include the ability to support both single and multiple IP addresses. In addition, each tool also has a graphical user interface (GUI) that allows users to key in the host IP and displays the ping statistics. However, most of these tools do not provide various ping options such as number of packets, packet size, delay between packets, etc. Even if these options are provided, ping is used to generate stable traffic where packet size and delay between packets are constant.

TABLE I: DIFFERENT TYPES OF PING UTILITIES FOR WINDOWS

No	Tool	Single IP	Multiple IP	Packet loss	Delay	Options	Random
1	Smart Grid Ping	✓	✓	✓	✓	✓	✓
2	WinPing	✓	✓	✓	✓	✗	✗
3	PingInfo View	✓	✓	✓	✓	✓	✗
4	Ping Util	✓	✓	✓	✓	✗	✗
5	IP Ping Tool	✓	✓	✗	✓	✗	✗
6	Net Ping	✓	✓	✗	✓	✗	✗

Due to certain limitations of the existing tools, a customized Ping utility, named Smart Grid Ping, was developed to overcome these problems. The fundamental idea of developing a new tool arose from the lack of the available ones. In fact, the customized ping tool developed in this paper has the ability to generate random traffic to represent the actual environment where network traffic is no longer constant as it comes from diverse applications and communication devices in the smart grid test-bed.

IV. METHODOLOGY

Smart Grid Ping is a ping utility written in C++ and is designed for Windows. It can be used to ping a single IP address or a specified range of IP addresses. The GUI provided by Smart Grid Ping was developed using Visual Studio 2008. The flow of the program is described in the Figure II.

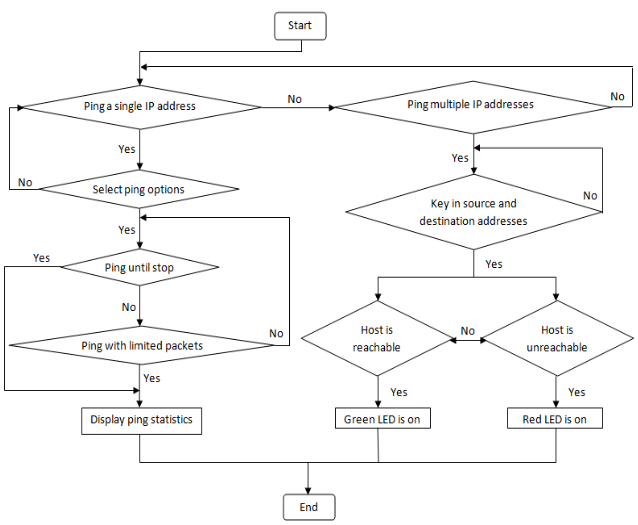


FIGURE II: FLOWCHART.

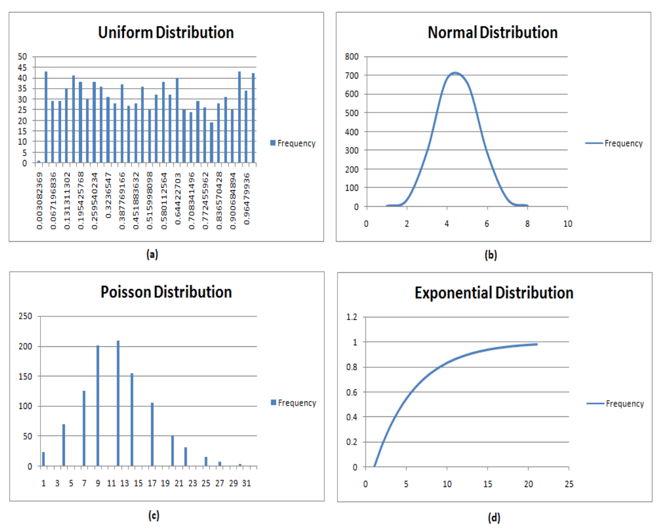


FIGURE III: DIFFERENT TYPES OF RANDOM DISTRIBUTION: A) UNIFORM, B) GAUSSIAN, C) POISSON, D) EXPONENTIAL.

The interface of Smart Grid Ping allows users to key in IP addresses together with various ping options. For instance, users can select the number of packets, packet size, delay between packets and timeout. In addition, users can also choose to send a certain number of packets or keep on sending the packets until they want to stop.

Besides sending a constant number of packets and packet size, set a constant delay between sent packets and timeout, users can select to generate a random number for each option. This number can be Uniform, Gaussian, Poison or Exponential distribution as shown in Figure III.

After a ping operation has been executed, ping statistics will be displayed, including the number of packets sent, received, percentage of packets lost, and round trip time. Moreover, in the window form designed for pinging multiple IP addresses, users can key in IP addresses of the source and destination hosts. 254 LEDs, corresponding to 254 IP addresses, are used to represent the hosts' status. Green LED indicates the host is alive and reachable, yellow LED shows that the host is down and unreachable, and red LED represents a host without an IP address.

V. RESULTS AND DISCUSSION

Smart Grid Ping consists of three window forms. The first window is the main menu where users can choose to ping a single IP address or a range of IP addresses. The Sing IP Ping Test form provides several ping options for a single host, together with ping statistics and output display. The Multiple IP Ping Test window lets users key in IP addresses of source and destination hosts. It also displays all the hosts' status in rows and columns using LEDs. Initially, all the LEDs are in grey. Once the ping operation has been executed, the LED representing each host will light up accordingly.

Figure IV and Figure V show the user's choices and corresponding results for pinging a single IP address. The former displayed the host was reachable, indicating that the device was alive. Meanwhile, the latter displayed unreachable host, showing that the device was currently unavailable or could not be reached. The results obtained from pinging multiple IP addresses are described in Figure VI. This window form provides a general view of all the devices in the network where each device is recognized by its IP address. The status of each device is represented by green, yellow or red LEDs, indicating the host is reachable, unreachable, or unassigned, respectively.

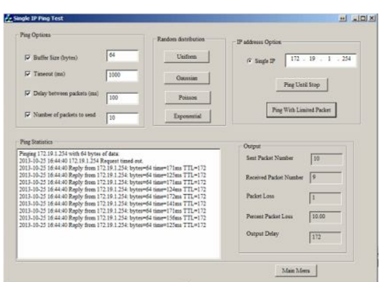


FIGURE IV: HOST IS REACHABLE.

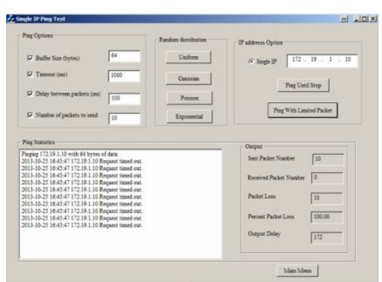


FIGURE V: HOST IS UNREACHABLE.

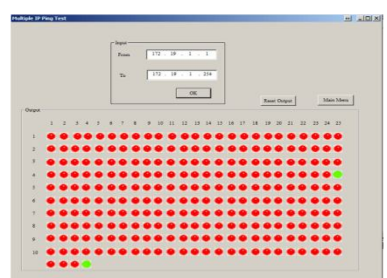
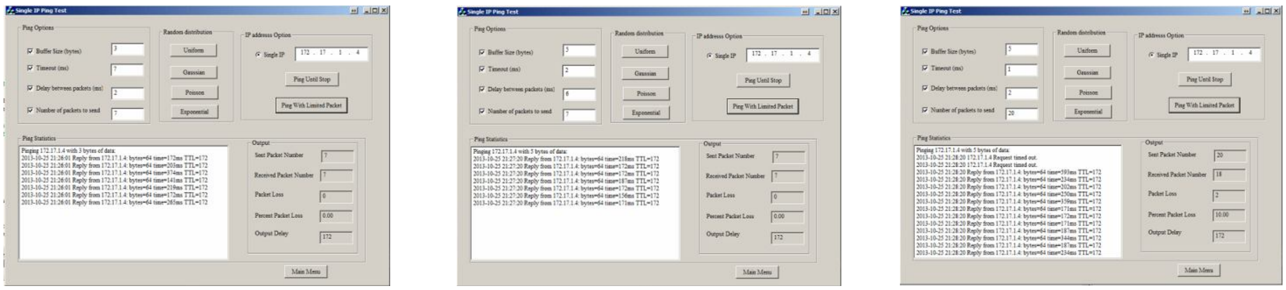


FIGURE VI: MULTIPLE IP PING TEST.

The Multiple IP Ping Test window lets users to view the devices' status over the whole test-bed area. This allows users to group certain regions with similar state together, such as reachable, unreachable, or unassigned. For instance, a series of continuous red LEDs from 172.19.1.1 to 172.19.1.99 indicates that the hosts corresponding to these IP addresses are currently not assigned. With this function, Smart Grid Ping helps system administrators detect any network problem if it arises by providing a quick view of network performance.

Under Single IP Ping Test window, besides using constant values for various ping options, users can choose to generate random number of packet, packet size, delay between packets and timeout. Smart Grid Ping allows users to select these numbers according to different types of distribution as examples shown in Figure VII.



A) B) C)

FIGURE VII: RANDOM DISTRIBUTION: A) GAUSSIAN, B) POISSON, C) EXPONENTIAL

The customized Ping utility was used in a dedicated smart grid test-bed, named UNITEN-TNBR, to test the availability, measure packet loss and delay of various devices in the communication network. The availability results obtained from different networks are shown in Figure VIII, Figure IX and Figure X.

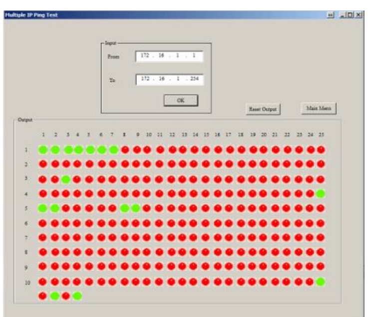


FIGURE VIII: 172.16.1.X NETWORK.

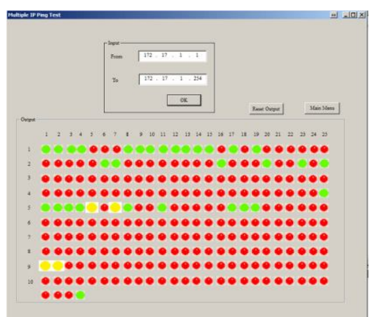


FIGURE IX: 172.17.1.X NETWORK.

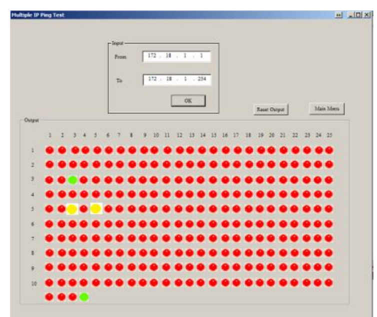


FIGURE X: 172.18.1.X NETWORK.

Different numbers of devices were installed in different networks (Table II). Under operation, a number of devices were up and displayed as green LEDs. Others were down and displayed as yellow LEDs. Red LEDs correspond to IP addresses that have not been assigned to any device in the network.

TABLE II: AVAILABILITY STATUS OF VARIOUS DEVICES IN SMART GRID TEST-BED

No	Network	Status	
		Up	Down
1	172.16.1.1 – 172.16.1.254	16 / 16	0 / 16
2	172.17.1.1 – 172.17.1.254	29 / 33	4 / 33
3	172.18.1.1 – 172.18.1.254	2 / 4	2 / 4
4	172.19.1.1 – 172.19.1.254	2 / 2	0 / 2

The customized Ping tool illustrated the same availability results as those obtained from a centralized network management system for smart grid test-bed [14]. Table III summarizes the packet loss and delay statistics, and compares with the values obtained using traditional Ping from the command prompt. It can be seen that there is no significant difference between two results. This shows that Smart Grid Ping can be used to check the availability, measure both packet loss and communication delay of numerous devices in smart grid communication network.

TABLE IIII: PACKET LOSS AND DELAY STATISTICS

No	Technology	Packet loss (%)		Delay (ms)	
		Smart Grid Ping	Traditional Ping	Smart Grid Ping	Traditional Ping
1	WiMax	0.42	0.59	209.53	215.72
2	Mesh RF	0.79	0.83	217.40	220.34
3	PLC	1.36	1.63	243.90	247.15

VI. CONCLUSION

This paper introduced a customized ping tool, named Smart Grid Ping, to test the performance of several devices in smart grid communication network. The software utility allows users to ping a single IP address or any specific range of IP addresses. It also offers a variety of ping options and different types of random distribution to generate random number of packets and delays. These are important characteristics in evaluating the performance of smart grid communication network.

The GUI provided by Smart Grid offers a geographical view of all the hosts' status in the network. The results obtained from this customized ping utility can also help administrators to be aware of any network problem if it occurs, identify the location where it happens and response quickly to secure the problem. As for future work, the function of Smart Grid Ping can be further improved by integration with Google Earth to provide an overview of all devices in a smart grid geographically.

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